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Problems Analysis and Solutions for the Establishment of Augmented Reality Technology in Maintenance and Education

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Thesis for the degree of Doctor of Science in Technology to be presented with due permission for public examination and criticism in Konetalo Building, Auditorium K1702, at Tampere University of Technology, on the 30th of January 2015, at 12 noon.

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Abstract

Maintenance is one important area in the life-cycle management of scientific facilities. The design of a maintenance model requires time and effort, and the best solutions and technologies need to be considered for its implementation.

Scientific infrastructures that emit ionizing radiation are complex facilities that require taking into account not only traditional maintenance approaches but also specific solutions to prevent operational and health risks. Radiation directly affects workers' health, and therefore new approaches for enhancing maintenance operations are sought. For instance, scientific facilities are integrating remote handling techniques to reduce the radiation dose of workers. As a result of the need for risk reduction, a fast and accurate maintenance procedure is required to provide working conditions for the equipment, increasing the safety in the facilities and reducing costs and maintenance time.

Augmented Reality (AR) is a technology that has previously shown benefits in the maintenance field. AR applications allow workers to follow virtual in-place instructions of the maintenance tasks displayed on real devices. This approach provides shorter maintenance time, as workers do not need to find the required help in the appropriate manual and reduces risks, as the right steps to follow are always displayed to the worker. This is especially important in scientific facilities, as less maintenance time implies less radiation affecting workers and equipment, while less risk reduces the potential damages created by a wrong procedure.

This thesis proposes a new platform to provide a flexible AR solution targeted to help maintenance procedures at scientific facilities. The platform comprises the required elements for the creation and updating and execution of AR applications, including maintenance-specific features. The platform includes a powerful AR engine capable of producing AR scenes in maintenance environments and an authoring tool for the creation of the AR applications. The platform has been tested in a prototype case in a real facility, where a guiding system has been designed to aid the collimator exchange at the Large Hadron Collider (LHC) at CERN.

In order to demonstrate the flexibility of the platform in adapting to other environments, it has been used as basis to develop a solution for a problem detected in a second field: education.

AR has been previously used in the education field with promising results. However, the technology has not been established in the large majority of schools and

universities. The difficulties in creating AR experiences for educators (related to the lack of time or the required programming expertise) have constituted a barrier to the expansion of the technology in the field. Therefore, new solutions that help to overcome this barrier are needed.

For this reason, the main platform developed in this thesis has been utilised as a basis to develop a new educational platform that aims to promote collaboration between developers and educators in order to overcome the detected problems.

Finally, during the development of the aforementioned solutions, a comprehensive review of the state of the art of AR technology has been carried out. During the study, the main drivers and bottlenecks of the technology in several fields have been analysed. The results of this analysis have been published with the aim of helping other researchers to find solutions that help the spread of AR technology.

Preface

The main focus of the thesis is to provide a solution for AR-based maintenance. The work has been carried out within the PURESAFE project, which is an Initial Training Network (ITN) for the training of young researchers, funded under the European Commission's Seventh Framework Programme Marie Curie Actions. ITNs have a twofold goal. On one hand, the purpose of ITNs is to develop the careers of Early Stage Researchers (ESRs), improving their research skills and integrating them in established research teams. On the other hand, the research results from these networks are expected to be of great scientific value and have high impact.

The aim of PURESAFE ITN is to provide solutions for cost-efficient life-cycle management of facilities that generate ionizing radiation. Therefore, new engineering techniques have to be studied, both in hardware and software. AR is a technology that has high potential to bring large benefits for maintaining these facilities. Therefore, one of the research packages inside PURESAFE has been focused on AR solutions for maintenance. The main results of the work developed in that research package are presented in this thesis.

The work presented in this thesis has been carried out at the SenseTrix company. I would like to express my sincere gratitude to my project supervisor Seppo Laukkanen, who gave me the chance to participate in this experience and for his support and guidance during the whole project. I would also like to thank him for his support, not only in the actual development work, but also in the research work and in the doctoral studies. Without his support, this thesis would have never been produced.

I would like also to express my sincere gratitude to Jouni Mattila, my doctoral supervisor at TUT and coordinator of PURESAFE project. His guidance and support towards the creation of this thesis have been very important. His efforts at reviewing all my writings, included the research papers, are highly appreciated. This thesis would have never been produced without his help either. His hard work in PURESAFE project is also gratefully acknowledged.

PURESAFE has provided me with the opportunity to interact with many researchers from very motivating partners. I want to thank all the participants in the project for the experiences and interactions during these years, especially to the other ESRs affiliated with the project. The friendly atmosphere created around all the project events has been an additional motivating factor through the whole project.

I also want to thank the authors that have helped me to produce the scientific publications presented in this paper. Without their help, it would have been impossible to carry out all the work.

Finally, I would like to thank all of those involved with the PURESAFE consortium and Marie Curie ITN Actions for giving me the chance to participate in such a great experience. The decision to join a new project in a distant and cold place was not easy, but the results of the project and the experiences were worth it.

Tampere 30.01.2015

Héctor Martínez Landa

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List of Symbols and Abbreviations

AR	Augmented Reality
AV	Augmented Virtuality
CAD	Computer-Aided Design
CERN	The European Organization for Nuclear Research
ESR	Early Stage Researcher
GPS	Global Positioning System
GSI/FAIR	Helmholtz Centre for Heavy Ion Research/Facility for Antiproton and Ion Research
GUI	Graphical User Interface
HMD	Head-Mounted Display
HTML	HyperText Markup Language
HUD	Head-Up Display
I/O	Input/Output
ITN	Initial Training Network
IP	Internet Protocol
LHC	Large Hadron Collider
MOOC	Massive Open Online Course
OCR	Optical Character Recognition
PURESAFE	Preventing hUman intervention for incrREased SAfety in inFrastructures Emitting ionizing radiation
ROI	Region of Interest
VR	Virtual Reality

XML	eXtensible Markup Language

List of Publications

This thesis comprises an introductory part and six original publications. In this chapter, a list of the publications and the candidate's contributions to the publications are introduced.

I. Martínez, H., Laukkanen, S., Mattila, J., 2013, A New Hybrid Approach for Augmented Reality Maintenance in Scientific Facilities, International Journal of Advanced Robotic Systems, 10:321.
II. Martínez, H., Laukkanen, S., Mattila, J., 2014, A New Flexible Augmented Reality Platform for Development of Maintenance and Educational Applications, International Journal of Virtual Worlds and Human Computer Interaction, 2(1).
III. Martínez, H., Laukkanen, S., 2014, STEDUS, A New Educational Platform for Augmented Reality Applications, 4th Global Conference on Experiential Learning in Virtual Worlds.
IV. Hyppölä, J., Martínez, H., Laukkanen, S., 2014, Experiential Learning Theory and Virtual and Augmented Reality Applications, 4th Global Conference on Experiential Learning in Virtual Worlds.
V. Martínez, H., Skournetou, D., Hyppölä, J., Laukkanen, S., Heikkilä, A., 2014, Drivers and Bottlenecks in the Adoption of Augmented Reality Applications, Journal of Multimedia Theory and Applications, 1(1).
VI. Martínez, H., Fabry, T., Laukkanen, S., Mattila, J., Tabourot L., 2014, Augmented Reality Aiding Collimator Exchange at the LHC, NIMA (Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment), vol. 763, pp. 354–363.
VII. Martínez, H., Laukkanen, S., 2014, An Augmented Reality Platform inside PURESAFE project, SBC Journal on Interactive Systems, vol. 5, no. 1.

Author’s contribution to the publications

This section clarifies the author’s contribution to the published work.

Publication I: The author wrote the paper and developed the algorithms presented in the paper. Seppo Laukkanen helped in the concept design and reviewed the paper. Professor Jouni Mattila reviewed the paper and made corrections and suggestions.

Publication II: The author wrote the paper and developed the platform presented in the paper. Seppo Laukkanen helped in the platform design and reviewed the paper. Professor Jouni Mattila reviewed the paper and made corrections and suggestions.

Publication III: The author wrote the paper and developed the desktop part (the main application and the AR applications) of the platform. Seppo Laukkanen reviewed the paper and developed the website part of the platform. Both authors collaborated in the development of desktop-website communications.

Publication IV: The author co-wrote the paper with Jenni Hyppölä. The author was in charge of the astronaut training part and the final review, while Jenni Hyppölä was in charge of the medical part and the experiential learning model analysis. Seppo Laukkanen reviewed the paper.

Publication V: The author took the leading role of this collaborative paper and managed the formatting and the submission process. The author co-wrote the introduction with Dr. (Tech) Danai Skournetou and Seppo Laukkanen and the conclusions with Dr. (Tech) Danai Skournetou. The author wrote the industrial and education sections, while Danai Skournetou wrote the tourism and marketing sections, and Jenni Hyppölä wrote the medical section. Seppo Laukkanen and Antti Heikkilä reviewed the paper.

Publication VI: The author wrote the paper, developed the prototype and tested it in the CERN facilities. Thomas Fabry helped in the management of the CERN-related content and in the deployment of the prototype in the real collimator. Thomas Fabry also contributed to part of the introduction and reviewed the paper and made corrections and suggestions. Seppo Laukkanen, Professor Jouni Mattila and Professor Laurent Tabourot also reviewed the paper and made corrections and suggestions.

Publication VII: The publication is a summary of the work carried out by the author in the field of AR-based maintenance within the PURESAFE project. The author wrote the paper and carried out the work presented in the paper. Seppo Laukkanen supervised the work, reviewed the paper, and made corrections and suggestions.

1 Introduction

We live in a changing world, where new technologies appear and create breakthroughs in everyday life. The goal of technology research is to enhance the way we live and improve our safety and comfort. This affects all aspects of life, from leisure to work. Advances allow us to create new technologies and to discover new aspects of life that bring new possibilities of further progress. Some of these advances, such as the recent discovery of the Higgs boson, are done in scientific facilities, such as CERN[1] and GSI/FAIR.[2] The management of these facilities requires complex engineering systems that cover several aspects of their life cycle.

Maintenance is one important area in the life-cycle management of scientific facilities. Implementing a maintenance model requires time and effort, and its application affects the entire operations of a facility, including shutdown periods in scientific facilities. According to the International Facility Management Association,[3] the design and construction of a facility comprise 2% of the costs, while operation and maintenance comprise 6% of the costs. The rest (92%) corresponds to payroll.

The maintenance concept involves the areas of repair philosophies, maintenance support levels, manpower, time required and associated costs [1]. The concept has two goals: formulation of maintainability requirements and provision of facilities for supporting the system. This means that maintenance cannot be a passive activity as in the past, when machines were repaired only after a malfunction. Nowadays, a maintenance programme has to be carefully designed and implemented from the beginning, including aspects such as safety, economic viability and so forth.

Traditional breakdown maintenance (i.e., not to do anything until there is a problem) is now being complemented or replaced with new forms, such as condition-based, total productive or reliability-centred maintenance. According to [1], maintenance can be divided in two groups:

- Breakdown maintenance: Intervention occurs only when a machine stops working.

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[1] CERN, The European Organization for Nuclear Research: http://home.web.cern.ch/

[2] GSI Helmholtz Centre for Heavy Ion Research/FAIR Facility for Antiproton and Ion Research: https://www.gsi.de/en.htm

[3] Report available in: http://cdn.ifma.org/sfcdn/advocacy/policypaper-building-futures.pdf?sfvrsn=2, last accessed 06-08-2014.

- Planned maintenance: Intervention is planned beforehand (when, what and by whom), taking into account considerations such as utilisation of the equipment, working conditions or special factors that may affect the equipment.

Planned maintenance can be divided into:

- Scheduled maintenance: The work is scheduled in consultation with the production department and based on experience.
- Preventive maintenance: The goal is to carry out periodic inspections and repairs to detect and avoid conditions that may cause the failure of the equipment.
- Corrective maintenance: As a result of preventive maintenance, repetitive failures can be detected and corrected in order to avoid future failures.
- Condition-based maintenance: In this type of maintenance, monitoring of the equipment is required and therefore is suited for high-cost and complex equipment. An intervention is carried out when a significant change in one parameter is found, instead of carrying out scheduled interventions.
- Reliability-centred maintenance: It consists of identifying the functional requirements of the equipment and the expected functioning. This information – together with considerations about the consequences of possible failures – is used to define maintenance planning.
- Total productive maintenance: The approach followed is to involve all employees in the process. Therefore, operators are also responsible for taking care of their own equipment.

Both maintenance systems (breakdown and planned) coexist nowadays. According to [2], by the end of 2000, more than 55% of maintenance programmes in the United States were using breakdown maintenance, while 31% corresponds to preventive maintenance, 12% to predictive maintenance (condition-based maintenance) and 2% to other types of maintenance.

In view of the previous considerations, maintenance is not a trivial issue, and it has to be carefully designed and implemented, taking into account many aspects. Once the approach to follow has been decided, the technologies to support the selected type(s) of maintenance have to be defined in order to have a coherent and useful system.

As a result of the high cost of complex equipment in scientific facilities, the devices and machines need to properly work during their whole life cycle. Therefore, maintenance includes not only repairing the equipment when a malfunction appears but also keeping it continuously working and carrying out periodic examinations. Hence, optimising the process is an important aim in the life-cycle management of scientific facilities.

The current approach for maintenance covers not only providing a working condition of the equipment but also ensuring safety for workers (e.g. reducing the radiation dose received by the worker in a scientific facility emitting ionizing radiation) and for equipment (reducing risks that may cause a major accident) in an efficient and cost-effective manner.

This is especially important in scientific facilities where the radiation directly affects the workers. The current trend in these facilities is to replace human intervention tasks with remote handling procedures. The use of remote handling helps to keep workers far from the radioactive spots. However, a large number of processes still have to be carried out by human intervention. Therefore, the integration of new technologies that support the enhancement of both types of maintenance (i.e. human intervention and remote handling) is desirable, as costs and risks may be reduced at the same time that safety increases.

Augmented reality (AR) is a relatively new technology that combines elements from real life and virtual worlds. Milgram [3] defined a reality-virtuality continuum in which the two ends are the real environment and the virtual environment. A representation of this continuum is shown in Figure 1. As it can be seen, AR is an intermediate state of this continuum, closer to the real environment, which means that the real environment is the main environment, and it is augmented with virtual elements.

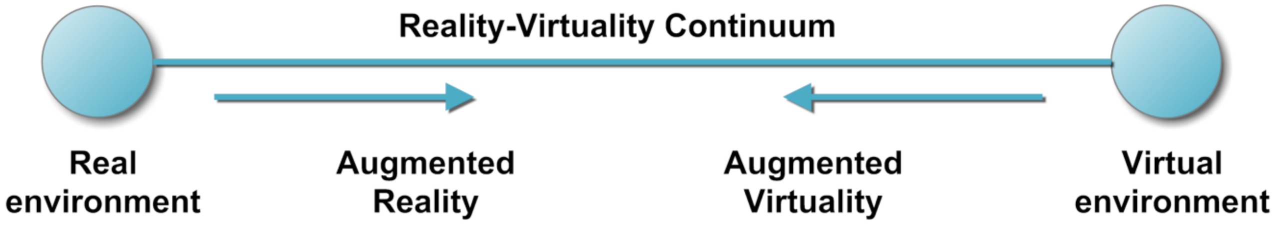

Figure 1. Reality-virtuality continuum.

Therefore, AR is a technology that allows enhancing reality by overlaying new information. This information can range from simple entertainment elements to complex information that can be naturally hidden to the human eye or measurements coming from different sources. Hence, the possibilities of applications that can be developed using AR are enormous. It is also worth noting that current multimedia information can be seamlessly integrated in AR applications to provide an enhanced experience. Thus, the effort of content creation is not as large as it could be if the development had started from scratch.

AR can be applied in many fashions. The most common approaches are (1) computer vision techniques in which images (e.g. a video feed) are analysed, interpreted and augmented using different algorithms, (2) global positioning system (GPS)-based schemes in which GPS coordinates are utilised to properly augment a video feed from a camera, and (3) setups in which the field of view of the user is directly augmented either by using see-through devices or projecting video on surfaces.

Of these three approaches, using computer vision algorithms to augment images from a video feed (e.g. Figure 2) has been more utilised so far. Within this approach, there are several possible implementation strategies, such as recognising predefined markers, detecting planar images, or even using objects and point clouds. The final goal is to obtain an appropriated origin of coordinates of the virtual world with respect to the real environment. Once the coordinate system is defined, the real environment can be properly augmented with a coherent rendering of the virtual content.

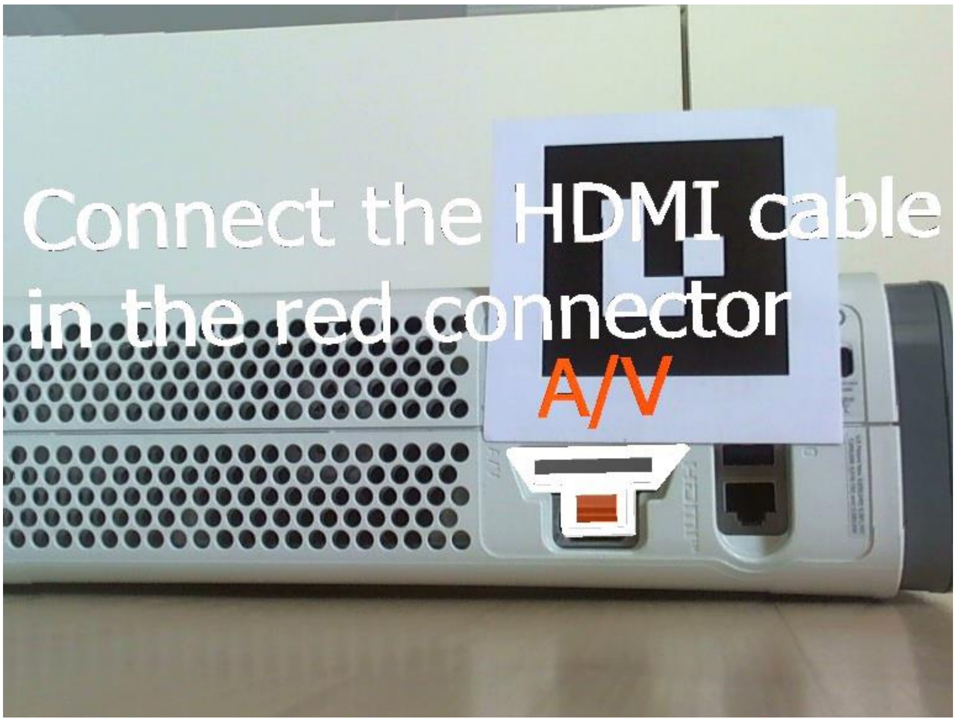

Figure 2. Example of a computer vision-based AR application. The marker visible in the image is recognised by computer vision algorithms, and it is used as the origin for the positioning of the virtual elements in the final scene. In this particular example, the application guides the user to connect the cables to the device. The text and 3D model explain the appropriated connector to use for the current step.

The basic architecture of a computer vision-based AR application is presented in Figure 3. A video feed is obtained, typically from a webcam or a built-it camera. This video is processed using computer vision algorithms to detect known patterns (e.g. markers, images, etc.) in the image. Once these patterns are found, a reconstruction of the 3D space coordinates is carried out in order to properly render the virtual content in the right position with respect to the real environment. Finally, the augmented scene is displayed, typically on a screen or a projector.

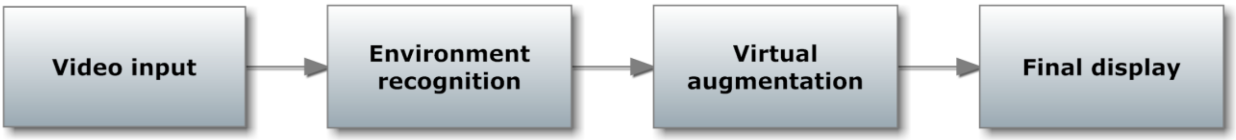

Figure 3. Basic architecture of a computer vision-based AR application. The application consists of four stages. First, the video input is obtained from a camera. Second, the environment seen in the video images is recognised. When the environment is known, the augmentation with virtual elements takes place. Finally, the augmented scene is displayed on a screen.

In recent years, AR technology has started to become more popular, not only among researchers but also in the general public, as more and more people become familiar everyday with the concept. Applications for entertainment (e.g. video games) and advertising are probably the most popular nowadays for the general public. There are other fields in which AR has proven to be a useful tool to enhance traditional applications, but the developed applications are not so common outside the research environment.

As mentioned before, maintenance in scientific facilities usually requires well-trained workers and a vast amount of information that should be organised in an efficient manner. Traditionally, workers have used printed manuals to follow instructions for procedures that they have to carry out. This has usually been tedious work, as the manuals are heavy to carry and difficult to use on site. Manuals usually contain detailed information about the equipment, with a large number of pages with text and images or schemes. Although the information provided is precise and useful, it takes time to find and read the appropriate text required for the target task. Also, if updates or changes have been made at a facility, the manuals may be outdated and need to be replaced, or supplementary information may be needed.

Nowadays, the increase in new technologies has allowed the use of electronic versions of manuals, which can also be updated if the system is well designed. Although this approach certainly enhances a task's efficiency, the workers still need to look for the appropriate content required for every step or device. Once the content is located, the workers need to read the information and understand it before starting the actual procedure. The information may even be enhanced by showing videos that explain the procedure. However, all this information is presented in a device out of the field of view of maintenance workers at the actual facility.

AR, however, provides a more intuitive solution, as it allows automatically recognising the working environment and displaying step-by-step instructions in the field of view of the worker. Once the AR system automatically recognises the situation, it is capable of providing accurate details of the procedure. This fact reduces the time spent at the maintenance site, as the worker does not need to search for the appropriate information. The help can be provided by means of 3D models and animations of the equipment that needs to be maintained. The real device is augmented with instructions to follow that help the worker understand the procedure as he or she sees the virtual process over the real device. Additionally, further information (in the form of text, audio, video, etc.) can be provided in the same augmented view to enhance the understanding if required.

Moreover, automatic data acquisition (e.g. task completion times) can be gathered for further analysis in order to analyse the possible bottlenecks and to formulate corrective measures if required. If time and errors are reduced, the efficiency of the maintenance increases as well as the safety of the worker. As mentioned before, scientific facilities aim to enhance the safety of workers and reduce the level of radiation dose that they receive. Providing a faster maintenance procedure potentially reduces the time that the worker is surrounded by radioactive equipment, thus improving safety.

Therefore, AR has high potential to enhance maintenance in scientific facilities. The implementation of an AR-based system at a scientific facility requires considering human intervention and remote handling, as both streams are required in such facilities. Moreover, the use of AR can be beneficial in the two maintenance groups mentioned before:

- AR can be designed together with the rest of the elements of a planned maintenance programme. Planned periodical inspections and repairs can be potentially enhanced by the use of AR. If tasks are distant in time, workers may forget how the maintenance has to be properly carried out. If they are closer in time, workers may feel self-confident and potentially forget some steps. In both cases, providing step-by-step visual help has high potential to prevent possible mistakes. The same applies to other planned strategies. For instance, condition-based maintenance can benefit not only from the aforementioned features, but also recordings from the measured variables can be both presented in the augmented view to the worker and recorded for future control.

- In the case of breakdown maintenance, a fast and reliable procedure is required, and therefore, providing an accurate AR guiding system could help to recover equipment to a working state in a faster manner. Moreover, workers may not be familiar with the procedures for taking care of a device, as intervention only occurs when the equipment malfunctions. In these cases, the in-place guiding instructions would be a valuable aid to workers for understanding what is wrong with equipment and how to solve problems.

So far, maintenance has been pointed out as one important aspect of operating scientific facilities. However, actual scientific knowledge is the most important factor in terms of operating these types of facilities. The findings obtained in scientific facilities are crucial for understanding the world. Therefore, new discoveries help us to enhance our lives and to develop further scientific studies.

Additionally, the findings obtained need to be taught to new generations. Education means transferring knowledge from one generation to the next. The scientific discoveries of today may be the basis for the education of tomorrow. Therefore, education pays an important role in the research-discovery-transfer cycle.

But, of course, education is not restricted to scientific education. All aspects of education are important, and therefore, when considering new tools for education, all branches have to be considered, as they all can benefit from the new solutions.

New technologies have been always around in education. Projectors and computer laboratories have been established in schools and universities for a long time. New devices, such as e-book readers and tablets, are becoming more common in classrooms and their standardisation has been already foreseen [4].

In recent years, the possibilities for e-learning have also increased. The number of platforms offering massive open online courses (MOOCs) has notably increased; students from across the world can access pre-recorded lectures on a specific subject and study at their own pace. Students can take advantage of these lectures to learn about almost any topic they are interested in, and they can even be evaluated by teachers and professors.

From the previous considerations, it is clear that educators are always looking for new technologies to be included in the learning process. However, in order to successfully implement new technologies, the involvement of educators is required in the process, and the appropriate tools and support need to be supplied to them [5].

Virtual reality (VR), the technology behind the virtual environment proposed in Figure 1, is a technology that enables the creation of computer-generated virtual worlds where the user can interact and immerse. VR has been used in education for a long time because of its capabilities of visualising abstract concepts that cannot normally be easily visualised by humans. By the end of the 20th century, the use of VR in schools was an emerging topic [6]. Fifteen years later, the technology has finally been adopted by the educational community, and the benefits of its use have been demonstrated (e.g. [7]). In recent years, a similar trend has appeared with AR. It is now becoming an emerging topic for educators, and many research studies have examined it. The level of interest is similar to that for VR in schools in the early days of its adoption.

AR technology is able to offer the same visualisation capabilities as VR, but AR provides two additional benefits:

- More intuitive interaction, as students can directly interact with the virtual content without the need to use interfaces, such as a keyboard or a mouse. Students can directly manipulate the markers or objects that are augmented with virtual content; therefore, direct interaction with the virtual content is possible.

- Integration with the working environment. Physical objects in the classroom can be augmented with virtual content, thus providing an enhanced in situ experience. Moreover, invisible parts or behaviours of real objects can be superimposed in the augmented view, allowing a better understanding of the behaviours.

Therefore, AR can potentially be the next technology to be established in schools as a natural evolution of the use of VR. Computers, projectors and tablets (devices capable of utilising AR applications) are already available in most schools and universities. However, there is still a long way to go until this establishment becomes a reality, and efforts to generalise the use of AR in educational environments are still needed.

AR has successfully been applied at all education levels, from preschool [8] to university, [9] and several applications have already been developed, showing promising results. Therefore, AR has proven to be a technology that can improve all stages of education as well as professional training. However, as mentioned before, the establishment of AR-based learning has not yet reached the majority of the educational community. The main reasons for this may be that educators lack an awareness of AR technology and that there are a relatively small number of designing and development tools oriented to educators.

AR is becoming a serious business branch in the technology field. According to one study developed by Juniper Research,[4] annual revenues from mobile AR services and applications will reach $1.2 billion by 2015, up from just over $180 million in 2013. They also foresee that in 2018, nearly 200 million unique users will utilise mobile AR apps, compared to the sum of 60 million unique users in 2013. This picture provides an idea of the fast growth of the technology. However, there is still a long way to go until AR becomes a mainstream technology for many fields. As stated, the majority of current AR applications focus on entertainment and advertising; games represent more than 40% of AR downloads in 2013, according to the report.

1.1 Objectives of the thesis

As mentioned in the introduction, AR has been successfully applied in several fields, and it is expected that its use will increase in the near future as a result of the popularity that the technology is acquiring with the appearance of new wearable devices (e.g. intelligent glasses) targeted to AR applications.

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[4] Press release available in: http://www.juniperresearch.com/viewpressrelease.php?pr=427, last accessed 19-05-2014.

However, there are still application fields that have not seen the full potential of AR potential, even when previous studies have shown good results. The overall objective of this research work is to bring AR technology closer to mainstream usage in the fields of maintenance and education. The aim is to provide new features to the field together with a generic solution that can be potentially used by anyone. The results from the research work are expected to be not only of scientific value, but also of commercial value.

AR is of great interest in the maintenance field as a result of the advantages of using this technology, such as reduced operational times and costs and safer procedures. The main concept behind the use of AR for maintenance is helping operators in the performance of tasks. The devices to be maintained can be augmented with virtual instructions that the operators need to follow to carry out proper maintenance. The instructions can be provided in several manners, from simple static images on the screen to more complex techniques, such as positioned 3D-animated models of devices and audio instructions.

Despite the possible advantages of using the technology, AR is still not well established in the large and complex scientific facilities. It is usually difficult to develop AR solutions for the maintenance of such facilities, as it requires programming knowledge and the tedious work of software libraries interaction. Although there are existing authoring tools for AR development that eliminate these limitations, the tools are meant for general purpose and usually intended for small-scale projects. Therefore, the aim of this thesis is to develop a platform that makes a step change by allowing the easy development of AR applications that take into account the design requirements of the maintenance field and the characteristics of large facilities.

In addition, in this thesis the design requirements for the use of AR in the maintenance field are analysed and best practices are integrated into the proposed platform. There are multiple aspects to consider in the management of a system (breakdown maintenance versus planned maintenance, human intervention versus remote handling, etc.). For this reason, the final platform should be designed to be flexible for adapting to different operating conditions, depending upon the requirements of a specific scientific facility.

Thus, a novel AR platform targeted for maintenance for scientific facilities is proposed in this thesis. The platform contains two main parts, an AR engine and an authoring tool. The reason for providing two independent tools inside the same platform is to adapt to a wide-range of working conditions. The AR engine is meant to run AR applications. The AR applications can be designed using the authoring tool, which allows the creation of new applications and the updating of existing ones. This work is mainly done in an office environment, so the authoring tool is not needed in the maintenance workplace. On the other hand, the AR applications are mainly used in the maintenance workplace, as they rely on the detection of predefined markers that are visible in the real equipment to be maintained (the platform also allows for the execution of the AR applications over a pre-recorded video instead of using a live video feed, which is useful for testing and analysis of the procedures). Therefore, providing independent tools can enhance the creation-execution workflow of AR applications. Moreover, AR applications may be developed by personnel different from those responsible for carrying out tasks. Hence, having separate tools helps to keep the system organised.

AR can be used for the two main branches of maintenance in large scientific facilities (i.e. human intervention and remote handling). Therefore, in the proposed platform, both branches and their specific characteristics have been considered in order to provide a useful solution for scientific facilities.

In order to prove the flexibility of the platform, further applications of the platform are proposed for the education field. The reason for selecting education as a second use case is dual. From one side, AR has proven to be a useful tool for education in previous research work.

On the other hand, education can benefit from AR, and some authoring tools have already allowed educators to create applications for their educational content [10]–[12]. However, despite these available tools, AR in education has not been widespread. One of the reasons for this is that educators cannot afford to spend time and effort in developing applications with the mentioned authoring tools. Therefore, new solutions for these bottlenecks need to be proposed. For this reason, the thesis also proposes a new platform for education that aims to generalise the use of AR in the field and to promote collaborative work in the educational community.

The main objectives of this thesis can be summarised as:

- Provide a flexible solution that allows the cost-effective implementation of AR technology in the maintenance field.
- Provide scientific facilities with the means of creating and updating AR solutions without the need for specialists with an AR background.
- Integrate all solutions and techniques into a novel platform that can be offered to scientific facilities.
- Demonstrate the flexibility of the proposed solution for maintenance by providing new solutions to specific problems in other fields (in particular, in education and training).
- Analyse the main problems and the current state of the art of AR, especially in the fields of maintenance and education, and provide conclusions to be considered for current and future developments.

1.2 Restrictions

The developed platform tries to provide flexible solutions for maintenance in scientific facilities. A dedicated project for a certain procedure (i.e. a project developed from scratch, implementing project-specific features for the target equipment) may be more accurate in some cases than using more generic solution, but the costs of implementing dedicated projects for every procedure increase significantly with the size of the facility. The proposed platform tries to establish a cost-effective solution, providing for a robust implementation that reduces costs compared to the implementation of dedicated projects, but keeping in mind that a dedicated application could provide more accurate results in some cases.

Although the approach for the educational platform removes the need for authoring tools, this approach cannot be easily applied to the maintenance field. The main reason is that the educational content is shared by the whole community; that is, the contents for teaching a specific subject are the same in every educational institution. On the contrary, maintenance procedures are closely related to the specific facility, and therefore, a common platform with the approach followed in the education case would not be feasible.

Nevertheless, teaching methods may not be the same for all educators teaching the same subject; therefore, this fact may be an additional restriction. However, in this study, it has been considered that the developed educational applications would be generally accepted by the majority of educators.

One important restriction is the lack of awareness of AR technology. Although the technology is rapidly growing, the majority of people are not familiar with the concept. AR is a technology that has not reached the mainstream public yet. Also, a large number of people that may be familiar with the technology associate the technology to the entertainment field, but not for other professional activities. This consideration may be an important restriction for the purpose of this work, which is to provide a means for generalizing the use of AR in the maintenance and education fields.

Considering the two use cases (i.e. maintenance and education), the maintenance field will probably be more reluctant to adopt AR solutions. The education field is already familiar with the use of multimedia technologies. VR, for example, has been previously applied to education and is widely used in the community. However, the maintenance field is traditionally tied to paper manuals, and multimedia technologies are not as common as they can be in the education field. Hence, moving from traditional models to new approaches in which AR solutions are integrated will be difficult. Therefore, it is expected that the deployment of the proposed solutions will need a greater marketing effort in the maintenance field than in the educational field.

1.3 Research methods

The AR engine included in the platform presented in this thesis has been developed following the standard methods of computer vision-based AR systems. These kinds of systems deal with two major technological problems, the tracking of the real environment and augmentation using virtual content.

As in most of the existing AR tracking systems, a marker-based solution has been selected as the main tracking system for the proposed platform. Although other tracking systems have also been integrated in the platform for testing purposes, the solution proposed does not include these alternative systems in the current final version. The main reason for using a marker-based system is that it provides faster and more robust detection and tracking compared to other techniques (especially for large projects where a large number of targets need to be detected), and it has been widely adopted by the research community. However, newer techniques based on image and/or object recognition are gaining importance and will probably be integrated into the platform in the future.

The augmentation part has been developed using a graphics engine that inherently allows the use of 3D models. The rest of the virtual elements to be utilised for the augmentation are rendered by means of plug-in systems inside the graphics engine. The most common virtual elements in AR applications have been enabled in the platform (e.g. images, videos, texts, audios, etc.). The appropriated positioning of the virtual elements in the final augmented scene relies on the information provided by the aforementioned tracking system.

1.4 Contribution of the present work

The main contribution of this research is the design and development of an AR platform targeted to the maintenance field. The platform comprises an AR engine with maintenance-oriented features and an authoring tool that makes it easy to create new applications. The design and implementation of the platform have been presented in Publication II. A summary of the work carried out during the development of the proposed solution can be found in Publication VII.

The platform is suited for aiding operators in carrying out procedures in both human intervention and remote handling cases. A special effort has been made to analyse and design features oriented to remote handling, as there are fewer related works in the literature compared to the case of human intervention. A real-use case for remote handling in CERN facilities has been carried out for that purpose. The available features of the platform were utilised while new features were developed based on the detection of further requirements for remote handling. The description of the implemented prototype can be found in publication VI. The difficulties found in the development and the proposed solutions have also been detailed in the publication in order to serve as recommendations for future developments in AR applications for remote handling in hazardous scientific facilities.

The developed platform has been designed to allow cost-effective deployments of large projects in scientific facilities by the integration of a novel hybrid AR approach and a database system. This proposed design allows the creation of a large number of applications for procedures that can coexist in the same environment. The hybrid approach and the respective algorithms are detailed in Publication I.

The platform has been also designed to be flexible in order to be applied to new application fields in the future. In order to demonstrate this flexibility, it has been used as the starting point for the creation of a second platform oriented to education. Therefore, the second main contribution of the thesis is the design and development of a new platform for AR-based education that introduces a new concept to overcome the main bottlenecks found in the field.

The main idea was not to develop AR applications for the sake of merely demonstrating the flexibility of the platform, but to develop a solution to a detected problem. As previously mentioned, educators are generally not using AR for teaching and training due to the required time and effort that the development requires. For this reason, a new concept has been developed and implemented in a platform in which educators provide the pedagogical value of the application and the dedicated programmers develop the applications based on the educators' requirements. The details of the educational platform are explained in Publication III.

Finally, a comprehensive review of the state of the art of the AR field in five major application domains – (a) industry and military, (b) training and education, (c) travel and tourism, (d) medicine and health care and (e) retail and marketing – has been carried out. The review has been utilised to analyse the design drivers and bottlenecks of AR in its current state, trying to identify the main factors that prevent AR from becoming a mainstream technology, especially in the industrial maintenance and education field. The analysis has been useful during the implementation of the aforementioned platforms while attempting to deal with the most important bottlenecks during development. Moreover, the results of this design requirements review and analysis have been published in a journal article (Publication V). Additionally, a smaller scale study focused on AR for training professional workers has been presented in a conference paper (Publication IV).

In summary, this thesis presents the results of theoretical and applied research in the field of AR for the maintenance and education fields. The goal is to overcome the problems detected by providing solutions that aim to help in the generalisation of the technology. The main contributions of this thesis can be summarised as:

- Analysis of current status of AR in the maintenance field. The analysis has been carried out in order to detect the main problems and requirements of the current use of AR in the maintenance field. The analysis includes aspects such as:
    - Determining the feasibility of a realistic approach for deploying an AR system in large scientific facilities.
    - Studying difficulties and possible solutions in the development of AR applications targeted to human intervention and remote handling.
    - Finding the best practices to provide AR authoring capabilities to facilities personnel.
- The development of a platform targeted to AR-aided maintenance in large-scale scientific facilities, considering the previous analysis. The platform offers a novel solution that includes an authoring tool oriented to the development of AR-based maintenance applications.
- The design and development of maintenance-related features, including the design of a novel hybrid AR approach suited for large projects, such as large-scale scientific facilities where a large number of devices and machines need to be maintained.
- The deployment of an application using the developed platform in a real complex environment as a use case. The use case is the collimator exchange at the LHC at CERN, where a crane is used to remotely perform the exchange. The application contains novel features designed to aid remote handling maintenance in scientific facilities.
- Analysis of current status of AR in the education field. The aim is to analyse the current tools existing in the state of the art and determine solutions that help to increase the use of AR in the education field.
- Attending to the previous analysis, the design and development of a novel AR platform concept for educational purposes that aims to overcome the current problems of AR in the field.
- A study of the main drivers and bottlenecks of the current state of AR technology through five major application domains. The study covers a cross-domain comparison of the studies found in the literature and includes an analysis of Rogers' innovation diffusion theory [13] applied to AR. A list of five drivers and five bottlenecks in the adoption of the current AR technology is provided as conclusion of the study.

2 State of the art

A review of the literature concerning the use of AR in maintenance and education fields is presented in this section.

In the first part of this review of the state of the art, several aspects concerning AR for maintenance are explained. The studies targeted to the two main types of interventions in scientific facilities (i.e. human intervention and remote handling) are introduced. Finally, earlier developments towards the generalisation of AR in the maintenance field are presented.

In the second part, the AR developments in the education field are reviewed. First, general aspects concerning AR in education are introduced. Second, an overview of the evolution of AR development, especially focused on education, and the related tools are detailed.

As one of the contributions of this thesis also consists of a comprehensive review of the state of the art of AR, further details can be found in Publication V.

2.1 AR in the maintenance field

Maintenance is one of the most active research fields in AR for industry, and several studies have described the benefits of using AR for maintenance (e.g. [14]–[17]). Some of the reported benefits are faster maintenance interventions with fewer errors and more efficient and safer procedures. As computers do not forget, human factor issues can be reduced using the assistance of computer-based tools, such as AR applications [17]. Furthermore, remote guidance and supervision from an expert is also possible by means of AR [18].

Traditional maintenance has been carried out by human intervention. However, nowadays maintenance in scientific facilities with ionizing radiation is also being performed by means of remote handling in order to keep operators as far as possible from the radiation sources. Therefore, in this review of previous research studies in AR, both types of procedures are considered.

2.1.1 Human intervention maintenance

Human intervention maintenance implies that the worker physically interacts with the machine or device. AR is an attractive solution for guiding workers during the performance of tasks by displaying virtual information in a suitable fashion (e.g. Figure 4).

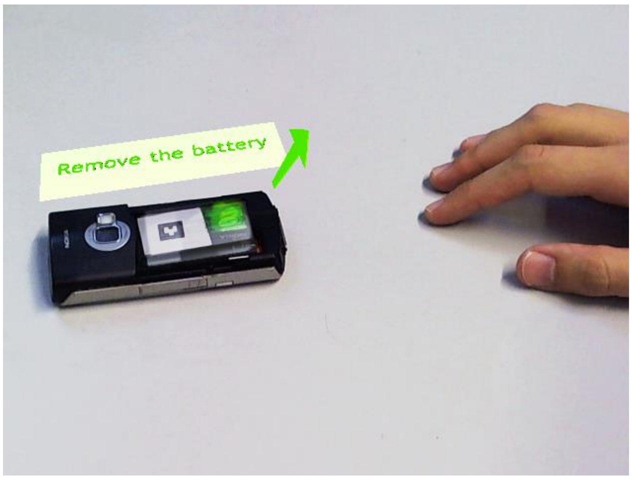


Figure 4. Example of an AR application for mobile phone maintenance. A virtual battery is displayed over the real battery. Also, an arrow and a text indicating the steps to follow are shown in the image, as they guide the worker through the removal of the battery.

Several AR prototypes have already been implemented for maintenance in different sectors. The next paragraphs present selected examples from the large list of AR prototypes for human intervention maintenance in order to provide an overview of the variety of different applications and sectors where AR can be applied.

In [17], a case study of an AR application for aircraft maintenance using a head-mounted display (HMD) is presented. From the list of tasks identified for the daily inspection of a Cessna C.172P, the oil-check subtask is used as a case study. The developed prototype guides the operator during the inspection procedure and is validated with real users with promising results. The study described in [19] presents a prototype of AR assistance for the psychomotor phase of a procedural task, also in the aircraft field. In particular, the prototype deals with several procedures of combustion chambers of a Rolls-Royce Dart 510 turboprop engine.

The prototype proposed in [20] is targeted to help in the maintenance of a dilute acid station, including tasks such as calibrating sensors, checking up on circuits and measuring container levels.

In [21], an AR prototype for the oil industry is proposed. In the paper, two case studies are presented: augmented virtuality (AV)-supported pump maintenance and AR-supported remote input/output (I/O) panel maintenance.

Photovoltaic pumping systems need to be maintained periodically, so improving maintenance efficiency and reducing costs is desirable. A first attempt to achieve this goal is presented in [22], [23], where a data set (components states, type of failures, sensors measurements, etc.) is used for providing information to workers by means of AR.

The approach described in [24] shows a case of AR utilised for operation and maintenance of optical access networks. Connector panels are difficult to use, as they comprise large arrays of connectors and numerous cables. In this paper, a cost-effective system to aid operators in locating the position of the appropriate connector is proposed. The authors also foresee future functionalities, such as helping the operator to replace a faulty switch.

The results provided in these publications are promising. Some of the conclusions are that AR is an intuitive and easy-to-use tool for maintenance [16], [17], [19] that enhances the task efficiency [16], [17], [22], reduces operational time [19], [20], [22], [23] and decreases accident risk [22], [23]. Moreover, AR has already shown good results in terms of training workers in hazardous facilities, such as nuclear power plants [25] or acid treatment facilities [20].

2.1.2 Remote handling maintenance

As presented in the previous section, AR has been widely utilised in research on human intervention. However, the number of AR-based studies of remote handling maintenance is more limited. There are some cases, such as in hazardous facilities with highly radioactive areas, where the maintenance has to be done remotely for the safety of the workers. The distance factor has to be taken into consideration, and the approaches for AR applications have to be different from human intervention. Some issues that have to be taken into account include the use of remote imaging systems instead of built-in cameras and the need for guiding aids for the control of remote devices.

In [15] some of the possible benefits of the use of AR technology for remote handling in radioactive areas are presented. These benefits range from collision avoidance to recording of the work carried out for later review. All these benefits can be translated into safer and more efficient performance.

Additionally, [26] presents a case study of AR applied to remote handling in an ITER mock-up scenario. In this work, a template-based matching algorithm is used to detect and track the water hydraulic manipulator in the video feed. The accuracy achieved in this work is high, and the tracking is done in near real time. However, the used markerless tracking method takes around 0.3 seconds to detect one object in the scene. If we think of a large number of different devices (such as the various types of collimators), this approach cannot be effectively used until the required time for the markerless algorithm is reduced to allow the detection and tracking of several devices in real time.

The work proposed in [27] presents a series of experiments that aim to improve the depth perception of teleoperation procedures. The target of the experiments is to enhance teleoperations at ITER by overlaying depth cues to the real view. From the different experiments, the results obtained show that the best performance using virtual cues is obtained by using stereo tracking.

2.1.3 Generalisation of AR maintenance

The great majority of research studies are prototypes aimed to solve a specific problem. However, the use of AR in industrial environments requires flexibility [28]. This flexibility means that AR tools should be easily reusable to adapt to different devices and procedures. Moreover, in order to establish a coherent solution, the implemented system should be able to include a large number of procedures and tasks within the same application or set of applications. The solution to these issues could be the standardization of the patterns to be recognized by the system and the implementation of authoring tools that allow facilities to create their own AR applications without the need of dealing with low-level AR programming.

2.1.3.1 Tracking systems

AR technology requires the understanding of the environment to display the appropriate context-aware information and to properly align the virtual content with the real environment. Computer vision-based AR applications rely on different tracking techniques. From the studies presented in previous sections, two main tracking approaches can be found: marker-based systems (including 2D barcode markers, fiducial markers, etc.) and markerless-based systems (including image-based systems and other feature-based techniques). Please note that even though only these two approaches are discussed here, additional approaches can be also found in the literature. The main reason for not including them in this section is that the number of studies that implement marker and markerless systems is extremely large compared to other systems.

Both approaches (marker-based and markerless-based) have been previously utilised for applications in the two use cases of maintenance considered here (i.e. human intervention and remote handling). For instance, [23], [27] are examples of marker-based systems related to human intervention [23] and remote handling [27]. The prototypes presented in [17], [20] are examples of markerless systems applied to human intervention, while the prototype proposed in [26] uses a markerless technique based on a template-based matching algorithm applied to remote handling.

In general, nowadays marker-based techniques have some advantages over markerless techniques. Marker-based approaches use less memory, and the tracking is faster and more robust. Therefore, for large projects such as maintenance systems in large facilities, marker-based systems can be considered to be generally more suitable than markerless approaches.

2.1.3.2 Existing platforms

The studies presented in previous sections are prototypes for one specific machine or device. Although they are very good prototypes, a more generic use application needs to be developed for their real application in order to be applicable to other large facilities with a large variety of machine subsystems and devices to be maintained.

As stated in [29], content creation in multimedia applications (e.g. AR, games, etc.) is a major topic. Large applications require a well-defined content development pipeline. Some platforms have already been developed in order to bring AR closer to the general public. In [29], a marker-based platform for development of AR applications for mobile phones is presented. Another approach for mobile phone development is presented in [30], where in situ authoring is enabled. A marker-based system for authoring AR applications with some interactive features is proposed in [31]. Also, there are currently several commercial platforms that include authoring tools for AR development, but they are mainly targeted to develop individual projects rather than complex projects and to designers, artists and marketing workers.

The aforementioned platforms are meant to be used for general purposes; therefore, they do not integrate maintenance-specific features. Although they can be used for creating prototypes, advanced maintenance-related features would be desirable. Moreover, some of the proposed platforms are not suitable for remote handling. For instance, the use of mobile phones as proposed in [29], [30] is hardly feasible, as the operator is far from the device and usually even in a separate room.

In [32], a system including an authoring tool for context-aware AR maintenance is presented. In this system, some maintenance-specific features are integrated, including and on-site authoring for operators to update content information.

The framework concept for mobile AR- and VR-assisted maintenance is proposed in [33]. The framework aims to combine traditional existing instructions (e.g. manuals) with augmented and virtual views, including the possibility of user annotations. However, in order to create the AR applications, knowledge of HTML and Javascript is required, which may prevent its usage by non-specialised workers.

Also, the platforms intended to be used for maintenance in scientific facilities should be targeted to allow the deployment of large projects. The authors of the study proposed in [29] are aware of this fact, and for the case study of a museum, they have developed a specific game engine that allows the deployment of larger projects than other case studies inside the same platform.

2.2 AR in the education field

According to [34], AR is one of the ten most important emerging technologies for humanity, especially when it is used in educational environments. The reasons for this asseveration usually rely on the inherent characteristic features of the technology, that is, immersive environments and interactivity.

The combination of real environments with virtual objects creates an immersive feeling for the user. As stated in [35], immersion in a digital environment enhances education in terms of:

- Multiple perspectives: Users can change the frame of reference between an exocentric frame of reference (i.e. a view of the object from the outside) and an egocentric frame of reference (i.e. a view from within the object).
- Situated learning: Learning in the same context where the knowledge is applied enhances the understanding of the educational content. Setting up complex environments in classrooms is usually difficult. Therefore, the same environments can be created in a virtual or augmented world in order to allow students to understand the real situation.
- Transfer: Users are able to apply the acquired knowledge in one situation to another situation.

AR is also a highly interactive technology which makes it suitable for the concept of “learning by doing” [36]. The interaction possibilities range from basic interaction with virtual objects (e.g. moving 3D models, playing videos, scaling objects, etc.) to complex interactive features, such as embedded intelligent virtual tutors [10] or devices that allow interaction between physical and virtual objects (i.e. tangible interfaces) [37], [38].

AR technology makes possible the visualization of almost any kind of educational and training content. It is especially useful in those cases where 3D visualizations of complex structures (e.g. chemical molecules; see Figure 5) are needed or when “invisible” behaviours (e.g. gravity forces, magnetics fields, etc.) need to be explained. Moreover, AR offers the possibility of interacting with objects that cannot be handled in real life (e.g. showing the behaviour of the whole solar system in a desktop size environment; see Figure 5) or using virtual machines and devices for training that are highly expensive or unique without any risk of damage (e.g. industrial robots).

Therefore, AR can be applied to almost any kind of educational subject, as it has been demonstrated in a large variety of examples that can be found in the literature, such as mathematics [39], [40], physics [41], [42], chemistry [37], [43], languages [44], medicine [45], Earth and environment learning [46], [47], natural sciences [8] or music [48], [49].

AR can be also used for training professional workers in different fields for several purposes, such as clinical breast exams [50], brain surgery [51], [52], bread production in a bakery [10], full-body movement [53], myoelectric prosthesis [54] or nuclear accident escape guidelines [55]. Therefore, AR can be applied not only in schools and universities but also at any kind of educational or training institution or organisation.

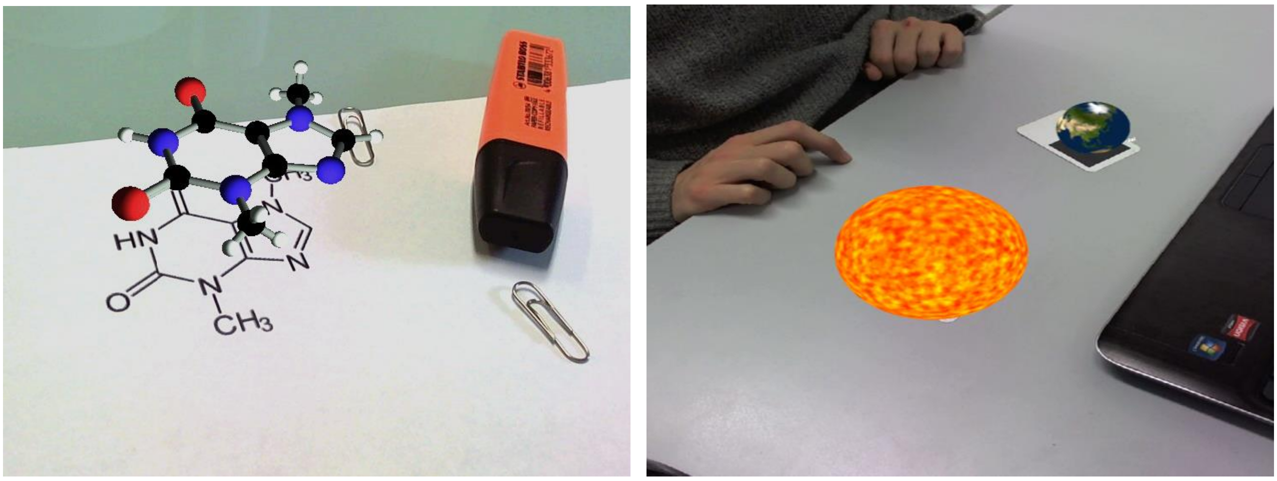


Figure 5. Examples of the use of AR in education. Left: Example of a typical use case of an AR chemistry application. A 2D representation of a molecule (theobromine) is augmented with a virtual 3D representation of the molecule. Students are able to see the 3D disposition of the molecule and can even turn it with their own hands by rotating the paper or by using the keyboard. In this case, instead of using a marker, the image of the 2D representation of the molecule has been used for positioning the virtual content. Right: Example of an interactive application of AR for learning about the solar system. This application is based on markers which the students are able to use in order to interact with the planets.

Moreover, AR brings further features to education and training. Collaborative applications have been shown to be of great interest in this field, and several studies have discussed the benefits of creating collaborative AR environments (e.g. [9], [43], [46]). Last but not least, AR technology has a fast learning curve, which means that users are able to start utilising the applications with very little prior information [8], [56].

Several studies have already shown that the use of AR in educational and training environments enhances the learning process (e.g. [44], [57]–[61]). Furthermore, students find the learning process funnier and more interesting when reality is mixed with virtual elements [45], [62]. Therefore, there is a growing interest in the use of AR for education and training purposes.

2.2.1 Authoring tools

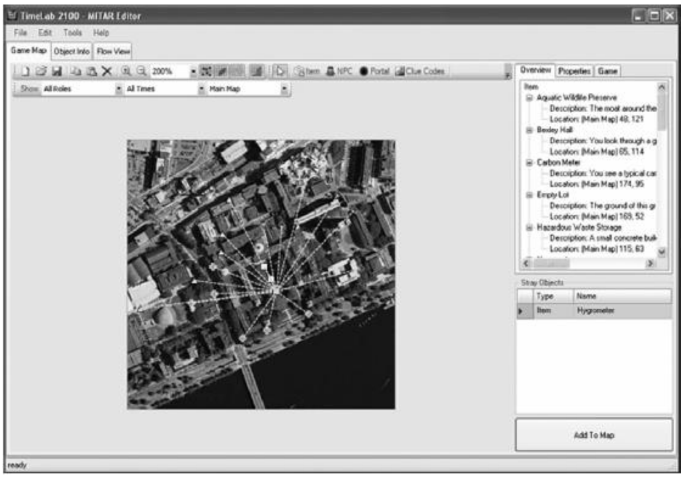
The AR applications for education introduced so far have been developed for a specific purpose and cannot be reused for other content and in other environments. Moreover, the applications are usually developed by programmers, as it is not always possible to involve educators in the development process. This problem was also common in the early stages of the use of VR for education, where educators were enthusiastic about the concept of using the technology, but costs and programming training of the teachers was a bottleneck [63]. In order to face this challenge, researchers have developed authoring tools in recent years to allow educators to create their own AR applications.

According to [64], there are different abstraction levels concerning AR development tools, ranging from low-level programming to high-level programming. Thus, before the appearance of authoring tools, AR development used to be carried out by using low-level libraries (e.g. ARToolKit [65]) or high-level libraries (e.g. OSGART [66]). Some tools also tried to facilitate the development of AR scenes by avoiding complex programming languages (e.g. [67]–[69]). However, these tools were still not very intuitive for all potential users (i.e. educators) due to the need for programming small scripts to use all the features or the required implementation of extensible markup language (XML) descriptions.

As can be seen from the previous considerations, programming skills are needed for the implementation of desired applications. Therefore, there is a gap between educational and training experts and AR developers, as educators are not usually familiar with programming environments and developers lack educational and pedagogical knowledge.

Therefore, several authoring tools targeted to education have appeared in recent years (e.g. [12], [41], [70], [71]). The aim of these authoring tools is to allow educators to develop their own educational AR applications without the need for programming.

In [70], a rules-based tool for development of outdoors collaborative educational games is proposed. It consists of a drag-and-drop interface (Figure 6) that allows the user to choose a map, create the characters and items, design the interactions and define the roles.



Item
- Aquatic Wildlife Preserve
  - Description: The moat around the
  - Location: [Main Map] 48, 121
- Bexley Hall
  - Description: You look through a g
  - Location: [Main Map] 65, 114
- Carbon Meter
  - Description: You see a typical car
  - Location: [Main Map] 174, 95
- Empty Lot
  - Description: The ground of this g
  - Location: [Main Map] 169, 52
- Hazardous Waste Storage
  - Description: A small concrete buil
  - Location: [Main Map] 115, 63

Type	Name
Item	Hygrometer

Figure 6. Interface of the development tool proposed in [70]. Users are able to define all the parameters of the game by means of drag-and-drop interaction.

With the help of the platform presented in [12], educators are able to create their own AR educational and training applications with an intelligent virtual tutor. The virtual tutor guides the students through the learning process by providing instructions and help. The platform comprises two graphical user interfaces (GUI) that can be seen in Figure 7. The first GUI is an authoring tool to define augmented scene, where the properties of the virtual objects (e.g. 3D models, web browsers, audio files, etc.) can be defined. The second GUI is the place where the user can define the interactions between elements and the behaviour of the intelligent virtual tutor. The definitions of the interactions and behaviours are based on natural language rules. Therefore, users can define the behaviour without the need for programming skills.

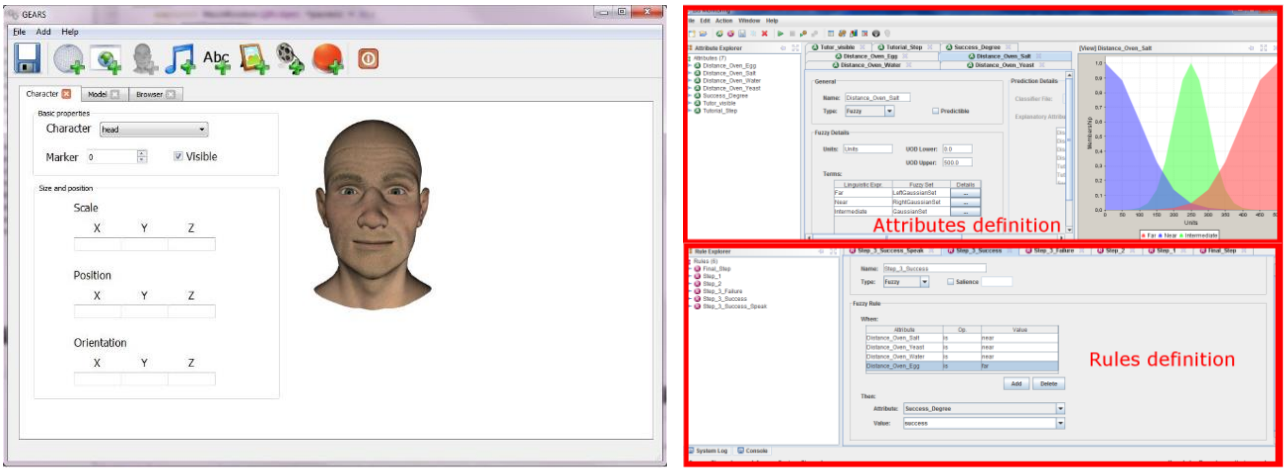


Figure 7. Screenshots of the authoring tools presented in [12]. The first tool (left) is a GUI to define the objects that will appear in the AR scene. The second tool (right) is a GUI that allows the user to define rules and attributes that will determine the interaction between virtual objects and the behaviour of the intelligent virtual tutor.

The tool presented in [41] provides capabilities for the creation of augmented books for teaching physics. However, in this case, the creation of AR scenes is made through a text-based configuration file instead of using a GUI. The tool allows the use of animations and interactive behaviour. The interactions can be utilised by selecting the predefined interactions enabled in the tool or by creating new interactions extending the corresponding class (this second option requires programming skills).

In [71], an authoring tool for AR creation within a 3D modelling software is presented. With the tool, users are able to develop 3D models as they would normally do using 3D modelling software. Later, the user can select these models and define the associated markers and images (markerless) to be used in the augmented view. The tool is built on top of commercial 3D modelling software to accelerate the workflow for those who are already familiar with the software. Although the tool can certainly help to develop AR scenes for those familiar with 3D modelling software, it can be difficult to use for those who have little or no experience with the mentioned software.

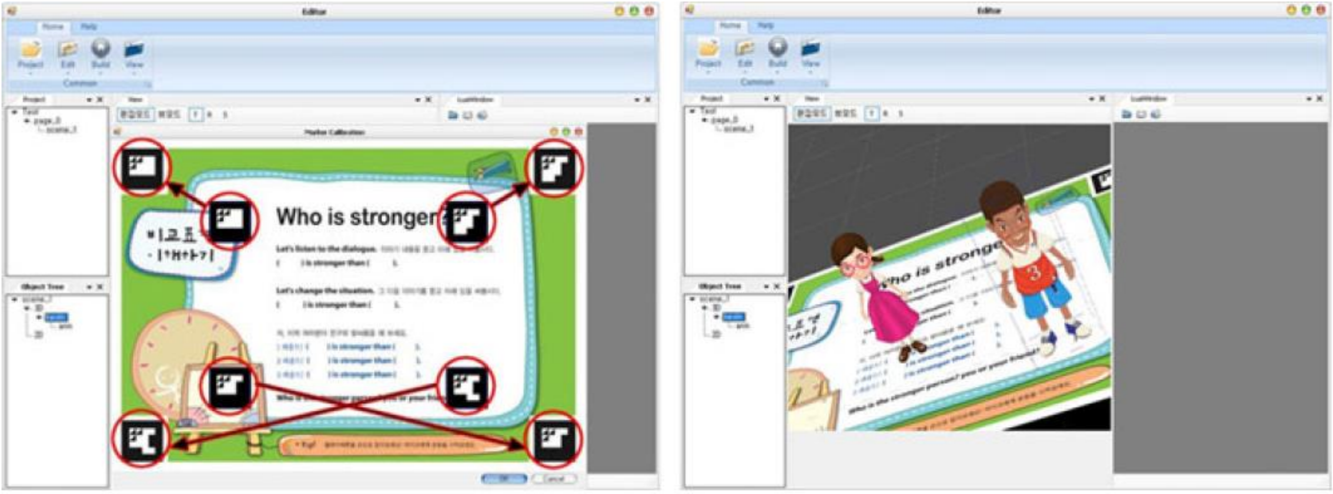


Figure 8. Screenshots of the authoring tool presented in [71]. In the left image, the user defines the markers that will be used for the augmentation. In the right image, the user manipulates the 3D models that will be displayed in the AR scene.

The mentioned authoring tools have finally filled the gap, allowing educators to create personalised AR applications for the educational and training content they target. However, there are two issues that still limit the progress of AR in the educational and training fields. The first issue is that although educators are able to create their own AR applications, it still requires time to get familiar with the authoring tool environment and to properly create the applications (precise positioning of virtual elements, defining interaction methods, etc.). This is not always suitable for educators, as the process can be still very time consuming. The second issue is that even if educators spend the required time for developing the AR applications, these applications stay on the educator's computer (or in the whole workgroup network), but they cannot be used by any other institution. Due to this fact, different institutions with the same educational or training problems need to create their own applications, which means that extra effort will be required.

3 Summary of publications

In this chapter, summaries of the publications presented in this thesis are provided and in section 0 the contributions of the author to the publications are detailed.

3.1 A New Hybrid Approach for Augmented Reality Maintenance in Scientific Facilities (Publication I)

In this paper, a novel AR marker and the algorithm to detect it and recognize it in an image are proposed. The aim of the proposed marker is to provide a coherent and persistent marker-based AR solution for large scientific facilities. The majority of available marker solutions are limited in the number of unique markers that can be used within the same application. Due to the conditions of the target scientific facilities, where a large number of markers is required, a proper solution is required. The solution proposed in this paper has been integrated into the platform explained in Publication II.

The new marker has been designed as a hybrid solution made up of two independent concepts. On one side, a 2D barcode marker has been used to track the position and orientation of the hybrid marker. The reason for the selection of this type of marker is that there are already available robust tracking algorithms for 2D barcode marker detection, and compared to other AR solutions (e.g. markerless tracking), it provides faster recognition using less memory. On the other hand, on top of the marker, a text code has been used to uniquely identify the marker. The recognition of the text code has been implemented using optical character recognition (OCR) techniques. For proper recognition by means of OCR, the text has to be aligned horizontally in the image, as the OCR technique is not robust against rotations and translations. Therefore, a homography has been used to rectify the original image, as the hybrid marker is usually distorted. For the computation of the homography, the information about rotation and orientation of the detected 2D barcode marker has been used as input. Once the image is reconstructed, the text is segmented and recognized by the OCR technique. Finally, all the required information of the hybrid marker is available to be utilised for the augmentation. The position and orientation of the hybrid marker in the 3D virtual world is provided by the 2D barcode marker recognition while the information related to the identifier of the hybrid marked is obtained from the text code. The training of an appropriate text font for the hybrid marker and the tests that were carried out are also presented in the paper, showing the feasibility and performance of the proposed technique.

As it is briefly mentioned in Publication I, the use of this system requires its integration with a database system in which the text codes of the hybrid markers are associated with the content (e.g. 3D models, videos, etc.) that has to be used to create the AR scene. The technique proposed in this paper and its integration with a database system into a larger platform are also explained in Publication II.

3.2 A New Flexible Augmented Reality Platform for Development of Maintenance and Educational Applications (Publication II)

This paper presents the main contribution of the whole thesis, as it explains in detail the platform developed. In the paper, the justification, a description of the architecture and functioning of the platform, and several use cases are explained. Although the main target for the platform is the maintenance field, it has been also used in the education field to demonstrate the flexibility of the platform.

The development of AR applications is usually carried out by software developers. However, the valuable information of the content to be used to augment the environment usually relies on experts in the field (e.g. maintenance operators, educators, etc.) who are not software developers. Therefore, authoring tools are needed. Although some authoring tools are already available, the majority of them are small-scale tools (i.e. it is not possible to create large-scale persistent projects). Moreover, those tools are usually defined for general use without taking into account the field-specific requirements. The platform proposed in this paper comprises an AR engine with maintenance-specific features for large-scale scientific facilities (e.g. the hybrid marker proposed in Publication I) and an authoring tool to allow non-programmers to develop AR applications for maintenance purposes.

The platform has been developed to be flexible to allow the development of AR applications for other fields and to include new field-specific features in the future. In order to demonstrate this flexibility, the platform has been used to develop a new commercial platform targeted to the education field. A brief explanation of the idea is presented in this paper, while a comprehensive description of the educational platform is detailed in Publication III.

As stated before, the paper also describes a set of use cases that have been developed to exemplify the possibilities of the platform, including a real use case for remote maintenance at CERN, which is also explained in more detail in Publication VI.

3.3 STEDUS, A New Educational Platform for Augmented Reality Applications (Publication III)

This paper presents a novel educational platform developed using the AR platform proposed in Publication II. Nowadays, it is already possible for educators to create AR applications with available authoring tools. However, AR applications are still not generalised in schools, universities or training institutions. Without taking into account the pros and cons of these authoring tools, two problems are found to be the main reasons for the low acceptance of AR in educational institutions. The first problem is that educators usually do not have time to learn how to use the authoring tools and to develop the AR applications, as they have to spend the majority of their time preparing and providing educational value. The second problem is that even if they spend the time for developing the applications, these applications are not easily shared by the whole educational community, but only for the educators' own network (in the best case).

In order to cope with the aforementioned bottlenecks, a new platform is proposed in this paper. The novelty in this approach is that the platform combines the two sides of the coin. On one side, the educators request the AR applications they need based upon their pedagogical requirements. On the other side, the developers carry out the implementation of the AR applications based on the aforementioned requirements. Finally, the developed applications are available not only for the educators that have requested them but also for all subscribed educators. Therefore, educators can benefit not only from the applications they have requested but also from the developed applications that have been requested by other educators.

In the paper, the platform is explained in more detail, describing its functioning and the different parts. The platform contains a main application from where educators are able to download AR applications from the servers and to run them. The platform also contains a website side where educators can interact with platform developers and with other educators in order to request new AR applications and/or improve existing ones and discuss the pedagogical aspects of these applications. The paper also discusses one real-use case that was the germ of the current platform.

3.4 Experiential Learning Theory and Virtual and Augmented Reality Applications (Publication IV)

The main contribution of this paper is to provide an overview of the benefits of using VR and AR technologies for education and training. The approach used for this goal is to analyse VR and AR applications for training professional workers (i.e. adult training rather than kids training) using experiential learning theory. In particular, the medical and astronaut training sector have been selected for this analysis.

From the analysis, VR and AR were demonstrated to be useful tools for training professional workers, especially in cases where it is difficult to reproduce a real situation, such as in the medicine field – where operations have to be done with human beings – or in the astronaut training environment – where conditions are not easy to replicate. The concept of learning by doing introduced by the experiential learning theory is suitable for the case of using VR and AR for training professional workers, as both technologies provide an effective environment for active learning.

3.5 Drivers and Bottlenecks in the Adoption of Augmented Reality Applications (Publication V)

The main contribution of this paper is the analysis of design drivers and bottlenecks of AR technology in its current state. The analysis covers five major application domains, which include industry and education, as they are the most relevant fields in this thesis. Additionally, three other major fields (tourism, medicine and marketing) are depicted that already use AR and that show promising results. This approach facilitates a cross-domain comparison which allows identifying a list of design drivers and bottlenecks in the adoption of the technology. The paper also includes a brief description of the history of AR and an overview of the related software and hardware.

The results obtained from the cross-domain comparison can be summarised in five main drivers and five main bottlenecks. The drivers include reduction of costs, a fast learning curve, the curiosity that AR brings to the users, the possibilities of tangible 3D visualization and the fun of use. On the other hand, the main detected bottlenecks are the lack of standards and flexibility, the limited computational power of current devices, the inaccuracy of tracking systems, the problems related to social acceptance and the excessive amount of information.

Another contribution of this paper is an analysis of Rogers innovation diffusion theory applied to AR technology. The drivers and bottlenecks found in the cross-domain comparison have been compared with Rogers' theory. From the five characteristics proposed by Rogers for the acceptance of a technology, only three are currently fulfilled by AR. Therefore, attending to Rogers' theory, AR still needs to fulfil the two remaining characteristics in order to be accepted more broadly.

3.6 Augmented Reality aiding Collimator Exchange at the LHC (Publication VI)

AR for maintenance has been previously carried out in cases of human intervention. However, its use in remote maintenance has been more limited. In this paper, a use case of AR for remote maintenance in scientific facilities is presented. The proposed prototype makes use of the AR engine included in the platform presented in Publication II. Moreover, during the development of the prototype presented in this paper, new features oriented to remote maintenance were implemented and integrated in the platform.

The use case presented in this paper consists of a real intervention in the LHC tunnel at CERN. In particular, the intervention considered is the exchange of a collimator with the help of a crane inside the tunnel. Collimators are special devices that mechanically narrow the beam of particles that is accelerated. Due to the limitations of access to the tunnel, the prototype has been developed using a real collimator inside a real-scale (in width and height) mock-up of the tunnel.

The paper presents novel features for AR-aided remote maintenance. The maintenance-job-task structure presented in Publication II is briefly introduced. The maintenance procedure is related to the collimator exchange, the jobs are the collimator removal and the collimator installation, and the tasks are the different steps that have to be followed in each job. Apart from traditional means of augmentation (3D models, videos, images, etc.), the prototype comprises a path guiding system that automatically detects the progress of the exchange, a head-up display (HUD) where different means of help are displayed (images of the right use of the crane controller, real-time zoom area of the region of interest (ROI), etc.) and the use of internet protocol (IP) cameras instead of traditional webcams.

Another contribution of the paper is the introduction of identified difficulties and proposed solutions that can help future developments of AR applications for remote maintenance in scientific facilities. Considerations about radiation, CAD (computer-aided design) and 3D model manipulation, path guiding and illumination are discussed.

3.7 An Augmented Reality Platform inside PURESAFE project (Publication VII)

This publication is a technical communication of the maintenance-related work presented in this thesis. The paper presents a summary of the work carried out within the PURESAFE project and offers a dissemination of the work through a paper in a journal that focuses on virtual and augmented reality.

4 Conclusions and future work

In this chapter, the conclusions and future work are presented.

4.1 Conclusions

The work developed in this thesis brings new solutions to the AR field, aiming to make possible the spread of the technology, especially in two fields: maintenance and education.

Maintenance in scientific infrastructures is a major topic in the life-cycle management of the facilities. A large number of considerations need to be taken into account when designing a new maintenance system. Because of the large cost of the complex equipment in scientific facilities, assuring that it works properly is a crucial issue. Therefore, accurate maintenance procedures need to be done.

Planned maintenance is acquiring more importance as a model to ensure the cost-effective maintenance of equipment. In scientific facilities, this planned maintenance usually requires the shutdown of experimental activities. However, shutdown periods in scientific facilities imply high costs, not only related to the actual maintenance but also related to the temporary stoppage of the facility activities.

Finally, scientific facilities usually emit ionizing radiation, which can directly affect the worker's safety. Increasing the safety of maintenance procedures is, thus, vital in the management model of the infrastructures, considering not only the safety of the workers but also the safety of the equipment to prevent possible accidents.

As a result of the need for ensuring the equipment high availability, reducing the maintenance times and increasing the safety in the facilities, this thesis proposes new tools to enhance the maintenance processes in scientific facilities. AR technology has already demonstrated that it can provide benefits in the maintenance field by saving time and money. However, there are not enough generic AR solutions targeted to maintenance. Therefore, this thesis proposes a solution oriented to the maintenance field that aims to be a generic tool that can be easily adapted to different conditions.

The main outcome of the work done is a new AR platform for the development and deployment of AR applications targeted to maintenance in scientific facilities. The platform comprises:

- A powerful AR engine with conventional capabilities and novel maintenance-oriented features.
- An easy-to-use authoring tool for the development of AR applications without the need for programming skills.

The architecture of the platform and its components has been described in Publication II, where the AR engine and the authoring tools are presented. The platform includes the most common AR features that can be found nowadays, such as augmentation with 3D models and multimedia content, means of interaction, and so forth. The platform also contains new maintenance-oriented features that have been developed to address new requirements found during the development of the platform.

The platform comprises a database system that includes a maintenance-job-task structure. This structure allows the definition of different levels of maintenance and provides a framework to create a large AR-based maintenance system instead of the individual prototypes that can be found in the literature. Every task inside the system is an atomic instruction that is provided to the worker. Therefore, it is possible to create a step-by-step guiding system that will aid the worker in the maintenance procedure. Publication II provides further information on this structure as well as one example.

The previous structure allows the definition of a large AR system, which is suitable for scientific facilities. However, current AR systems only support small scale projects as a result of the limitations in the number of different tracking elements. Theoretically, markerless systems could be designed for almost infinite number of different tracking elements. However, the use of markerless techniques for large projects with current technology is not feasible due to the high requirements of these kinds of systems. Therefore, marker-based systems are nowadays more suitable for large projects.

From all marker-based systems, those based on 2D binary markers are the most appropriated in terms of robustness and processing time. However, these systems are limited to a maximum number of unique markers. For example, in a system using 2D binary markers with a 3x3 matrix, only 64 different markers are available. In order to overcome this limitation, a novel hybrid approach has been developed and presented in Publication I. The approach is based on 2D binary markers combined with a text code and OCR technology. The marker design, the algorithm to detect it and the training and testing are presented in Publication I. This approach, combined with the maintenance-job-task structure, finally allows a realistic deployment of a large AR system for maintenance in scientific facilities.

In the current state of the art, the majority of the AR-based maintenance studies are oriented to human intervention. However, remote handling is an important part of the maintenance systems in scientific facilities. Therefore, more studies targeted to remote handling maintenance are required. Publication VI presents a study for AR for remote handling in a real facility. The purpose of this study is to utilise the developed platform (Publication II) to implement a prototype in real conditions and analyse the feasibility and the difficulties during the implementation. Therefore, the main problems detected during the implementation of the prototype have been presented in Publication VI. The analysis of these problems and the solutions proposed in the study aim to help future developments in AR-based remote handling field.

In Publication VI, novel features oriented to remote handling that have been integrated into the platform (Publication II) are also presented. These features comprise a keypoint-based guiding system that helps the remote operator to guide the equipment through the facility, zoom options for a close-up view of the ROI and the visualization of additional information (e.g. device controllers) in a HUD.

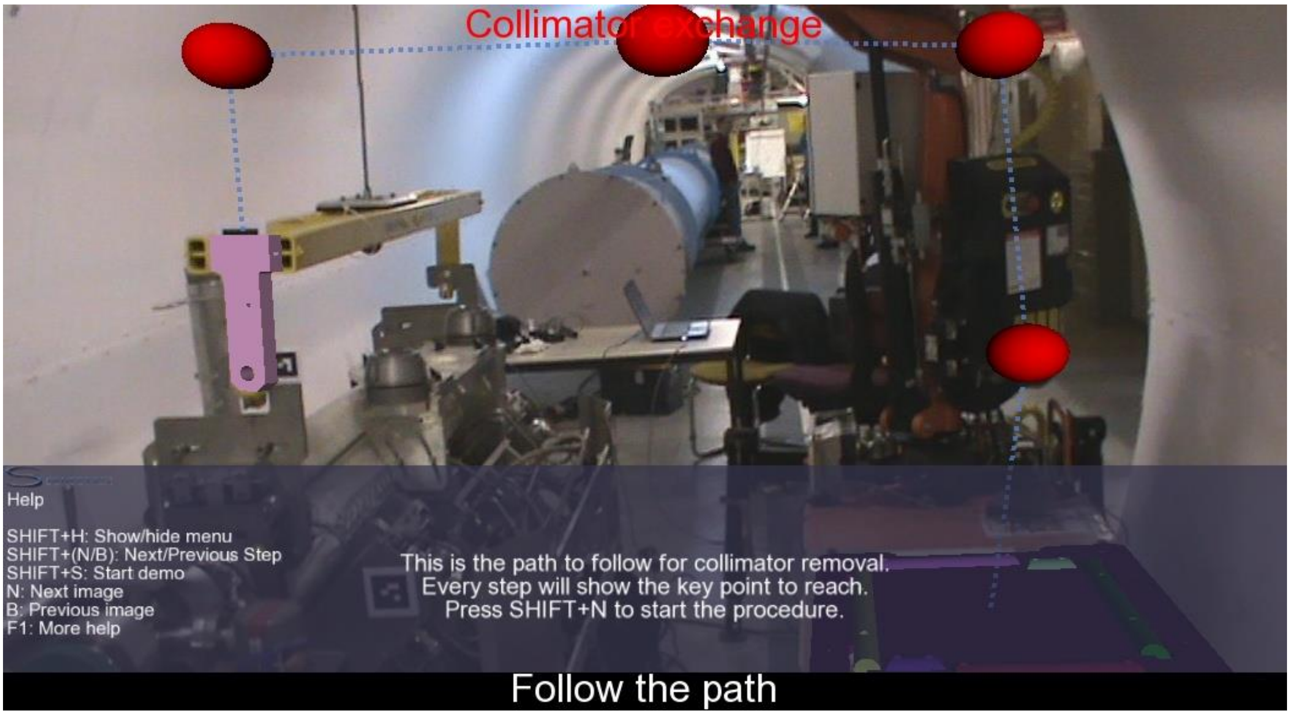
Finally, Publication VI also introduces briefly two novel features that have already been integrated into the platform: (1) virtual reconstruction of real environments from the information obtained by the AR system and (2) a multimarker configuration for enhanced tracking.

The use of AR in the maintenance field brings high impact benefits such as the minimisation of operational maintenance time (including smaller shutdown periods), increased safety for workers (especially important in radioactive facilities), avoidance of possible mistakes and risks, and reduced costs. Upon these general maintenance benefits, the proposed platform provides additional benefits:

- It is suited for both human intervention and remote handling.
- It includes a design for scalability of solutions for large projects and/or facilities and a structure for coherent management of AR applications.
- It allows facilities to create and maintain the AR system without the need for external assistance by using the developed authoring tool.

The platform is a cost-efficient solution for improving maintenance in scientific facilities. The deployment of the platform can be done within the facility without the need for additional hardware, as it can work with standard computers. On the other hand, the platform is also adaptable to a target facility’s specific requirements, such as distributed computer systems, the use of network cameras, and the like.

The proposed platform has been tested in a real facility. Figure 9 shows the prototype that uses the AR engine in the real facility. This application has been developed to aid the collimator exchange at the Large Hadron Collider (LHC) at CERN (the details of the prototype can be found in Publication VI). The procedure is carried out using remote handling maintenance, as a crane is controlled remotely to perform the exchange. Therefore, the operator needs to rely on the visual information obtained by a camera. The information from the 2D camera can be difficult to understand due to the lack of a third dimension (depth information). Thus, additional information provided by the AR view can enhance the understanding of the real situation. In the image, the AR application provides the operator with a path to follow in order to proceed with the collimator exchange. The path is made up of keypoints that the operator has to follow to reach the final goal (also displayed with a virtual 3D model). When the procedure begins, only one keypoint is displayed at a time to clearly show the current goal. This application provides a visual example of how AR can enhance a remote handling task.



This is the path to follow for collimator removal.
Every step will show the key point to reach.
Press SHIFT+N to start the procedure.

Figure 9. Example of a maintenance application using the developed AR engine. The image shows a prototype for aiding collimator exchange at CERN. The image and the related prototype details can be found in Publication VI.

The prototype has been developed and tested in a real collimator and its associated crane. The prototype feasibility has been demonstrated in real time experiments during a real collimator exchange. The developed high performance application can provide a frame rate of 30-35 fps with a resolution of 720x576 while displaying around 10,000 polygons (i.e. when using specific parts of the models). However, if the full models are used, the frame rate drops to 8-10 fps with the same resolution and displays around 175,000 polygons. The specifications of the computer used for the tests are displayed in Table 1.

An important goal of the work is not only to provide AR applications for aiding maintenance workers while performing the tasks but also to provide solutions that allow the development and maintenance of these applications. Hence, the impact of the platform relies not only on the maintenance-oriented features included in the engine but also on the authoring tool developed for that purpose.

Table 1. Specifications of the computer used for the collimator exchange prototype testing. Table from Publication VI.

Processor	AMD Turion II P560 Dual-Core 2.5GHz
RAM	6 GB
Graphics card	AMD Radeon HD 6650M
Webcam	Logitech HD Pro Webcam C910
IP Camera	AXIS PTZ 214

The purpose of the authoring tool is to allow non-programmers to develop AR applications targeted to maintenance in an easy fashion. Therefore, the authoring tools in the AR field are an important matter of study. The development of AR applications is usually a hard process in which several programming and engineering issues need to be considered. On one side, AR requires the recognition of the real environment, which usually implies working with computer vision algorithms (e.g. feature detection, homography, etc.), algebra (e.g. transformation matrices), GPS and/or sensors, and the like. On the other side, the rendering of virtual objects requires knowledge of 3D modelling (including animation, lighting, etc.), multimedia formats, and so on. Therefore, the development of AR applications is a multidisciplinary work, and knowledge in a large variety of fields is required. As a result, the development of easy-to-use authoring tools that allow the creation of AR applications without the need for the aforementioned skills is required in order to open AR authoring to the main public.

The authoring tool presented in this thesis has been designed to take into account the features integrated in the AR engine in order to allow a seamless integration between both parts. Therefore, the application has been designed with a window-based user-friendly interface that allows users to easily understand how to define the augmented scenes. The AR application that is defined with the authoring tool runs using the aforementioned AR engine.

Figure 10 shows an example of an image definition to be used in the augmented scene. The user can select the image to display in the AR scene, edit its properties, define the associated marker in the real scene and see a preview of the selected file. The output file containing all the defined information can be opened in the AR application, which makes use of the AR engine. In future, the goal is to enhance the tool in order to include more properties and features.

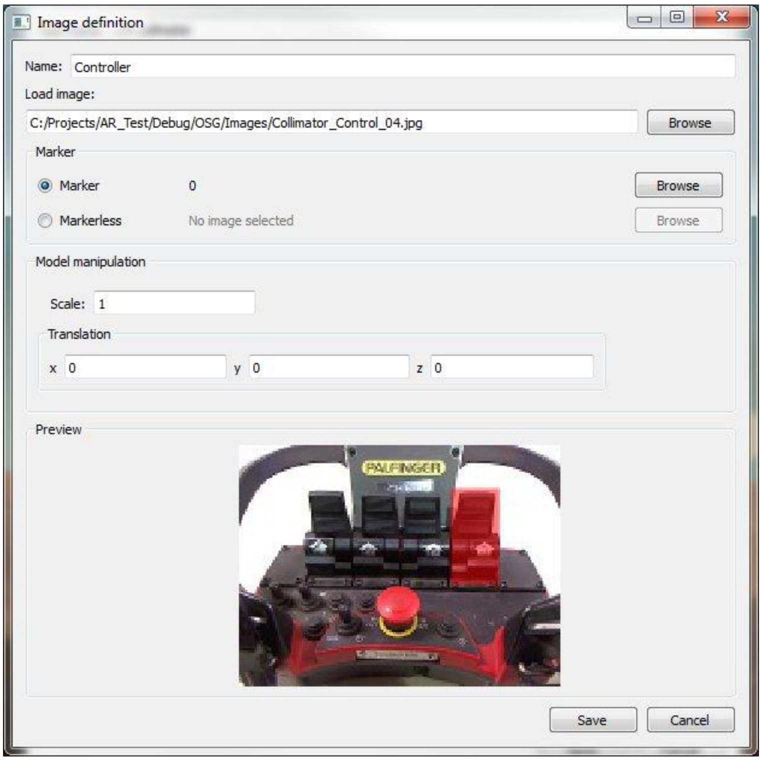


Image definition

Name: Controller

Load image: C:/Projects/AR_Test/Debug/OSG/Images/Collimator_Control_04.jpg

Marker

● Marker 0

○ Markerless No image selected

Model manipulation

Scale: 1

Translation

x 0 y 0 z 0

Figure 10. Screenshot of the developed authoring tool. The screenshot shows the definition window of an image to be used in the augmented scene. The screenshot appears in Publication II.

Although the same approach could be followed for education (actually authoring tools have been already proposed in previous research studies), two bottlenecks have been identified in the use of authoring tools in education. On one hand, although the tools are not difficult to use technically, educators usually cannot afford the required time for developing the AR tools, as they need to concentrate on other aspects of the learning process. On the other hand, if they could afford the time and were to develop AR applications, the applications would not be easily shared by the whole educational community. In the maintenance field, the applications are customised for devices present in the facility, and therefore, it is difficult to reutilise them in other facilities. However, in the education field, the learning content is usually the same for a large number of educational institutions; therefore, the sharing of applications would be beneficial for the whole community.

Therefore, in an effort to overcome these bottlenecks, a new educational platform has been developed and presented in Publication III. The platform introduces a novel concept that allows all members to benefit from the available applications contained in the platform. The applications are developed by expert programmers based upon the requirements of expert educators and trainers.

Then, the applications are made available to all platform members, regardless of the institution that requested them, providing a shared environment that benefits the whole community. The new platform also provides a common framework for educators and trainers to meet and discuss the pedagogical content and to request new applications or modify existing ones based on their discussions. However, the success of this approach will depend on the number of educational institutions that join the platform.

The platform presented in Publication II has been used as basis for the development of the new educational platform presented in Publication III. This approach has been followed in order to prove the flexibility of the former platform at the same time that a solution to the detected problem in the use of AR in the education field is provided.

Finally, a comprehensive study of the literature has been carried out. The study examines not only AR in maintenance and education but also AR applied to other fields. Several aspects of the state of the art of AR in the maintenance field have been analysed, such as marker tracking systems (Publication I), existing tools (Publication II) or remote handling (Publication VI). The benefits of using AR in education (Publication IV) and the main bottlenecks in the adoption of the technology in the field (Publication III) have been also studied. These studies have been used to carry out a larger study concerning the adoption of AR in a wider view. As a result of this study, a paper analysing the drivers and bottlenecks of the technology in five main domains (industry and military, training and education, travel and tourism, medicine and health care, and retail and marketing) has been published (Publication V). The five detected drivers and bottlenecks in the adoption of AR applications are summarised in Table 2.

4.2 Future work

The future work is involving further development of the proposed platform and tools. The goal is to provide enhanced solutions and promote them among potential customers, while attempting to bring AR closer to the general public.

The developed baseline design of platform is ready for deployment. However, it is likely that in a short time period, further changes will be made to provide a more complete version. In order to achieve enhanced solutions, new features and techniques will be studied. However, an important effort on user tests should also be done to determine the design problems of the proposed solutions.

According to Table 2, there are currently five main bottlenecks in the adoption of AR technology. This thesis faces mainly the first bottleneck (no standard and little flexibility). However, the other bottlenecks still require more effort.

Table 2. Summary of drivers and bottlenecks in the adoption of AR. Table from Publication V.

Drivers		Bottlenecks	
Reduction of costs	Costs can be reduced by using AR in several manners (e.g. reducing costs in manufacturing processes, reducing errors, safer procedures, etc.)	**No standard and little flexibility**	There is no current standard for AR applications. The majority of applications do not allow their use in other domains, and thus, the creation of new applications is usually required with the additional effort and time that it entails.
Fast learning curve	The technology is intuitive and easy to use. Therefore, the adoption by newcomers is easier than in other technologies.	**Limited computational power**	Many AR applications require complex computer vision algorithms to work. These algorithms tend to be time consuming for current devices (especially for mobile devices).
Curiosity	The idea of “expanding” the real environment with virtual content usually catches the attention of users that feel tempted to use the applications.	**Inaccuracy**	Some of the techniques are still not accurate enough to provide a robust localization of the virtual content to be displayed in the augmented view.
Tangible 3D visualization	Visualization of 3D content in real life and the possibilities of interaction offer added value.	**Social acceptance**	New devices (especially glasses) are in their first years of existence, and they have not been fully accepted in social practices.
Fun	The technology offers a component of fun in many cases that can be useful in several fields (especially in education and tourism).	**Amount of information**	The amount of information to be displayed in the augmented view may exceed the needs of the user. This problem may become critical when advertising becomes popular in AR applications.

New AR-enabled wearable devices are becoming more common and in a near future the computational power of these devices will allow the integration of the developed AR engine. Portability is very important in maintenance field, especially in human intervention. Maintenance workers need to move through the facilities and take the maintenance tools with them. Therefore the use of lighter devices will enhance the working conditions.

Inaccuracy is one major bottleneck in AR. Although marker-based approach is robust, there are still some problems when the marker is partially hidden or with extreme light conditions. In order to overcome these limitations, the AR engine already integrates a multimarker feature that aims to enhance the accuracy of the system and that is being tested for the guiding of robotic arms and mobile robots. However, this feature is not fully integrated in the authoring tool yet. Therefore, its integration will be carried out after the aforementioned tests.

The social acceptance of new devices should not be a problem in maintenance field, as they should be seen as an additional working tool. In education, however, the use of AR glasses could be more difficult as privacy is a high concern, especially in schools and universities. Therefore, while AR glasses are not accepted in social environments, it is unlikely that they will be accepted in classes and universities and traditional devices, such as computers and projectors or tablets will probably be more accepted.

The amount of information displayed in an augmented view needs to be extensive enough to clearly provide the required information, but without distracting the user from the final purpose of the application. Therefore, providing tools for the creation of AR applications allows the experts to develop the applications based on their own expertise. However, the provided information can be still overwhelming for the user and customizable interfaces need to be implemented.

Regarding the educational platform, it has been implemented, and it is starting to be promoted among institutions. The goal is to create a network of educational institutions that are interested in the concept and develop applications based on their requirements. Some institutions have already demonstrated their interest in the platform, and the first steps towards research projects that will allow further development of the applications are being planned.

Together with the development of new educational applications, there are also current plans to introduce predefined physical objects that would work with the developed applications. The objects would be augmented to show related information. For example, different boxes and blocks could be used to explain the forces involved in objects moving through different slopes, where virtual arrows would augment the physical blocks. Or, the contents of test tubes could be shown via 3D models of molecules; the reactions when mixing them by means of augmenting the molecules over the tubes could also be shown. The aim is to provide additional means for human–computer interaction with the applications in order to enhance the learning process.

The developed main platform also aims to be flexible so that it can be applied to other fields. Currently, it has already been applied to the education field, as explained before, and small prototypes for marketing have also been implemented. In the future, more prototypes for the marketing and media fields will be sought, and it is probable that a common solution targeted to those fields will be designed.

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ORIGINAL PUBLICATIONS

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A NEW HYBRID APPROACH FOR AUGMENTED REALITY MAINTENANCE IN SCIENTIFIC FACILITIES

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A New Hybrid Approach for Augmented Reality Maintenance in Scientific Facilities

Regular Paper

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Abstract Maintenance in scientific facilities is a difficult issue, especially in large and hazardous facilities, due to the complexity of tasks and equipment. Augmented reality is a technology that has already shown great promise in the maintenance field. With the help of augmented reality applications, maintenance tasks can be carried out faster and more safely. The problem with current applications is that they are small-scale prototypes that do not easily scale to large facility maintenance applications. This paper presents a new hybrid approach that enables the creation of augmented reality maintenance applications for large and hazardous scientific facilities. In this paper, a new augmented reality marker and the algorithm for its recognition is proposed. The performance of the algorithm is verified in three test cases, showing promising results in two of them. Improvements in robustness in the third test case in which the camera is moving quickly or when light conditions are extreme are subject to further studies. The proposed new approach will be integrated into an existing augmented reality maintenance system.

Keywords Augmented Reality, Maintenance, Human Intervention, Scientific Facilities

1. Introduction

Maintenance can be carried out by human, semi-remote or fully-remote interventions. Human intervention in large and complex scientific facilities, such as CERN (European Organization for Nuclear Research) or GSI-FAIR (Facility for Antiproton and Ion Research), can be difficult due to the complexity of the procedures and machines to be maintained. This human intervention can be enhanced by means of visual in-place maintenance instructions and safety advices (e.g., maximum radiation dose reached, hot areas to avoid touching, etc.), provided by augmented reality (AR) technology, allowing the worker to carry out the tasks more quickly and more safely.

Hazardous facilities need to follow safety principles, such as ALARP (As Low as Reasonably Practicable). This principle requires that the radiation dose received by the workers must be as low as possible while taking into account the balance between any risks and benefits. Human interventions are planned according to the ALARP approach in order to ensure workers' safety inside these hazardous facilities. With the help of AR, the worker can complete maintenance tasks inside hazardous environments faster and avoid errors, which means that they will be exposed to radiation for minimum duration.

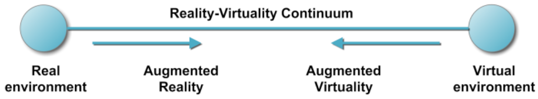

Figure 1. Reality-Virtuality Continuum.

AR is a technology that is used to merge virtual information with the real environment in real-time. Milgram defined in [1] the Reality-Virtuality Continuum (**Figure 1**), where AR is an intermediate state between the real environment and a completely virtual environment. This means that the user is conscious of the real environment and that this environment is enhanced by means of many multimodal means of interaction.

AR has been used in many fields, such as medicine [2], [3], [4], education [5], [6], [7] and entertainment [8], [9], [10]. Maintenance is one field where AR can play an important role [11], [12]. Maintenance tasks can be augmented using this technology, thus allowing the worker to carry wearable AR equipment instead of traditional heavy and difficult-to-use manuals. AR is also an aid to safety, as it can warn workers whether they are in danger or whether a procedure has been carried out in the wrong way.

However, most AR-based maintenance projects that have already been developed are only prototypes for one specific machine or device. Some of these works can be found in [13], [14], [15]. Although they are very good prototypes, for their real application a more general use application needs to be developed in order to be reusable in large facilities with a large variety of machine subsystems and devices to be maintained. In fact, there have been some approaches to this generalization [16], but they displayed certain problems as to the ease of use of the proposed systems. Nevertheless, some of the state of the art AR prototypes for maintenance use have already shown good results in terms of ease of use [13], [17], task efficiency [13], [17], [18], [19] and decreasing the risk of accidents [18], proving that this technology can enhance maintenance work.

The work presented in this paper deals with the lack of general purpose applications by means of a new approach for marker definition and recognition. A new AR marker is defined, as well as an algorithm for its detection. This new approach has been integrated in an under development system that will enable the ready creation of AR applications for maintenance in large scientific facilities.

The rest of the text is organized as follows: in chapter 2, an overview of current problems and the possible solutions related to the AR field for maintenance is presented. Chapter 3 describes the proposed solution and the algorithm designed for the detection of the proposed marker. Chapter 4 details the training and testing of the OCR-A font for the proposed approach. In chapter 5, some issues about the deployment of the final solution in real facilities are presented. Finally, in chapter 6, some conclusions and future work are discussed.

2. Fundamental problems and overview of solutions

2.1 Augmented reality for maintenance

AR applications gather information from the environment (such as images captured by a camera or user input) and analyse it. Once the information has been processed, an output is created and delivered to the user (e.g., an augmented image or audio output) in an attempt to achieve a natural feeling for the user, meaning that they perceive the augmentation as a part of the real environment.

The procedure followed by a typical AR maintenance application is as follows: when a predefined pattern is recognized by a camera, the AR system looks in the storage for the multimodal information associated and the marker that is augmented with it. The multimodal information represents any instructions, procedural assistance and safety advice for the maintenance, allowing the worker to carry out the work easily and avoid mistakes. **Figure 2** shows an example on how AR can enhance a maintenance procedure. The image shows a green overlay that represents the augmentation area (e.g., LCD glasses or screens). This means that the worker is able to see the real scene in the background and the augmented part on top of it. As can be seen in the image, virtual models and arrows are displayed on top of the original image showing the instructions for the removal of the grey box from the machine. The information provided to the worker is not limited to 3D models, as it can also include images, text messages, videos, audio instructions and audio/video conferences with supervisors. Any kind of multimodal help could be provided to the worker when necessary in order to make their work easier.

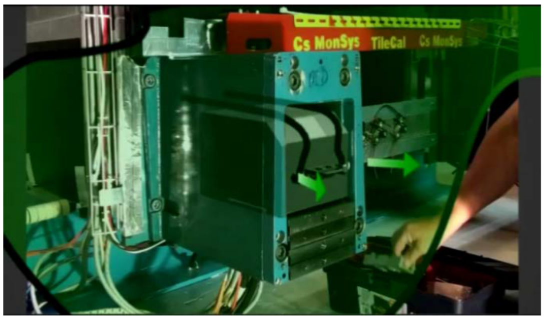

Figure 2. An example of an AR application for maintenance.

2.2 Identified problems

AR applications use pattern recognition algorithms in order to work. Among those algorithms, marker and markerless techniques are the most common approaches. Some also consider using QR (Quick Response) codes [20] for AR applications. However, the great majority of QR code applications rely on a different concept, since when the code is recognized the application gets the encoded information - which is mainly text, like a web address - but not 3D spatial information of the QR code with respect to the camera. This cannot be considered as AR but something different like extended reality, as the virtual content is displayed in a different context (e.g., a web browser, a video player, etc.) to the real environment. Moreover, the recognition in those applications can be done only if the QR code is seen clearly and with little distortion in the image. In order to use QR codes for genuine AR applications, a robust library should be developed. There are some research studies that use QR codes for AR applications [21], [22], but there are not available in libraries for the research community to test in order to compare the robustness of these works with the robustness that other AR libraries have shown. In fact, the work presented in [21] relies upon the camera pose estimation in the device sensors and how the user manipulates the device instead of the real tracking of the QR code, while the work presented in [22], although promising in tracking the QR code, gives a low frame rate (10fps), which means that it cannot be used for real-time applications. Moreover, most of current research trends over the last decade in AR have been focused on the marker and markerless techniques, as they have proven to be sufficiently robust and accurate for real-time tracking.

Markerless techniques have developed very quickly in recent years and they are making AR applications look more natural, since they do not need to add extra information to the environment because of the fact that they track points in real images. However, prior training of the images for detection must be performed. For small or singular projects, this approach is good enough (and even better, due to the fact that it can be more visual) as only a few images have to be trained. However, if we think of large projects where hundreds or thousands of patterns are needed simultaneously, these techniques are not advisable because of the time required for the training, the increase in the time used by the algorithm in recognition as the number of images to be tracked grows, and the high memory use.

Marker-based techniques have some advantages over markerless techniques for large facilities, as they use less memory and the tracking is faster and more robust. Marker-based applications can also be divided into two groups: marker patterns and 2D barcode markers. Marker patterns show similar problems to markerless techniques, as they require some training and the computational cost rises with the number of markers to track (although the required time and memory use are lower than in the previous technique). 2D barcode-based applications do not require a training process as the system already knows every marker. Those markers have a predefined pattern made up of black and white squares inside a matrix. For this reason, the recognition is faster, more robust and requires no training and uses less memory.

As a result of these considerations, 2D barcode markers appear to be suitable techniques for large-scale projects. However, there are still restrictions with this method. For example, with a 3x3 matrix only 64 different markers are available. This number can be incremented by using larger matrices, but incrementing the size of the matrix makes the recognition less robust for small marker sizes and for long distances between the marker and the camera.

2.2 Proposed solution

In order to cope with this limitation and provide a larger number of available markers, this paper proposes a new hybrid technique where a new marker has been defined. The new marker is made up of a 2D barcode marker and is complemented by one text code above it. In previous approaches, the marker differentiation is made during the marker recognition step. In the proposed approach, the 2D barcode marker is used for detecting the position and location, while the marker differentiation is performed by the reading of the text code.

This new approach will be integrated into an under-development system that will enable large scientific facilities to easily design and develop augmented applications including multimodal interaction for the maintenance of scientific instruments as well as other, related, devices and machines.

AR maintenance researchers have shown great interest in multimodal interaction, such as speech recognition [23], gaze interaction [24], opportunistic controls [25] or combinations of various modalities of multimodal interaction [26]. The AR-based maintenance system that will integrate the new approach presented in this paper implements several multimodal interaction interfaces ranging from the most traditional ones (keyboard and mouse for input and augmented video as output) to more novel interfaces, such as gesture and marker interaction. The purpose of the final system is to be as general as possible, allowing for the easy application design for large scientific facilities and a natural Human-Computer Interaction (HCI) for the maintenance worker.

3. System and algorithm description

3.1 System overview

This paper proposes a hybrid approach for marker detection that will be used in an AR-based maintenance system for large scientific facilities. The proposed system works as follows: it gets the image from the camera and detects the marker using a hybrid approach for the marker. Once the marker has been recognized, the system queries in a database for the specific information associated with that marker and augments the final output according to it. The content information for the augmentation is usually hardcoded in most prototypes due to the low number of elements to display. However, this is not possible for large facilities being thus crucial the use of a database that manages all the elements and information required for this kind of system. The purpose of this paper is to describe a new hybrid approach for marker detection and, therefore, the rest of the paper will explain only the details from the marker recognition subsystem.

3.2 Hybrid approach overview

Figure 3 shows the proposed approach for new marker definition and the technique for its recognition. The image containing the marker is fed into the system. This image contains the hybrid marker in any position and orientation with respect to the camera. The 2D barcode marker is detected first. With this information, the image is manipulated with computer vision techniques in order to achieve a readable screen-aligned text and, afterwards, the text code is segmented and read using optical character recognition (OCR) techniques. The following section explains this procedure in more detail.

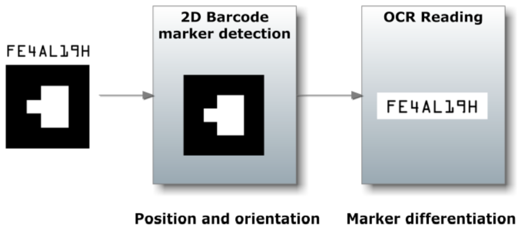

Figure 3. Overview of the new marker approach and algorithm.

3.3 Algorithm description

The current state of the art recognition libraries for 2D barcode markers are very robust and work smoothly on current computers. For this reason, this work utilizes an already available library.

The algorithm first uses ARToolKit [27] for 2D barcode detection and tracking. ARToolKit is a well-known marker recognition library and one of the most commonly used libraries in AR applications due to its accuracy and robustness. It provides information about the marker, such as the screen position of the corners of the marker in the image and the orientation of the marker, which will be useful in the next step.

The goal after detecting the marker is to read the text code above it, as trying to read the whole image can be time consuming. The marker is seen in the image in a distorted way. The recognition of the marker is very robust even if the marker is not seen as a perfect square, but the text recognition is very weak if the text is not screen-aligned. In order to have a screen-aligned text, it is necessary to rectify the image. As the marker is a planar surface, a suitable way of reconstructing the image is to compute a homography [28] between the image captured by the camera and a new, rectified image. The calculation of a homography enables the calculation of the correspondence between points in two images (or planes in general). This means that it is possible to calculate the correspondence between points in the non-screen-aligned marker and those in a screen-aligned square.

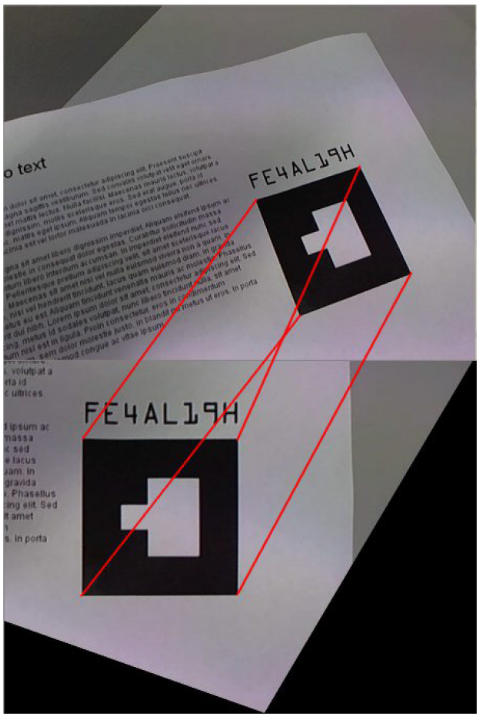

Figure 4. Original (up) and rectified (down) images. The red lines show the correspondence between corners.

The homography between two planes is defined by a non-singular 3x3 matrix. The matrix calculation is made using the correspondence between the known coordinates of points seen in the original and rectified images. The homography matrix needs eight equations to be calculated, which means that the minimum number of points needed is four (as each correspondence between points involves x and y coordinates).

Once the marker has been detected, the homography is computed between the four corners of the marker and a virtual square. With the orientation of the marker, it is possible to know the order of the corners of the marker and, thus, form the correspondences with the virtual square. The homography matrix obtained is used to create the rectified image. In **Figure 4**, both images - original and rectified - are shown. As can be seen in the image, the four corners of the original image have their corresponding corners in the rectified image.

The text in the rectified image is suitable for the OCR process. As has been mentioned before, trying to detect text in the whole image can be a highly time consuming process. For this reason, the area above the marker is segmented and scaled into a new image, as can be seen in **Figure 5**.

Figure 5. Segmented text.

The new image is ready for OCR but the image can be blurred, for several reasons (e.g., the image has been taken in motion, the marker is very small or it is far from the camera, etc.). In order to achieve better recognition, the image is sharpened using the unsharp masking (USM) technique before the actual text code recognition. The USM technique consists of creating a blurred image that is subtracted from the original image, thus creating an unsharp mask (a threshold is used to decide which pixels will define the mask). Later, this mask is used in combination to a high contrast version of the original image and the original image itself to create the final sharpened output image. Figure 6 shows two examples of the original images (left) and the images obtained after the unsharp masking (right). As can be seen in the images, the UM method makes a slightly sharper image.

Figure 6. Original (left) and sharpened (right) images, using the unsharp masking technique.

At this stage of the process, the image is fed to the OCR engine. Although the image is very small, the OCR process is still time consuming, and so the homography computation, image restoration and OCR reading processes are carried out in a different thread. **Figure 7** shows the two main threads inside the system. The main thread is in charge of the image acquisition, 2D barcode marker detection, multimodal augmentation and final output, while the OCR thread gets the raw image from the main thread as well as the information following the 2D barcode marker detection. The output from the OCR thread is fed to the main thread in order to get the correct multimodal information for the augmentation. The OCR thread enables the continuous checking of the text code above the marker, while the main thread works in real-time without freezing, allowing the system to properly identify the real text just in case it is missing in some frames due to blurred or defocused images.

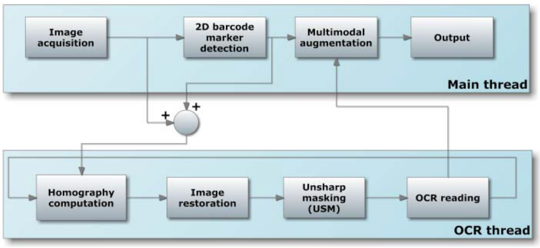

Figure 7. Main threads and their interaction. The main thread is in charge of the main flow, from the image acquisition to the final output, while the OCR thread computes the computer vision step used to recognize the text.

4. OCR-A font training and testing

OCR technology has certain problems with regard to how characters can be mismatched. For example, number '0' and the capital letter 'O' can be easily mixed. For the purpose of robust character recognition, a specific OCR font, called 'OCR-A' [29], is used in this study as an alternative for traditional fonts. OCR-A is a text font that is meant to be easy to recognize by computers and humans. This font is standardized as ISO 1073-1:1976 [30]. The OCR-A font is monospaced (it has a fixed-width), which makes it easier not only recognition but also for the creation process, as the marker also has a fixed-size. The OCR system used in this work was originally trained to recognize sans-serif fonts by default. For that reason, in this project the system has been trained to recognize the OCR-A font. After the training, some tests were made to compare the results in character recognition. To do so, OCR-A has been tested against a sans-serif font (Arial).

The tests consist of a series of recognition loops. Every loop consists of 200 readings of the text above one marker. The texts are eight characters long and contain characters that are likely to be mismatched. An example of text could be

"0ODB8T71". The recognized text is compared against the real text that is introduced into the system by the user through the keyboard. A success means that every character has been properly recognized. If one or more characters are not recognized or mismatched, the reading is considered to be a failure. After the 200 readings, the percentage of success is calculated. This process has been repeated six times for every case study. In order to get more realistic results, the tests were carried out with a conventional webcam in autofocus mode in an attempt to recreate an environment close to the final, real use.

Three case studies at two different resolutions were carried out. The selected resolutions were 800x600 pixels and 640x480 pixels, which are very common values for most webcams. Resolutions under those values have proven to have very poor performance for the aims of the application. The three case studies are as follows:

- A static camera, consisting of the recognition of text above one marker with both the marker and the camera in a static position. This is the most stable case, as the images are sharp (unless the autofocus fails) and, thus, the recognition is more robust.
- A handheld camera is one typical use of the application where the marker is fixed over a table (or attached to a static surface) and where the user holds the camera trying to avoid strong movement. In this case, some images may be blurred due to the user's pulse or some failure in the autofocus.
- A moving camera gives the worst test results; here, the camera is randomly and continuously moved and zoomed by hand so that most frames are blurred or even defocused. This should not be a desirable use of the final application, as these movements make the viewing experience of the content barely satisfactory for the user.

Figure 8 shows the results of these tests. For every case of the study, the mean success rate of the six repetitions (200 readings each repetition) has been calculated in percentage terms. The standard deviation is also displayed in the figure. As seen in the image, OCR-A gives better results than Arial in all of the case studies.

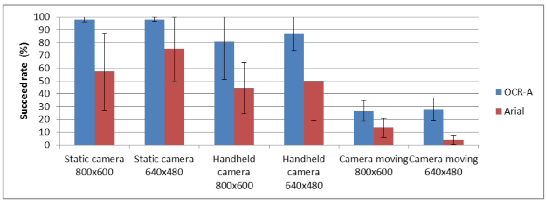

Figure 8. Comparison of the results of the tests carried out for OCR-A and Arial. The OCR-A fonts give better results in all cases. Static camera tests showed the best results. Handheld camera tests also showed good results, as the text is recognized in the majority of cases. The worst results come (as expected) from the moving camera tests, as many images are blurred or defocused.

The success rate is higher in all cases when using the OCR-A font, being notably high when using a static camera. The results from the moving camera (strong movements) are, as expected, not very robust, as the movements make the images blurred or defocused. However, the results are still much better in the case of the OCR-A font. Although these results may not seem good in the case of the moving camera, it is important to point out that the algorithm is continuously reading the text code, which means that it will work even if some frames are blurred or defocused due to the fast camera movement.

The high values of standard deviation are a consequence of the mistakes in recognition. If the text contains characters that are easy to mismatch, the recognition will fail in most readings, throwing up a low success rate. On the other hand, texts that are more robust in relation to OCR recognition will provide better results. In the best cases, when not using mismatching characters, Arial could achieve results almost as good as OCR-A, but for general use (this means using only alphanumeric characters), Arial will fail more frequently than OCR-A.

It is important to point out that the failures produced by the OCR-A font are, in most cases, due to the missing of a character because of a blurred image or a similar problem rather than a mismatch between characters. However, Arial failures are more closely related to mismatched characters, such as recognizing '0' as 'O', 'B' as '8' or '6' as 'G', etc.

Special character recognition - meaning non-alphanumeric character recognition - is also an important issue, as it increases the number of available codes. After the OCR-A testing process explained above, an additional effort has been made to allow for the highest number of available characters for the final system. In order to increase that number, a second testing process has been carried out. All characters (alphanumeric and special characters) in the OCR-A character set have been trained, although not all of them will be used. In the preliminary tests of this second process, twenty-two of those special characters have shown robust results in the recognition process. Eight special characters are usually recognized, but the recognition is not robust enough to be included in the system. Finally, eighteen special characters are not well recognized or even recognized at all, so those characters will not be included in the system either.

After the selection of the twenty-two special characters that work robustly, a new test including only those special characters in the text code above the marker was carried out. Three different texts were tested. For every text, ten loops of 200 readings per loop have been performed. The texts used and the results from this test are shown in **Figure 9**, below. As can be seen, the results are not as good as expected. The reason for these results is that some characters are sometimes mismatched. The first text contains two characters that are sometimes mismatched with another two characters. The second text, which gives better results, contains only one character that is mismatched with another character. None of the characters of the third text is mismatched, and thus the success rate is over 90%. As can be guessed by the standard deviations of the two first texts, the problematic characters are properly recognized many times, but the high probability of a mismatch advises against the use of these problematic characters. For this reason, the three problematic characters were removed for the last test. It has been noticed that there is one character which, although most of the time it is well-recognized, may cause some mismatching problems and, for that reason, it has also been removed. In the last test, three new texts including only the eighteen selected characters were read. In this test, three loops of 200 readings per loop were carried out for every text in three different cases (static camera, handheld camera and moving camera, all cases with a resolution of 800x600). The results of this test are displayed in **Figure 9**, below. As can be seen, the results are very similar to those obtained in **Figure 8**, so ultimately those eighteen characters will be used together with the alphanumeric characters.

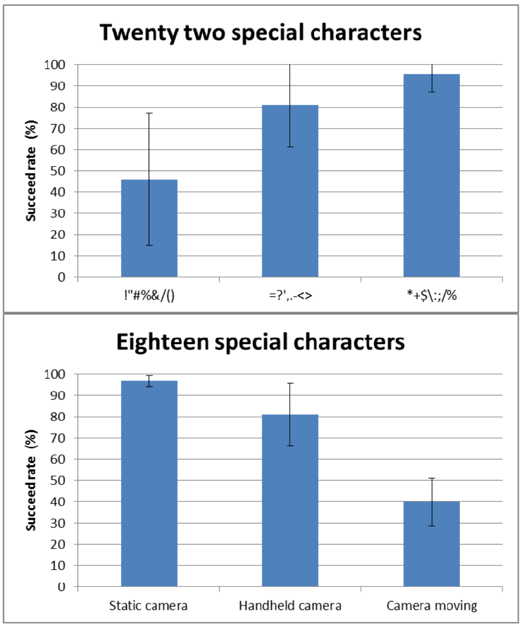

Figure 9. Results of the special character recognition tests. The results from the first test (twenty-two special characters) show that when some characters are present in the text, the success rate decreases for the same test conditions. The second test (eighteen special characters) shows that after the removal of four problematic characters, the results are very similar to those presented in Figure 8, when only alphanumeric characters where used.

5. Deployment issues

The work presented in this paper proposes a new method that will be integrated into a system under development that enables the creation and execution of AR-based applications for maintenance in large scientific facilities. For this reason, some issues have to be considered in the deployment of the final solution. This chapter exposes some of these considerations.

5.1 Real facilities' conditions

One of the most important issues to deal with in these kinds of systems is to test it against real conditions. For this reason, some preliminary tests were performed in a real facility. The chosen facility was a 40 m long and height and width real scale LHC (Large Hadron Collider) mock-up at CERN.

The tests were performed using different markers over a real collimator. Those tests have shown that the marker can be properly recognized in real cases by the proposed algorithm, even under different light conditions (natural, halogen and actual facility light conditions have been tested).

Figure 10 provides an example of those tests (from top to bottom, the original frame, the rectified image and the segmented text). In this particular case, the marker used is white instead of black, as with those presented in previous images. Both black and white markers were tested over the collimator, showing similar results in terms of marker detection and text recognition.

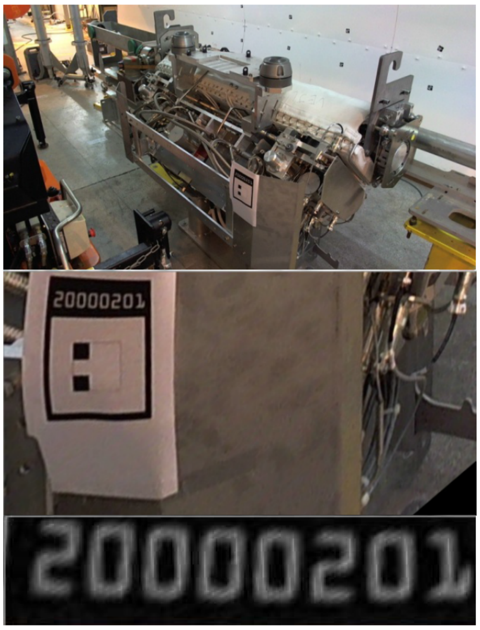

Figure 10. One example of the tests performed at CERN. The images show (from top to bottom) the original frame, the rectified image and the segmented text.

Another aspect that has to be taken into consideration is radiation. During the tests, paper markers were used. In many cases, the final system will need permanent markers over the devices. As some areas that have to be maintained may have high radiation levels, proper material for the markers has to be used. If a radiation-resistant material is not used, the radiation may modify the appearance of the marker or even destroy it. For this reason, markers made up of anodized aluminium will be used in those cases, following a similar approach to that presented in [31], where photogrammetric targets made from anodized aluminium are used for measuring the position of the collimator.

5.2 Training for workers

AR is an intuitive technology with a quick learning curve such that even users who have never used an AR application before have been seen to use them with good results [32]. For this reason, the final system that includes the approach presented in this paper may be used even without previous training. However, it is always advisable to provide workers with a short training period explaining the most basic features of the system and the concept of AR itself. As this training will be minimal in most cases, workers do not need to get every detail of every machine or device to be maintained, as this information can be provided by the AR application itself. For this reason, the costs involved in the training process can be reduced.

6. Conclusions and future work

6.1 Conclusions

This paper proposes a new hybrid approach for AR applications oriented towards applications that are used in large scientific maintenance projects with hundreds or thousands of different marker patterns to be detected. The marker used in the proposed system is a new concept of a marker composed of traditional 2D barcode markers and a text code string.

Pattern recognition and computer vision algorithms have been used to detect the marker, segment the text code and read its characters. The final marker is then augmented according to the information contained in a database.

The pattern recognition algorithms are robust for marker scaling and rotations. However, the OCR method is sensitive to large image rotations. For this reason, the original image needs to be rectified so that the text to be read is in the right orientation. To that purpose, a homography between the four corners of the marker and four virtual points is computed. With the help of the homography matrix, the original image can be rectified independently of the marker rotation into a properly aligned image where the text string is displayed horizontally.

In order to verify the performance and quality of the proposed approach containing marker recognition and OCR, some tests were carried out. These tests include not only the performance of the system itself but also a comparison between a sans-serif font and an OCR-A font. From the results, it can be concluded that the OCR-A font gives better performance in terms of success rate for the different tests and, thus, the OCR-A font was selected as the most suitable font for the final system.

This paper has also presented certain issues to take into account when the final application is deployed. Those issues consider facilities' conditions and training for workers.

6.2 Future work

Most AR applications ground the perception of the real environment in computer vision techniques. The proposed work follows the same approach. The work presented in [33] suggests that in future, indoor AR applications will integrate computer vision systems with external fixed tracking schemes. It is expected that more sensing technologies (such as RFID) will be tested and integrated in the final system as complementary environmental sensors if they prove advantages in terms of more robust and accurate tracking systems.

Another important aspect is to improve the robustness of the marker recognition. For this purpose, new ideas will be explored, such as using infrared tracking methods, like in [34], together with reflective markers, as proposed in [35].

The study of how workers react to the final application will also be performed, probably at GSI facilities. It is important to know whether the information provided is sufficient and whether it is distracting workers from actual maintenance tasks.

An important issue in state of the art AR maintenance applications is that they are usually hardcoded applications that cannot be used by non-experts [36]. Although the proposed system is still lacking an authoring tool, some steps to solve this problem have been already taken (such as using databases) and it has been planned that an easy-to-use authoring tool will be developed in order to allow non-programmers to create and edit the final applications.

7. Acknowledgments

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II

A NEW FLEXIBLE AUGMENTED REALITY PLATFORM FOR DEVELOPMENT OF MAINTENANCE AND EDUCATIONAL APPLICATIONS

by

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A New Flexible Augmented Reality Platform for Development of Maintenance and Educational Applications

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Abstract- *Augmented Reality (AR) is a technology that has gained an increasing interest during last years. Several fields (e.g. maintenance and education) have already started to integrate AR systems in their procedures. The preliminary results obtained from those works show a promising future for the technology. However, the number of tools that allow non-programmers to create new applications is still limited. Moreover, the great majority of these tools have still some limitations in terms of flexibility and reusability. The purpose of the platform presented in this paper is to face those problems and provide new means of AR application development. The main target of the platform is to serve as a unified system for aiding operators in the maintenance procedures in large scientific facilities. However, an important goal is that the platform can be flexible enough so it can be adapted to other fields. In order to demonstrate this flexibility, the platform has been also used to develop educational applications and a commercial educational platform.*

Keywords: Augmented Reality, maintenance, scientific facilities, education.

1. Introduction

Augmented Reality (AR) is a technology that combines images of real environments with virtual objects displayed on top of these images in real time. This combination allows the creation of interactive applications where a large amount of virtual information coexists with the real environment. As a result of the features provided by AR technology, two fields that can take a great advantage of the extended information and the interactivity capabilities are maintenance and education.

Although the technology has drawn the interest of many experts from different fields, there is usually a gap between the content value, which relies on the experts, and the application development, performed typically by developers that are not related to the application target field. Usually, a great collaboration effort is required to develop an AR application targeted to one specific field. If we think of maintenance, for example, the tasks to carry out are well known by operators and other experts in the facility. However, developers from an external software company usually do not have knowledge about the tasks or devices to maintain. Moreover, the material to be used for the augmentation (e.g. 3D models, manuals, videos, etc.) is developed and stored in facilities computers and there is a need for appropriate format conversion and transfer of the files to the software developers in order to be used in the final application.

Some tools have arisen in recent years to fill the gap. These tools can be used with little programming skills (although some of them still require some knowledge) and would allow experts to develop their own applications. However, there are still some drawbacks that prevent the generalization of the technology. The majority of the tools lack of flexibility and appropriated features to be used in large scale projects where hundreds or even thousands of applications need to coexist.

The work presented in this paper tries to cope with these limitations by means of an AR platform that includes an AR engine and an authoring tool, as well as some novel features oriented to the creation of maintenance AR applications for large scientific facilities as well as to provide flexibility for the

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development of AR applications for different fields, such as education.

2. Related Work

Maintenance is one field where Augmented Reality can play an important role [1]. The possibility of guiding operators with virtual instructions displayed over the devices to maintain makes AR a suitable technology to enhance the maintenance procedures. There are currently several works in the literature that use this technology for that purpose (e.g. [2], [3], [4]). However, the main output of those works is usually one prototype that is used in one case only which implies a lack of a reusable general purpose Augmented Reality-based maintenance system which is usually required in industrial environments [5].

Education is another field that has already seen the benefits of using AR (e.g. [6], [7], [8]). Students find the learning process funnier and more interesting when reality is mixed with virtual elements [9], [10]. As in maintenance field, the majority of developed AR applications are prototypes for one use only and they are not usually reusable.

As stated before, there is a common problem in the development of AR applications. Programmers have the knowledge for the creation of AR applications, but they lack of content knowledge (e.g. pedagogical educational content). On the other hand, specialists from the fields (e.g. maintenance operators in facilities and educators) have the knowledge of the content and how to use it, but usually have little experience in programming. Nowadays there are already some authoring tools that allow the creation of AR applications for several purposes (e.g. [11], [12], [13]). However, these applications still require the programming of small scripts or XML descriptions. There are also some applications that allow the development without the need of programming skills (e.g. [14]). Although these applications are good enough for individual prototypes, they lack of some interactivity features and in some cases they are restricted to the visualization of 3D models only. Moreover, there are some cases where large amounts of tracking markers and a great flexibility are needed (e.g. large facilities where hundreds or thousands of devices need to be maintained and where the instructions for the maintenance may change along the time).

The platform proposed in this paper aims to provide a flexible framework to focus in the content development instead of spending time and effort in developing individual prototypes. The platform consists of a common AR engine with a large number of features and an authoring tool to easily create the desired applications. The goal is that through the use of an intuitive interface, every user, regardless his/her programming skills, is able to develop AR applications that will make use of the AR engine. Moreover, a database and a new AR marker approach [15] have been also included in the platform to allow the flexibility and coexistence between AR applications.

The main target of this platform is its use in the maintenance field, as the development has been achieved inside PURESAFE project [16]. The goal is to aid maintenance operators in large scientific facilities such as CERN or GSI in the maintenance procedures. The AR applications for maintenance guide operators to successfully perform their tasks (either by human intervention or by remote handling) saving time and costs, as well as providing safer methods for them. Additionally, thanks to the previous knowledge in AR for educational purposes of the main researcher [17], the platform has been also adapted to create an educational platform which is already commercially available [18].

The remainder of the text is as follows: chapter 3 details the proposed platform, including the developed engine and authoring tool as well as the AR applications. In chapter 4 some results in form of applied examples are presented. Finally, section 5 presents some conclusions.

3. Materials and Methods

In this chapter a general overview of the platform is presented. The platform comprises an engine and an authoring tool. The engine is in charge of running the final AR applications that have been created using the authoring tool. The architecture of the engine, the authoring tool and the description of the AR applications are detailed in the following sections.

3.1. Engine Architecture

The engine has been completely developed using C++. A large number of different libraries have been integrated into the engine. Two of the most important libraries inside the engine are ARToolKit [19], a well-known library for AR marker tracking, and OpenSceneGraph [20], which is a powerful 3D graphics API. These two libraries deal with the two common challenges in any AR application: the understanding of the environment and the rendering of virtual content. However, as additional features have been introduced into the engine, the number of libraries integrated is large, as mentioned before. For this reason, the engine has been built as a modular engine in order to easily integrate new functionalities. Figure 1 shows the main modules of the engine.

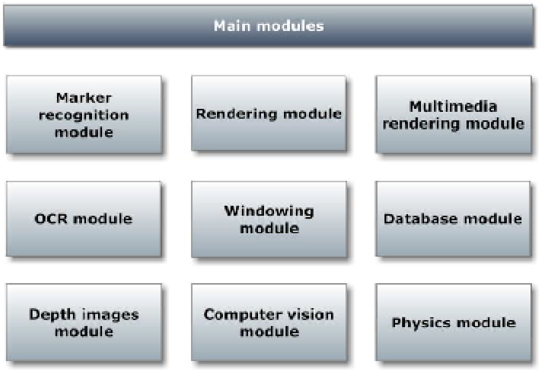


Figure 1. Main modules of the engine.

The engine has been designed as a component-based architecture where the components (i.e. the modules) offer several interfaces (e.g. session configuration, tracking information, etc.) in order to allow the communication between them. This approach allows flexibility as components can be reused and/or substituted by new ones if needed (e.g. when a newer and more robust Marker recognition module has been developed or if there is a need to change the Rendering module for a more powerful one). The modules have been integrated into higher level components that correspond to the phases explained later and shown in Figure 2.

The engine supports the creation of new applications by a plug-in system (integrated in the Windowing module) where every new application is considered as a new plug-in. The engine contains an abstract class that plug-ins need to implement. The methods provided by the abstract class allow setting up the application (i.e. loading the tracking system and the required virtual elements), updating the values of variables according to the AR tracking and user input and displaying the resulting AR scene. The engine also offers the methods provided by the modules presented in Figure 1 allowing every application to use them when needed. This design provides great flexibility and allows the creation of independent applications that can coexist in the same working environment.

The plug-in system has been designed following a database-centric architecture where the use of databases and the aforementioned Database module allows the definition and edition of the content and behaviour of the application. Moreover, if two AR applications require the same global behaviour (e.g. using the same tracking system, the same interaction capabilities, etc.), they can be developed as a single plug-in that makes use of two different databases where the specific information is stored.

The engine has four main phases which correspond to the high level components mentioned earlier: Initialization, Recognition and tracking, Content management and Rendering. The relationship between the four phases and the engine modules can be seen in Figure 2.

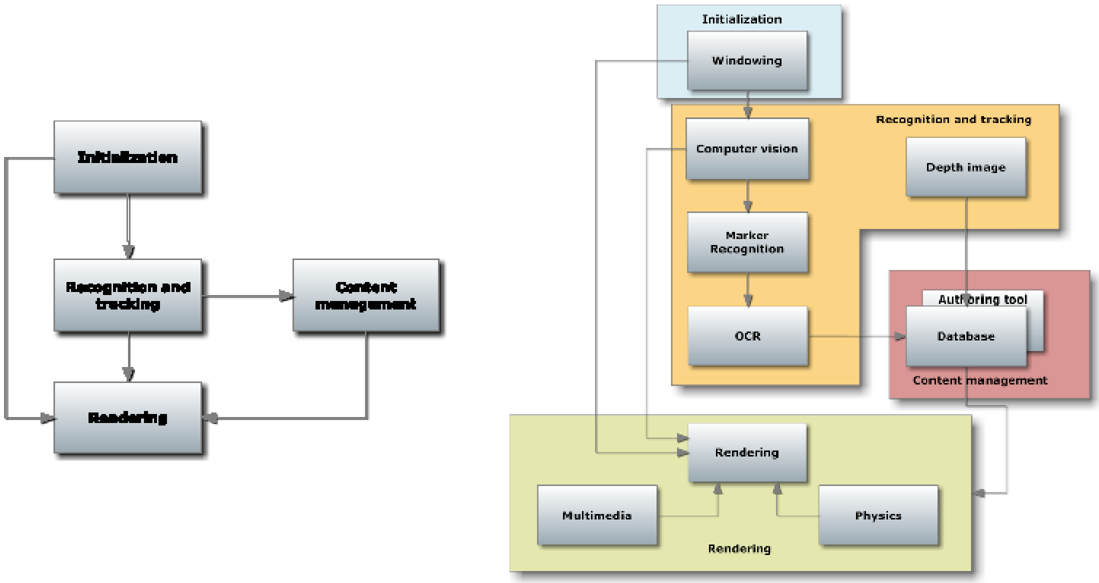


Figure 2. Phases of the engine and their relationship with the engine modules.

During the Initialization phase, the windowing module is in charge of displaying the options to the user in order to allow the selection of the configuration for the current session of the AR application.

Once the user has selected the right configuration, the Recognition and tracking phase uses this information to set up the video feed and start the recognition and tracking. The engine accepts as input different video options, such as live video from a camera, pre-recorded video, images or depth video. Regardless the video input, the engine uses the images to detect markers visible on them. The engine also integrates the possibility of using a multimarker setup in order to provide more accuracy in some cases where one of the markers can be hidden (e.g. due to maintenance procedure) or when light conditions may render proper tracking of markers more difficult.

The engine is able to detect two different kinds of markers. The first type of marker is a 2D barcode marker, which is a traditional approach in AR applications. The second type of marker is a novel marker approach that has been designed for the proposed platform [15]. This novel approach consists of a hybrid marker that uses 2D barcode markers together with a text coding system. The marker is first detected using traditional algorithms for marker detection. With the position and orientation of the marker, the text is segmented from the image and read using Optical Character Recognition (OCR) techniques. Finally, the output is the position and orientation information combined with a unique id that encrypts, together with the database system, the necessary information for the augmentation. The goal of this second type is to overcome the limits of maximum number of unique 2D barcode markers, allowing thus more flexibility to the engine, as a higher number of unique markers can be used within the same application. This is especially important in maintenance field, as a large facility may need a high number of unique markers in order to uniquely identify all the devices that need to be maintained using an AR application.

When any of the aforementioned markers has been detected, the engine looks for the appropriate content to augment the scene in the Content management phase. The engine contains a database module where all the information is stored. The databases can be created and edited by using the authoring tool developed for the purpose. The use of the database module provides great flexibility, as the virtual content information can be edited outside of the source code of the engine (i.e. there is no need for changing the code of the engine to adapt it to new applications). Moreover, the virtual content that will be used for the augmentation can be stored locally or in a net storage system.

Finally, during the Rendering phase, the images obtained for the tracking are augmented by the rendering module using the information provided by the database module.

3.2. Authoring Tool

In order to allow the easy creation of AR applications that make use of the engine, an authoring tool has been developed. The authoring tool has been implemented using Qt [21].

The authoring tool allows the creation of individual AR applications and a set of maintenance tasks:

- Individual AR applications: These applications are not related to other applications and they can be run independently.
- Set of maintenance tasks: This is a special feature thought for maintenance field. As maintenance procedures usually comprise several tasks, there is a need for combining all these tasks into the same application. To cope with this requirement, the authoring tool allows the definition of three elements: maintenance, job and task.
    - Maintenance: Every maintenance element is an individual maintenance procedure and contains one or more jobs.
    - Job: Every maintenance procedure can contain one or more different jobs that need to be carried out. Every job contains one or more tasks.
    - Task: A task contains all the steps and instructions that need to be performed in order to complete the maintenance. Every task can be considered as an independent AR application. However, the different tasks are connected through one or more jobs. Every task is made up of several virtual elements that are displayed when the maintenance worker is using the AR application.

Figure 3 shows an example of the interconnections between the different options inside the set of maintenance tasks. The example depicts a simplified computer repairing company. In the list of maintenance procedures appear all the different maintenance procedures that the company performs (repair desktop, repair screen, repair keyboard and repair mouse). Every maintenance procedure contains one or more jobs that can be common (e.g. Open device) or specific for each maintenance procedure (e.g. Remove graphics card). Finally, for every job, there is a set of tasks that can be shared by several jobs (e.g. Unscrew) or specific for the current job (e.g. Insert new card). The right side of Figure 3 shows the final flow of one maintenance procedure, containing a set of jobs that, in turn, encompass a set of tasks.

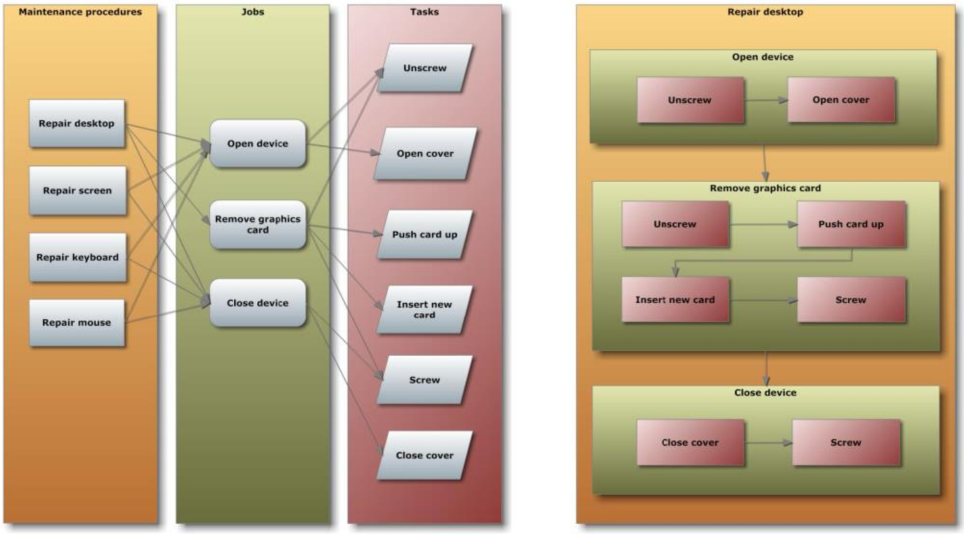


Figure 3. Example of interconnections between maintenance procedures, jobs and tasks (left) and the flow for one maintenance procedure.

As stated before, the authoring tool has been implemented in order to be intuitive and easy to use. The application contains several windows for the definition of the different virtual elements, as well as maintenance, jobs and tasks definitions. Figure 4 shows an example of an image definition. The user can select the image to display in the AR scene, edit some properties and see a preview of the selected file. In future, the tool will be enhanced in order to include more properties and features.

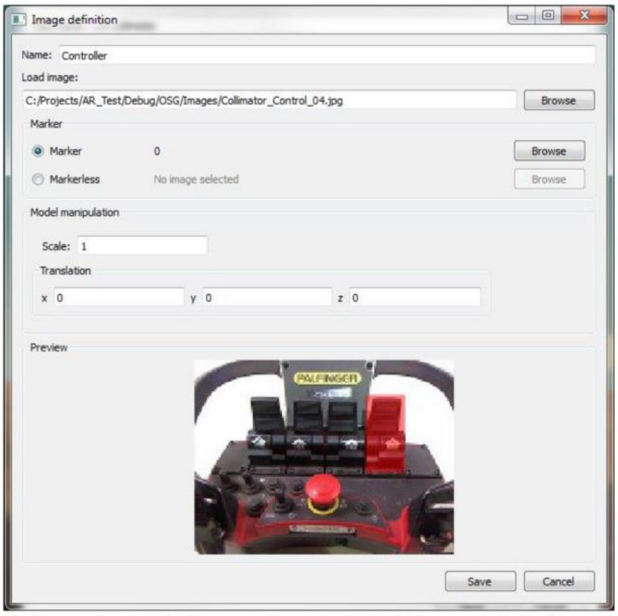


Image definition

Name: Controller

Load image: C:/Projects/AR_Test/Debug/OSG/Images/Collimator_Control_04.jpg

Marker

● Marker 0

○ Markerless No image selected

Model manipulation

Scale: 1

Translation

x 0 y 0 z 0

Preview

Figure 4. View of virtual element (an image in this case) definition window.

3.3. AR Applications

This section describes the interaction between the user and the AR application. Figure 5 shows a schematic view of the interaction flow in the application.

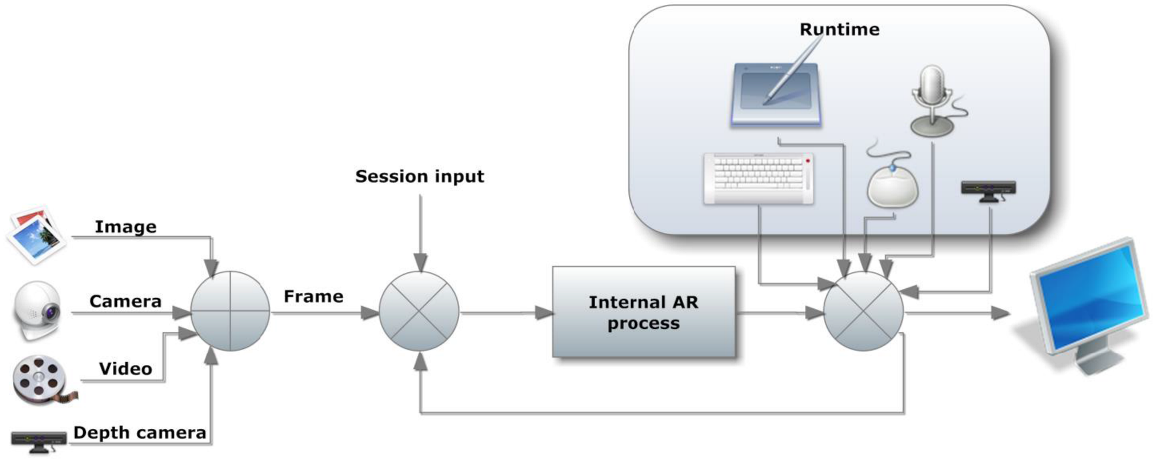


Figure 5. Schematic view of the HCI in the AR application.

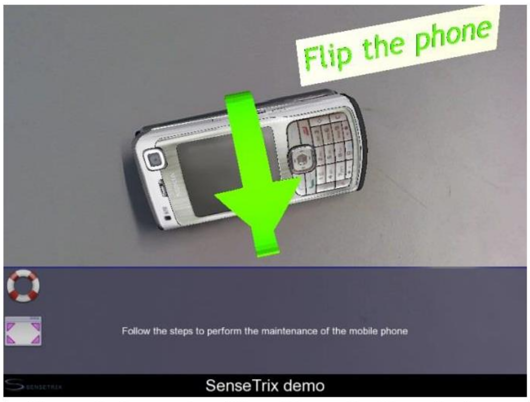
The application starts with a Graphical User Interface (GUI) window where the user selects the session configuration. The session consists of the selection of the application to run whether it is an AR guided maintenance procedure or a normal AR application. This information is stored internally in the database system and displayed in the GUI allowing the user to select the appropriate input. In the GUI, the user is also able to select the image input. The image input tells the system where the source of frames for the AR tracking and for the final display is. As mentioned before, there are four possible choices:

- Camera: This is the most common option, as the AR applications are used in real time. The camera can be either a built-in camera, a webcam, a camera attached using the USB port or an IP camera connected to the network.
- Video: In some cases it may be needed to use a pre-recorded video instead of using a live video feed (e.g. when the maintenance instructions need to be redesigned or for supervision process).
- Image: Finally, there might be some cases where the use of static images is needed (this is useful for the creation of the maintenance instructions).
- Depth camera: It is also possible to select a depth camera (e.g. Kinect camera) for the input. If this option is selected, the RGB (Red, Green and Blue, i.e. traditional colour images) and the depth images from the camera are used as input of the AR process. This feature is currently experimental only.

All information provided in the GUI window is fed to the system where the internal processes explained in the engine description take place. The output of this process is combined with the runtime user input to both produce the final output and to feedback the internal process.

The user can interact with the application in several ways. Depending on the hardware, the user can interact with keyboard and mouse (e.g. a traditional desktop or laptop), with touch screen (e.g. tablet, mobile phone or other touchable devices) or with voice commands (this feature is currently planned, through a speech recognition system, but not implemented). If the depth camera has been selected previously, the input from the depth image can be also used at this stage (e.g. gesture recognition).

The final display is a multimodal augmented scene where the real scene is combined with virtual elements (3D models, images, videos, texts, webpages and voice commands). The final display has been designed to be user friendly and to provide as much information as needed without distracting the user from the actual maintenance procedure. For this reason, two HUD (Head-Up Display) menus have been implemented in the application. Both menus can be shown or hidden as requested by the user. The first HUD menu is a menu displayed in the bottom part of the image. This HUD has been designed to display the instructions and additional information that cannot be displayed as AR content for several reasons, such as the situation when there is no relationship with physical objects or the display of objects not visible in the scene. The second HUD menu, called help menu, is a menu that overlays the whole screen as it is intended to be used for application configuration (e.g. AR threshold selection or filtering switching) and therefore it is only used to adjust the application. This menu is, however, semi-transparent, allowing the viewing of the AR scene in the background. A typical screenshot of the application is shown in Figure 6.



Follow the steps to perform the maintenance of the mobile phone

Figure 6. Example of the AR application display.

As it has been explained in this section, there are several means of Human Computer Interaction (HCI) while using the application. Apart from those mentioned before, it is also important to point out here the inherent interactivity character of AR applications. The use of markers allows a high level of interaction as users can directly manipulate the virtual objects that are displayed on top of them (e.g. moving them freely in 3D space or pausing and playing videos). This is especially important in the education field, as it allows students to interact with the learning content and thus learning by doing [22].

4. Results

Several applications have been already developed using the proposed framework. Some applications for maintenance purposes have been already implemented for demonstration purposes. Figure 7 shows two examples of AR applications for maintenance. The upper image in Figure 7 shows guiding instructions to remove the battery for a mobile phone. The application explains, step by step, the procedure required to disassemble a mobile phone in order to exchange the SIM card. This application was one of the first fully functional applications created with the platform and it was developed for demo purposes as it can be easily carried to the facilities where the use of AR maintenance has to be demonstrated. Although the exchange of a SIM card is usually a simple issue, the application shows the potential of AR guiding for tasks that require several steps, such as maintenance procedures.

The bottom image (Figure 7) illustrates an example of AR remote maintenance where guiding instructions to collimator exchange at CERN are provided to the operator. The application guides maintenance operators to achieve the remote exchange of a collimator inside Large Hadron Collider (LHC) at CERN by means of keypoint guiding. The operator controls a crane to remove the old collimator and to install the new one. During the process, several helping elements are augmented over the real scene or displayed in a HUD as needed. The application was successfully tested in a mock-up at CERN.

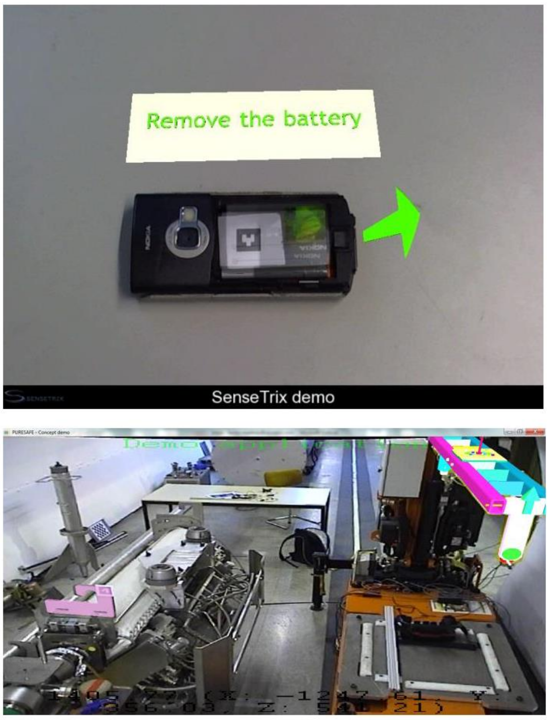


Figure 7. Examples of AR applications for maintenance.

The framework has been also used for educational purposes. Figure 8 shows two examples of AR for educational purposes. In the upper image (Figure 8), an example of planetary educational application is displayed. The distances between markers were used in order to teach the distances between planets and their rotational behaviour. The application also shows the two rotational behaviours of the Earth (i.e. rotation and translation around the Sun) and several textures can be selected in order to provide different views of the planet, such as level of water or the view of the Earth at night.

In the bottom image (Figure 8), an example of a mathematical AR application is shown. The application consists of several games where mathematics skills are tested (e.g. asking for the results of operations) and mathematics-related memory games (e.g. remembering the prime numbers) are offered. There are ten big physical markers on the floor corresponding to numbers from 0 to nine. The goal is to hide those numbers included in the answer to the question that has been provided by the application. This application was designed to be used in a large screen with a projector for the Mathematics day in Heureka, the Finnish Science Centre.

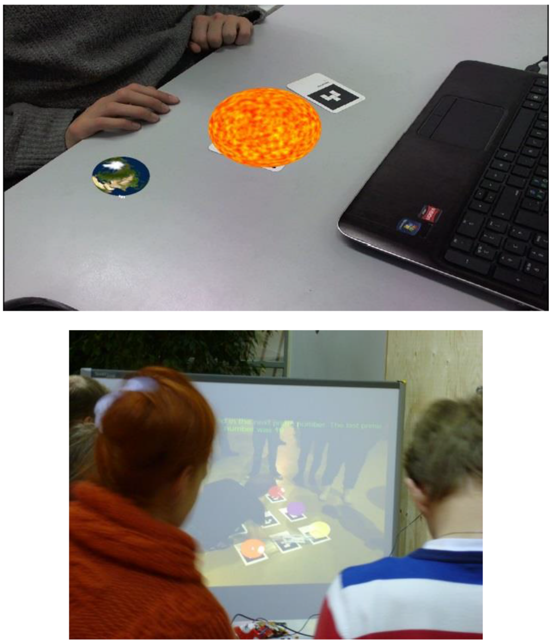


Figure 8. Examples of AR applications for education.

As it can be seen from the previous examples, the platform has been already used with positive results in maintenance and education fields. Moreover, the framework has been used to develop an already available commercial application, called STEDUS [18]. STEDUS is an educational platform that provides educational institutions access to AR applications. The AR applications work using the developed engine, while the development of these applications has been made by using the proposed authoring tool.

5. Discussion

This paper presents a new platform for AR application development. The platform consists of an engine in charge of the application running and an authoring tool for the development of the applications. The platform has been built to integrate the majority of common AR features (e.g. displaying of virtual elements or tracking of markers) and includes some novel features, such as a new AR hybrid marker approach combined with a database system to uniquely identify a large number of devices to maintain in the same facility (e.g. large scientific facilities), several means of interactivity combined into the same tool (e.g. multimodal augmentation and maintenance specific step guiding system) and a maintenance-job-task-oriented structure for maintenance purposes.

The platform tries to overcome some drawbacks in the current AR systems for maintenance and education, such as flexibility and the use in large scale projects. The platform has already demonstrated its flexibility as it has been applied not only to the main target (i.e. maintenance in scientific facilities), but also to the educational field. The platform can be easily integrated into large scale projects (e.g. large scientific facilities, such as CERN or GSI) by making use of the database system and the new AR marker approach that have been integrated in the system. Moreover, the platform has been built following a plugin approach that enables the coexistence of multiple AR applications in the same environment sharing a common engine.

Another important advantage of the platform is that allows non-programming users to develop AR applications by means of utilizing the implemented authoring tool. The tool can be used for general purpose application development, but it is especially useful in maintenance field, as a building feature based on maintenance-job-task structure has been designed for this purpose. As a consequence, the authoring tool can be delivered to the maintenance facilities (or any other organization, such as educational institutions) in order to allow experts (e.g. maintenance experts, educators, etc.) to develop AR applications based on their needs and requirements. Furthermore, the applications can be updated (e.g. new 3D models need to replace old ones, some steps of a maintenance procedure have been removed or replaced, etc.) by using the authoring tool without the need of changing the code which enables a long life cycle of the application without the intervention of an external software company. Therefore, the need of dealing with technical issues related to AR technology is eliminated and experts can concentrate their efforts in applying their knowledge (e.g. maintenance procedures, pedagogical learning, etc.) to the content of the application.

The platform has been successfully used for the development of several applications both in desk-size demos and in real in-place applications (e.g. CERN and Heureka). Moreover a commercial solution is making use of the proposed platform for the creation and execution of AR applications for educational purposes. In a future it is foreseen that new fields (e.g. marketing, tourism, etc.) could benefit from the use of the platform due to its flexibility.

The next steps for the platform are to develop further the authoring tool in order to include new features that enhance the maintenance, especially in those cases where the maintenance has to be done remotely. Some examples that are currently being studied are the guiding of robotic arms and mobile robots. The purpose is to analyse the benefits that AR applications could bring to such kind of systems and to gather the requirements that may be needed. Once this step has been carefully evaluated, the output will be used for implementing the new features in the authoring tool.

Also, the features that are experimental at this stage (i.e. depth camera and voice commands) will be studied further in order to finally integrate them in the most suitable way. The information from the depth camera can be useful to detect gestures of the operator (current testing), but also to detect 3D spatial information of the devices and the environment. The voice command feature (i.e. text to speech feature which provides voice commands from a predefined text), which is already working in the engine, will be integrated into the authoring tool to enable the users of the tool to define the commands to be augmented in the final application. Moreover, there is also a plan to integrate a speech recognition system (i.e. a system that recognizes the user's voice) in the engine in order to allow bidirectional voice commands.

Acknowledgements

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III

STEDUS, A NEW EDUCATIONAL PLATFORM FOR AUGMENTED REALITY APPLICATIONS

by

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4th Global Conference on Experiential Learning in Virtual Worlds

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STEDUS, a new educational platform for Augmented Reality applications

Héctor Martínez and Seppo Laukkanen

Abstract

Augmented Reality (AR) is a technology that has drawn the attention of educators in the recent years. The technology combines virtual worlds with the real environment, creating an immersive and interactive experience for the students and trainees. Several experimental works have shown that the use of AR for learning and training purposes provides good results. However, there is no common method or practice for using AR for learning purposes. Some years ago, the creation of AR applications was possible only by means of programming. Due to this fact, it was difficult to implement the technology in the learning environment, as programming skills were needed and creating the applications was time consuming. In the recent years, researches have realised about this problem and they have been trying to cope with it. Nowadays, as a result of research work, there are some already available authoring tools that enable educators to create their own applications. However, this process is still time consuming (and sometimes also still difficult) for the educator as the applications need to be created individually and they usually stay on the creator's computer only. They can be reused by the educator and even by the educator's institution, but other institutions cannot take advantage of the work. In this paper we present STEDUS, a new platform that enables schools and universities to have a common access to a growing number of AR applications for learning purposes. The applications are created on demand and offered to all subscribed customers. In this platform, the creation process is carried out by technical workers, while the educational work relies on the educators. The platform contains a common engine for Augmented Reality and enables the educators to download the available applications that they may need. Therefore, institutions from the whole World can benefit of the work that has been carried out in other places, thus creating a collaborative environment.

Key Words: STEDUS, Augmented Reality, Educational platform, Training platform, Augmented Reality on Demand (ARoD), Collaborative environment.

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1. Introduction

Augmented Reality (AR) is a technology that combines Virtual Worlds with real images. Usually, a live video of a real scene is captured by a camera and is augmented using the power of Virtual Reality and other multimedia contents. This technology provides, thus, an interactive augmented environment. This approach makes possible the visualization of any kind of educational and training content with high levels of interactivity. It is especially useful in those cases where 3D visualizations of complex structures (e.g. chemical molecules) are needed or when "invisible" behaviours (e.g. gravity forces, magnetics fields, etc.) need to be explained. Moreover, AR offers the possibility of interaction with objects that cannot be handled in real life (e.g. showing the behaviour of the whole solar system in a desktop size environment) or using virtually machines and devices that are highly expensive or unique without any risk of damage (e.g. industrial robots).

Several studies have already shown that the use of AR in educational and training environments enhance the learning process (e.g. Kaufmann and Dünser 2007, Balog et al. 2007, Billinghurst and Dünser 2012). Therefore, there is a growing interest in the use of AR for education and training purposes. However, there are still some drawbacks that prevent the general use of this technology in the field.

The creation of AR applications has been traditionally tied to programming experts who made use of several programming libraries, such as ARToolKit (Kato and Billinghurst 1999). This means that, generally, programming skills were needed for the implementation of the desired applications. Therefore, there was a gap between the educational and training experts and the AR developers, as educators were not usually familiar with programming environments and developers lacked of enough educational and pedagogical knowledge.

Researchers have realised about this problem and several authoring tools have appeared in the recent years (e.g. Haringer and Regenbrecht 2002, MacIntyre 2004, Ledermann and Schmalstieg 2005, BuildAR 2008, Martínez et al. 2011, Dünser et al. 2012). The aim of these authoring tools is to enable non-programmers to create AR applications. Although the majority of these tools are not specifically focused on educational and training purposes (some exceptions are the work presented in Martínez et al. 2011 where users are able to create their own educational applications with an intelligent virtual tutor or the work proposed in Dünser et al. 2012 that provides capabilities for the creation of augmented books), they can be used by educators to create their own educational applications.

The mentioned authoring tools have finally filled the gap, allowing educators to create personalised AR applications for the educational and training content they target. However, there are two issues that still limit the progress of AR in educational and training fields. The first issue is that although educators are able to create their own AR applications, it still requires time to get familiar to the authoring tool environment and to properly create the applications (precise positioning of virtual elements, defining interaction methods, etc.). This is not always suitable for educators, as the process may be still time consuming. The second issue is that, even if educators spend the required time for developing the AR applications, these applications stay on the educator's computer (or in the whole workgroup network), but they cannot be used by any other institution. Due to this fact, different institutions with same educational or training problems need to create their own applications, which means that a double effort (or even more) needs to be done.

This paper presents STEDUS, a new educational platform which tries to cope with the aforementioned issues. The platform allows subscribed institutions to access to AR applications. The applications are developed by programmers based upon the requirements provided by educators. This means that educators can concentrate in the pedagogical content without spending time in the development of the applications. The great advantage is that the applications developed are shared by institutions from the whole World, making it worth the time spent as educators can benefit not only from the applications they have designed and requested, but also from the applications designed and requested by other educators.

The concept presented in this paper is similar to the concept of Video on Demand (VoD), i.e. subscribed users are able to watch unlimited videos on demand. Therefore, we present STEDUS as an Augmented Reality on Demand (ARoD) platform where subscribed users can access to the AR content (i.e. AR educational applications) on demand. The proposed platform provides an additional advantage compared to VoD concept, which is that users are not passive to the content creation as the content they are going to use can be directly affected by their needs.

The rest of the paper is structured as follows: section 2 describes the STEDUS platform and its components, providing an overview of the whole platform and the user interaction. In section 3, the novelty of the platform and a pilot experience are discussed. Finally, in section 4 the future steps for the platform are commented.

2. STEDUS platform

This section overviews the proposed educational platform in its current state. STEDUS is a platform that allows the use of AR applications for education and training and the collaboration between institutions for enhancing the applications and thus, the learning process.

STEDUS application is the main core of the platform as it is the application that comprises the common engine for the AR applications and handles all the educational and training content. It is an application where users can easily download and run the AR applications. From STEDUS, users connect seamlessly to STEDUS server and browse for the desired content (i.e. the AR applications). Once the right AR application has been found, the user is able to download it and run it from the same application. The installation of the AR applications is totally transparent to the user as there is no intervention required.

STEDUS platform contains also a website where users (e.g. institutions, universities, training companies, etc.) can log in and request new applications.

Users can also interact between them by means of a forum where they can discuss not only about STEDUS itself but also about the learning and training content.

Fig. 1 details the use case model of the platform. The model describes visually the behaviour that has been introduced in the paragraphs above. There are four actors and four use cases. The main actor (i.e. the user) is able to install/update the AR applications (first use case) by interacting in a transparent way with the user called “STEDUS server” and also to use the AR applications (second use case). Both use cases involve the utilizing of the STEDUS application.

The other two use cases are related to STEDUS website. The main actor can interact with other users (which can be considered as a new actor in the model) and also request new AR applications. This request is handled by the actor called “STEDUS developers” who is in charge of developing the applications upon the requested requirements and updating the actor called “STEDUS server”.

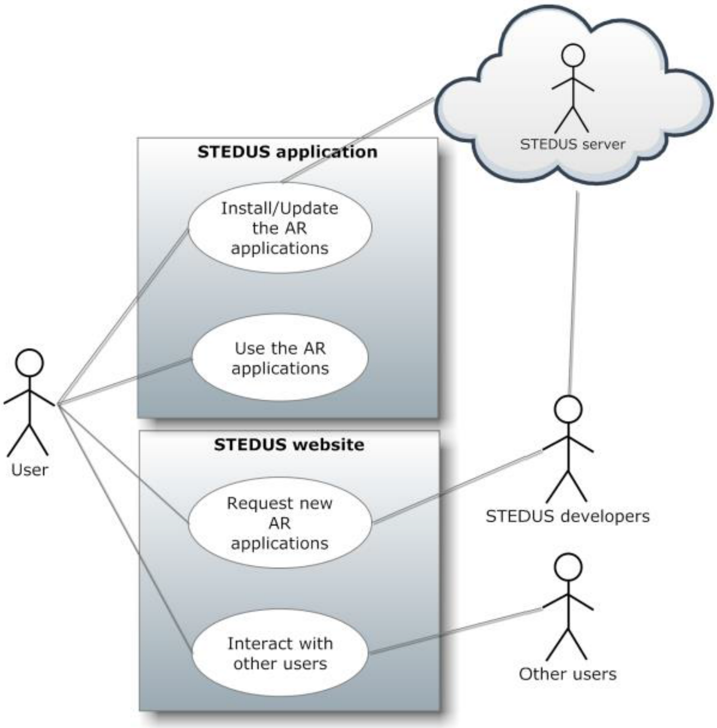


Fig. 1 Use case model of STEDUS platform.

The interface of STEDUS application has been designed to be simple and intuitive. The interface is made up of a panel with the list of categories and applications to allow the user to navigate through them and to select the desired AR application to be run. The same navigation behaviour has been implemented for browsing through the available AR applications on the STEDUS server.

Fig. 2 shows the activity diagram of the user interface navigation in STEDUS application following the notation of UML (OMG, 2005). As it can be seen, the navigation has been designed to be simple to use as it has been mentioned before.

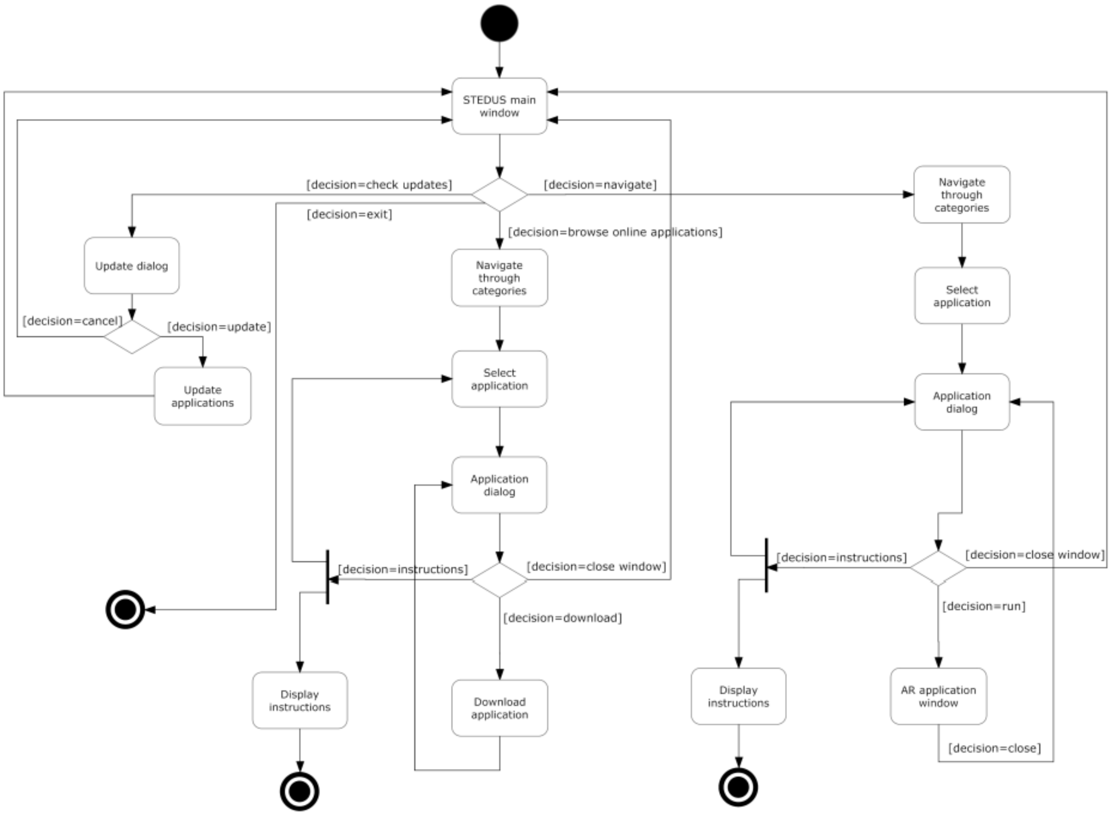


Fig. 2 Activity diagram of the user interface navigation in STEDUS.

When the application is launched, the currently available categories and applications installed in the computer are displayed by means of category navigation. Once the application is selected, the application dialog appears showing the information related to the application. From this dialog, the user is able to run the application and also to open detailed instructions (these instructions are handled by the default pdf reader installed in the computer). Finally, if the user selects the "Run" button, the running of the AR application begins.

The navigation through the available AR applications contained in the STEDUS server follows the same approach. When the desired application has been selected, a similar application dialog appears showing the same information. In this case, instead of running the application, the user is able to download and install the application.

Finally, there is a third option in the activity diagram that allows users to update the applications that have been already installed in the computer.

Fig. 3 shows a screenshot of STEDUS application. In the figure, the available subcategories in the computer for the current category (i.e. mathematics) are displayed in the main panel. These categories and subcategories are generated when an AR application has been downloaded and installed from the STEDUS server.

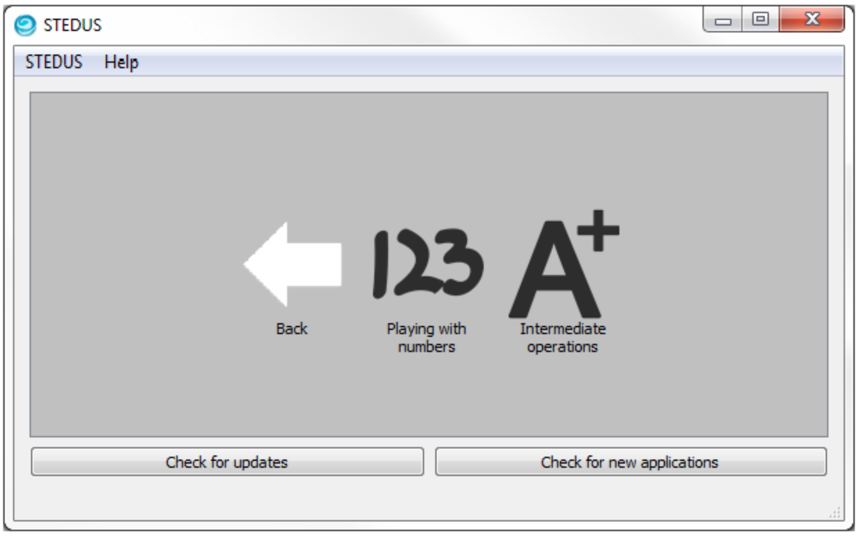


Fig. 3 Screenshot from STEDUS application.

Once the user starts an AR application, a dialog showing information about the application (e.g. description and instructions) is displayed (Fig. 4). In this dialog, the user is also able to select the desired camera and the resolution. Finally, when the camera and resolution have been selected, the application starts.

Licensed to [illegible]

Select demo:

Intermediate additions

Mathematics advanced game. Try to answer more complex mathematics questions!
Hide the right numbers and press the space bar to know if you are right!

Select camera:

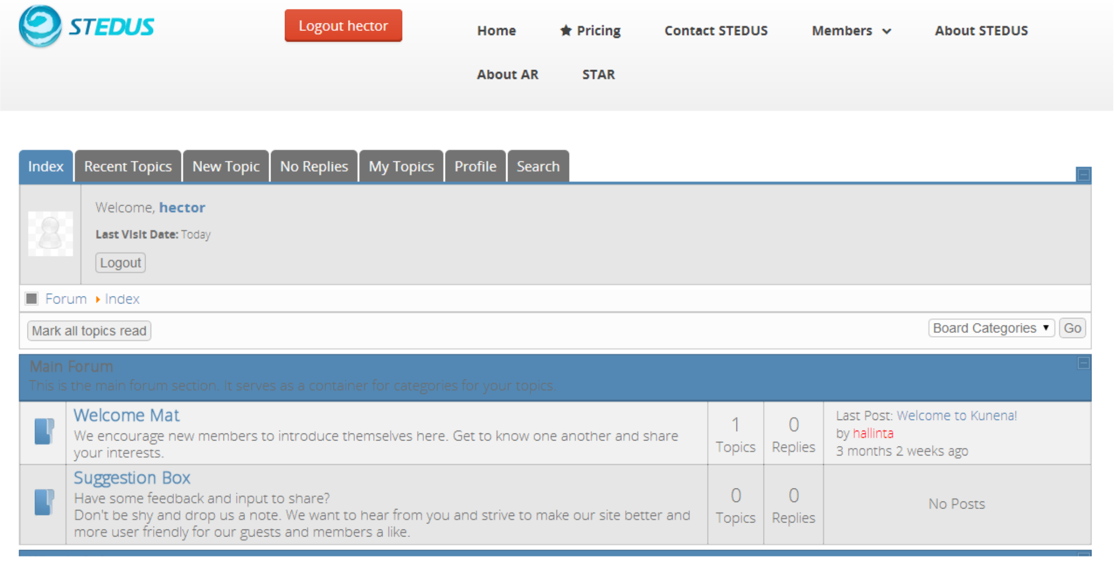
HP TrueVision HD

Select the resolution:

640x480,MFVideoFormat_YUY2

Fig. 4 Example of AR application dialog.

As it has been mentioned before, STEDUS platform comprises also a website where users can request new AR applications and also interact between them by means of forums. Fig. 5 shows a snapshot of the forums already available for members in the STEDUS website.



Welcome, **hector**

Last Visit Date: Today

Main Forum

This is the main forum section. It serves as a container for categories for your topics.

Welcome Mat We encourage new members to introduce themselves here. Get to know one another and share your interests.	1 Topics	0 Replies	Last Post: Welcome to Kunena! by hallinta 3 months 2 weeks ago
Suggestion Box Have some feedback and input to share? Don't be shy and drop us a note. We want to hear from you and strive to make our site better and more user friendly for our guests and members a like.	0 Topics	0 Replies	No Posts

Fig. 5 Snapshot of STEDUS forums.

3. Discussion

In this paper, we have presented a new platform for education and training by means of AR applications. The platform combines the pedagogical knowledge from educators and the technical skills from the developers to create AR applications with high value in terms of usability and learning content.

The platform follows the concept of Video on Demand services to provide what we have defined as Augmented Reality on Demand service. This means that subscribed users can make unlimited use of the available applications. The list of applications grows with the time with an added value: the users are responsible to define the requirements for the new applications as well as suggesting improvements to those already existing. This approach has a double advantage as users can define applications based on their needs but also take advantage of the applications that have been designed by other users as all applications are shared by all users in the platform. Moreover, the platform contains a website where users can interact directly and discuss about the learning and training content, the requirements for existing or new applications and the output they receive from the use of the applications in their own institutions.

The STEDUS application has been designed following a minimalistic approach with a clear and easy to use interface where the required user input is minimal. The goal is that the user interacts with the AR applications instead of dealing with the download and installation processes.

Currently, the platform contains only demo applications as it has been recently launched. Although they are completely functional without limits, we consider these applications as demos due to the fact that they have been developed without the help of pedagogical experts, which is the goal of this platform. These applications have been developed to show the potential of AR for education and to provide an overview of the platform functioning.

However, these demo applications currently available in the platform have been already tested with real users in a pilot experience in the Mathematics Night held in Heureka, the Finnish Science Centre (Heureka, 2012). The applications were placed in one setup prepared for the event and the experience was open to the general public. Although no formal feedback was obtained by means of traditional questionnaires due to the age of users (mainly kids), the response in terms of usability and interest from users was satisfactory. The curiosity was a key factor to draw the attention of the audience. Once they were in front of the setup, they quickly understood the functioning of the application thanks to the inherent fast learning curve of the technology that has been perceived in several studies (e.g. Damala et al. 2008, Sumadio and Rambli 2010). Although the applications were not developed by educators, a knowledge acquisition from the kids was observed as they were performing better in the successive turns of the game (e.g. kids from ages around 10 years old were able to learn and memorise prime numbers).

It was also observed that, during the whole event, a large number of participants returned to repeat the experience, showing that there is not only an interest in the learning part but also an entertainment component that engages the users. There was an additional interesting outcome from the experience: as many users were kids of very small age, the use of the application involved their parents too in order to help them to achieve the goals, creating a collaborative experience between them.

In Fig. 6, an image from the pilot experience at Heureka is displayed. In the image, two AR applications can be seen. The first one is a big screen application where users have to hide the right numbers to get the answer for a mathematics question. Each marker in the floor correlates to one number from 0 to 9. The second application is presented over a table with the use of a monitor (left part of the image). In this case, the application was a game where users had to guess or remember the distance from the Earth to the Sun. Users had two markers with the Earth and the Sun on top of them and the goal was to fix the right distance while they were seeing the behaviour of the rotational movement of the Earth around the Sun according to the distance. As it can be seen, the applications used were highly interactive which was translated in a great interest from the users from all ages.

Fig. 6 Setup used for the pilot experience at Heureka.

In words of Siina Vasama, Event Producer at Heureka, the feedback from the event was also very positive, showing thus, the interest from all parts involved in the education process (i.e. educators, parents and science institutions):

> At the Night of Mathematics in December 2012 at Heureka, the Finnish Science Centre, Mr. Seppo Laukkanen and Mr. Héctor Martínez from SenseTrix organized a workshop using their pilot applications. This pilot was designed especially for the Night of Mathematics and it gave children of all ages the possibility, for example, to do sums and practice with prime numbers. We had some 2000 visitors at the event, and the feedback on SenseTrix's workshop was very positive. Children had fun and said they learned a lot. Many came back several times. In science centre terms, the workshop had both drawing in -power and holding-power. Parents clearly appreciated this new way of learning and were themselves interested in using the technology. We also had many teachers among our visitors, and we heard many of them wishing they had this kind of tools at school. People appreciated the physical aspect of the workshop, as well as the social one: they jumped around and talked a lot while counting.
> Siina Vasama, Event Producer, Heureka, the Finnish Science Centre

4. Future work

The proposed platform has been already developed and deployed online (STEDUS 2013). As STEDUS is in its early stage days, the number of available

AR applications is still limited due to the fact that, up to date, the major effort has been made to develop the overall platform. The next step to follow is to develop new AR applications targeting different educational fields (e.g. physics, chemistry, natural sciences, etc.). Some demo applications (understanding "demo" as fully functional applications developed without the advice of pedagogical experts) will be developed in short term and fully pedagogical-based AR applications will be developed upon the requirements of the first subscribed institutions.

Besides the development of new AR applications, the goal is to introduce the use of physical objects that will be augmented to enhance the learning process. Some examples may be the use of different boxes and blocks to explain the forces involved in objects moving through different slopes, where virtual arrows would be augmenting the physical blocks, or the use of test tubes showing the 3D molecules of their content and/or the reactions when mixing them by means of augmenting the molecules over the tubes. The goal of this approach is to improve the interactivity of the process showing behaviours and concepts that cannot be seen in real life (e.g. the forces between objects or the molecules of substances) combined with the physical elements related to these behaviours and concepts.

5. Acknowledgements

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IV

EXPERIENTIAL LEARNING THEORY AND VIRTUAL AND AUGMENTED REALITY APPLICATIONS

by

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Experiential learning theory and virtual and augmented reality applications

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Abstract

Virtual Reality (VR) and Augmented Reality (AR) technologies are gaining growing interest not only among companies but also academics. VR is a technology that enables the creation of computer generated virtual worlds where the user can interact and immerse. AR is a newer technology compared to VR that takes advantage of the virtual worlds and enhances the experience by mixing them with the real environment. Both technologies have demonstrated to be very useful in a large number of fields. One of the fields that can take more advantage of these technologies is education and training, as a result of the great interactivity level, allowing the user to experiment the concepts that he/she is learning. AR and VR technologies have also been used in entertainment applications.

Compared with traditional 2D textbooks, images and videos, advantages of AR and VR technologies include 3D approach with visuality, interactivity, and fast learning curve. AR and VR enable recreation of environments and offer various possibilities to explain and illustrate complex issues. With special equipment, AR and VR also enable sensations other than visual and auricular.

In this study, we reflect possibilities of AR and VR in the light of experiential learning theory. Experiential learning is "learning by doing" and reflecting the learning experience. Thus, it requires active involvement and analytical skills to conceptualize the experience, as well as ability to reflect, solve problems and make decisions. The study examines different applications and purposed use of AR and VR in regards of Kolb's (1984) Experiential Learning Model (ELM).

Introduction

Learning by doing has long been known as the most effective method of acquiring new skills. Confucius wrote around 450 BC: "Tell me, and I will forget. Show me, and I may remember. Involve me, and I will understand."

Experimental learning was first introduced in 1984 by David A. Kolb. The concept of experimental learning includes all learning from a concrete experience, through reflective observation, to abstract conceptualization, and finally, to testing in new situations and new experience. This can be illustrated as a cyclical pattern, the Experimental Learning Model (Kolb, 1984).

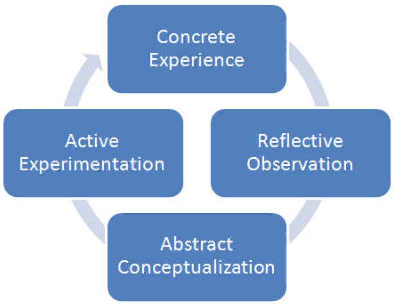

Fig 1. Experimental Learning Model. Adapted from Kolb, 1984).

The idea of Augmented Reality (AR) and Virtual Reality (VR) dates back to the beginning of the 2000th century, but as AR and VR require complicated algorithms and computing power, they have only become available since the last decades. VR is a technology that enables the creation of computer generated virtual worlds where the user can interact and immerse. It is three-dimensional interactive environment. Augmented reality is a newer technology compared to VR that takes advantage of the virtual worlds and enhances the experience by mixing them with the real environment. This technology can enhance a real object by imposing virtual elements over it. By this means, e.g. a needed procedure can be demonstrated for training purposes. Both technologies combine 3D approach with interactive visual and auricular elements. Special equipment can be used to enable other sensations, e.g. sense of touch. AR and VR enable recreation of environments and offer various possibilities to explain and illustrate complex issues. AR has been used e.g. on virtual advertisement and demonstrations on television (e.g. reconstructing situations in a football match). Nowadays applications include among other education, training and entertainment. Research and development is being done in e.g. healthcare, education, military, and enterprise applications. At the moment, AR is in a progressive state. Wearable technology such as goggles and contact lenses are being brought to the market, and it is expected their use and application areas will growth notably in the near future.

The required level of prior information is low, and new skills and knowledge are acquired rapidly. This summarizes a fast learning curve of AR technology (Sumadio & Rambli, 2011; Cascales & al. 2013). Virtual objects combined with real environments let users immerse themselves in a multi-sensational educative environment. This immersion in a digital environment has multiple perspectives that enhance education, namely changing frame or reference; situated learning, and transfer (i.e. the application of the acquired knowledge) (Dede, 2009).

AR has been used in guiding assembly processes with favourable results, as shown by several studies, including e.g. standardization of the manufacturing training that would reduce costs and training time, and allow workers to learn at their own pace (Hou & al. 2013; Wang & al. 2013; Peniche & al. 2013; Morkos & al.).

In this paper we will reflect existing AR and VR applications in regards of the ELM. We will do this by overviewing training applications in medical field and a case study in astronaut sector, as two examples of the possibilities of AR in adult training.

AR in medical sector

AR is beneficial in training doctors, as well as in medical education and while explaining patients their condition and treatments. AR provides a realistic method to train medical skills, as well as objective feedback, without a presence of an expert supervising the exercise (Botden & Jakimowicz, 2009). AR aids medical trainees to acquire proficiency in required procedures (Yeo & al. 2011). In medicine, AR is especially useful in surgery. It increases the (virtual) transparency of the patient, higher accuracy and precision with fewer risks, possibility of diagnosing the patient's condition during surgery and guided surgery within less time (Li, 2006). AR supports Minimum Invasive Surgery (MIS) approach, aiming at the least possible inconvenience for the patient. Together with 3D visualization and modelling, AR provides a virtual transparency of a patient, which helps surgeons to conduct minimally invasive surgery that provide greater benefits to patients (Nicolau & al. 2011).

Sielhorst et al. (2004) presented a birth simulator for training purposes, consisting of a haptic device in a body phantom and software simulating biomechanical and physiological functions. A distributed training tool for endotracheal intubation using 3D AR was proposed by Rolland et al. (2003).

AR may also prevent patient and operator from other risks such as exposure to radiation in some procedures in medicine (Fritz & al. 2012) and elsewhere. VR training applications for shoulder and knee operations have been used with good results in orthopaedics (Mc Carthy & al. 2006; Cannon & al. 2006; Gomoll & al. 2006).

VR in training astronauts

Training astronauts comprises theoretical and physical phases. However, the training in the handling of objects in zero gravity is usually difficult due to the expensive costs and availability of physical prototypes. As a result, Rönkkö et al. 2006 proposed an approach where the use of VR for assembly training in zero gravity conditions faces the first stages of the training process. The goal of this work was to allow future astronauts to become familiar with the sequence of operations and object behaviour in zero gravity. Actions such as handling freely floating objects or connecting and disconnecting parts can be simulated in virtual worlds. In particular, the developed training platform was targeted to the training for the laptop assembly sequence in orbit on a wall mounted Fluid Science Laboratory (FSL) rack inside the Columbus module in the International Space Station (ISS). The setup used for that purpose was a two-screen based VR system with two projectors. The developed platform enabled multimodal interaction with the virtual world by means of datagloves, trackers and speech. The application involved not only the trainee, but also the trainer as he or she was able to guide the trainee when required. The interaction features of the system are described in more detail in Rönkkö et al. 2003. This interactivity combined with the virtual simulation of zero gravity provides a realistic immersive experience to the user.

The results from the user tests showed that the representation of virtual objects was realistic and that the system was easy to use. One of the users was an actual astronaut, who, after testing the system, pointed out that the technology (i.e. VR) has large potential for training and module orientation in aerospace industry. As a conclusion of the work, the authors state that the technology shows promising future for training in the field. The proposed system provided a realistic immersive experience with a simple setup (compared to the real one) that was, in addition, portable and reusable. These kinds of systems are especially useful for low-cost training in facilities where mock-ups are expensive or not available. Also the use of interactive virtual worlds provides a realistic training that cannot be experienced with textbooks or videos. This is crucial in cases like zero gravity, as the object behaviour in these conditions is dramatically different to the behaviour that we are used to in normal Earth conditions. Although the system cannot replace entirely the real mock-ups, the benefits of its use in early stage phases of the training process may reduce costs and facilitate the training in different parts of the World, as the real mock-ups are usually expensive and limited to specific locations.

Discussion

Experimental Learning involves several senses in the learning process. The more comprehensive a learning experience is, the more memorable it will be. Using AR and VR in education and training activates multiple senses such as vision, sense of touch, and hearing. AR and VR technologies can be used to create environments and situations that are not available or easily accessible in reality. However, not all conditions can be modeled even by using these technologies. As for example, a sensation of zero gravity cannot be achieved in normal conditions.

AR and VR provide both highly educating but also entertaining environment for learning. As discussed in this paper in the light of previous studies, AR and VR enhance the learning experience and make it more efficient and effective. Thus, the number of repetitions and time used for them may be reduced, which in terms reduces cost and makes the effective use of facilities easier.

The ELM defines learning as an active and iterative process, which requires reflection of the learning content. We assume this is the case when AR and VR are used in training among adults. In medicine, the real training possibilities are often scarce, as most operations with patients require experience. However, experience cannot be acquired without training. The more doctors or medical students that have possibilities for training, the better medical experts they will be. AR and VR applications provide a safe and realistic method of training without any harm or risk for patients. With AR and VR applications, medical procedures can be practiced and repeated several times. Different situations and possible complications can be simulated in order to practice also for cases that are rare or unlikely to happen. This kind of training requires open mind and active approach from students and doctors, and it is thus how the ELM is applied. Medical students, or doctors, are provided a concrete, though simulated example of a certain medical condition, to which they must respond (i.e. provide a solution), or a situation or procedure can be demonstrated to them. With reflective observation, they can provide a solution to the question in hand, based on their knowledge and existing skills. The new knowledge and skills acquired by the exercise can be further developed and deepen by abstract conceptualization. This can be helped e.g. by discussing the exercise in a group. As the procedure or a certain technique has thus been practiced and processed, it can be applied for either treating patients in practice, or for further training, e.g. using an acquired skill for another simulated purpose. The same applies for astronauts. The skills and procedures they require in their work are hard to practice on the ground, as the environment in space is significantly different. Emulating working conditions that are difficult to recreate in a real environment (e.g. zero gravity) provides means of low-cost training capabilities. As a result, the training can be carried out in several places around the World instead of using a specific singular facility built for the purpose. By using AR or VR in their training, new skills can be acquired easier and with less time, in more realistic conditions. In general, the training aimed at enhancing professional knowledge and capabilities requires processing the content that has been learnt. The acquired skills are usually soon put in use, either for practicing, or real purposes. Thus, the ELM approach is highly useful in AR and VR facilitated training, as they both support active learning and provide an effective environment for learning by doing.

Combining ELM approach in AR and VR applications, as we have done in this paper, provides several opportunities for further research. It would be interesting e.g. to study applications on other field, or do comparative studies of AR or VR based training with more traditional training methods, in order to prove their effectiveness and efficiency with measurable data.

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V

DRIVERS AND BOTTLENECKS IN THE ADOPTION OF AUGMENTED REALITY APPLICATIONS

by

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Drivers and Bottlenecks in the Adoption of Augmented Reality Applications

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Abstract- *In the last decade, Augmented Reality (AR) has been one of the emerging technologies that have been in the centre of attention among academics and business practitioners. Despite the numerous studies which have demonstrated the multitude of benefits derived from AR applications, the technology has not reached yet its full potential due to various bottlenecks which are preventing it from becoming the mainstream technology that many have anticipated. In this paper, we first present briefly the history of AR followed by the evolution of related software algorithms and hardware devices. The main contribution of this paper is the overview of the drivers and challenges related to the adoption and diffusion of AR across five major application domains; (a) industry and military, (b) training and education, (c) travel and tourism, (d) medicine and health care and (e) retail and marketing. Such overview facilitates especially a cross-domain comparison, which here enabled us to identify a list of five drivers and five bottlenecks in the adoption of the current AR technology.*

Keywords: Augmented Reality, drivers, bottlenecks, technology adoption.

1. Introduction

Augmented Reality (AR) is a concept where elements from real life are augmented by additional visual information after recognizing the environment in order to guide the augmentation (i.e. to position and orientate augmented content). In 1994, Milgram and Kishino defined a Virtuality Continuum (VC) [1]. In this continuum, the concept of Mixed Reality (MR) is set between two ends: (a) Virtual Reality (VR), an environment where the user is totally immersed in and (b) Real Environment (RE). MR refers to the combination of elements from both ends of the VC (i.e. a mixture between real and virtual worlds). One state inside the VC is AR, which refers to those cases where the RE is augmented by virtual objects. This definition explains the most common approach of AR nowadays, where images of a real environment (e.g. video feed from a camera) are augmented with elements from virtual worlds in real time (e.g. 3D model, images, videos, text, etc.).

The first known reference to AR concept was provided in 1901 in [2] where the idea of overlaying metadata on top of people (basically, information about their real character) through the use of spectacles was mentioned. Yet, it took almost a century until the AR term was first announced in 1990 by Tom Caudell [3] when he was working for Boeing and one of the first AR-relevant papers was published in 1992, presenting an AR system prototype called KARMA [4]. The same year, one of the first AR systems (Virtual Fixtures) from US Air Force was released [5]. Even though AR was introduced in early 1990s, the technology that is based on has its roots deeper embedded in history. Specifically, AR evolved from VR which in turn originated from simulators in 1920s. For instance, in 1950s, Morton Heilig introduced Sensorama (patented in 1962 [6]), the first machine with AR elements that provided sensing-related techniques utilizing 3D images, sound, wind, vibrations, and aromas; however, it never sold commercially largely due its high cost, complexity and scalability limitations. Also, in 1961 the first Head Mounted Display (HMD) was introduced [7].

AR development became easier after Hirokazu Kato from HitLAB introduced ARToolKit in 1999 [8]. This among other technological developments (namely gained by computer gaming industry) in early 2000 attracted more developers to AR. Due to

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the increasing interest in AR technology, researchers and experts from different fields are nowadays working together to develop new applications that can bring the benefits of AR technology to the respective fields. The number of different useful applications and recent developments of smartphones and AR-goggles by large companies like Google [9], indicate that AR can be one of the hyped technologies in the next years.

Despite the numerous studies demonstrating the multitude of benefits derived from AR applications, the technology has not reached yet its full potential due to various bottlenecks which are preventing it from becoming the mainstream technology that many have anticipated. While there is a large amount of studies discussing the benefits and problems encountered in the adoption and diffusion of AR technology, the majority of these focus on a single application field of AR. Motivated by this observation, in this paper, we study what drives but also what impedes the adoption of AR technology across five major domains, and taking into account both the developers' and final users' perspectives. The main goal is to provide a general overview of the current state of the art and to provide hints for future developments.

Unlike the invention of a new technology, which often appears to occur as a single event or jump, the diffusion of that technology usually appears as a continuous and rather slow process. Yet it is diffusion rather than invention or innovation that ultimately determines the pace of economic growth and the rate of change of productivity [10].

Technology acceptance models are used to explain how users come to use or accept a specific technology [11]. For instance, Louho et al. defined technology acceptance as the way people perceive, accept, and adopt technology use [12]. According to the Technology Acceptance Model (TAM), the success of a system is based on an individual's behavioral intention (i.e. attitude) to use it and this is determined by two factors: perceived usefulness and perceived ease of use [13]. Perceived usefulness is defined as the degree to which the user believes that using the system will enhance his or her performance. Perceived ease of use is defined as the degree to which the user believes that using the system will be free from effort.

According to Rogers innovation diffusion theory, five characteristics of a technology determine its acceptance [14]:

- Relative advantage (the extent to which it offers improvements over available tools),
- Compatibility (its consistency with social practices and norms among its users),
- Complexity (its ease of use or learning),
- Trialability (the opportunity to try an innovation before committing to use it),
- Observability (the extent to which the technology's gains are clear to see).

The remainder of the paper is structured as follows: section 2 describes the AR-related software and hardware and how these have evolved over time. Section 3 overviews the drives and bottlenecks in AR adoption across five of the fields where AR has been used most extensively. In section 4, a discussion about the drivers and bottlenecks is presented. Finally, section 5 presents the conclusions.

2. AR Software and Hardware

The evolution of AR has been tied to the available computational power. In particular, during many years in the past, computers were not powerful enough to process video feed, analyse it and overlay virtual content on top of it in real-time and with the necessary level of accuracy. With the increasing availability of computational power, the AR-related techniques have evolved and more complex algorithms can nowadays be supported. Moreover, the current trends show that even more advanced and complex techniques would be supported in the following years.

There are two main challenges in AR development related to software: the recognition of the environment and the rendering of virtual content. As the rendering of virtual content is a mature technology thanks to VR, AR researchers have focused mainly on the former task, i.e. the recognition of the environment. This has been performed traditionally using computer vision algorithms or positioning-based systems. Marker based algorithms have been widely used long in the past as they enable a robust and fast recognition process. ARToolKit [8] and derivative studies have diffused the use of marker-based systems and nowadays, these are still one of the most important approaches. However, this approach is limited by the requirement of attaching the markers to the real world and thus, new approaches were studied in order to overcome the above limitation. For instance, the evolution of computer processing enabled the use of image-based algorithms. The main benefit compared to marker tracking is that no additional markers need to be placed in the real world, as images that are already present in the captured video can be used.

One of the current research trends is to detect not only real objects but also humans. Specifically, point cloud based systems allow detecting real objects using their corresponding 3D models not only for the augmentation, but also for the spatial recognition and also to track movements of humans. As it can be seen, the evolution of software algorithms towards a more natural tracking system is a constant. However, it requires higher computational power and therefore, the standardized use of these tracking systems is still far in the time.

From the hardware point of view, there are three main components required in the majority of the AR applications. The first component is a camera that is used to capture the real environment (although the use of the camera can be avoided in some see-through systems that may use GPS or non 3D positioning of virtual elements). Almost any kind of off-the-shelf camera (e.g. USB cameras, built-in cameras, IP cameras, industrial cameras...) can be used for an AR application, depending on the requirements of the rest of the hardware. The video captured from the camera (or any other spatial acquired information), together with the virtual information, needs to be processed by the second component, i.e. the computing unit. The last component is a device where the final augmented information is displayed (e.g. a flat screen). Additionally to these three elements, further hardware, e.g. GPS, human motion sensors, accelerometers, gyroscope, etc., can be included into the designed system in order to serve a specific purpose.

Traditional computers with USB or built-in cameras and flat screens have been the most common setup for the early AR systems. However, with the growing computing power of handheld devices (i.e. smartphones and tablets), AR technology has started to be integrated also in these devices as they are constitute all-in-one hardware systems. In 2008-2009, the first commercial AR browsers for smartphones were introduced. These AR browsers were based on GPS tracking instead of computer vision, as the computing power was still not enough for image recognition. With the fast evolution of smartphones and the expansion of tablets, the number of computer vision based AR applications is growing rapidly. Moreover, Head Mounted Displays (HMD) have been for long in the centre of attention among researchers because they can also serve as all-in-one devices. However, so far existing prototypes have been heavy to use and the computing power has also been limited, preventing their wider adoption.

In the recent years, new lighter glass-type devices have started to appear with higher computing power which makes them particularly suitable as AR devices (e.g. Vuzix Wrap 1200DXAR [15], Google Glass [9]). The last Consumer Electronics Show (CES) has shown this trend as several AR-glasses have been presented (e.g. Epson Moverio BT-200 AR glasses [16], Lumus DK40 smartglasses [17], ORA-S AR eyewear [18], etc.). In the future, it is expected that these devices will further evolve enabling an even higher number of AR applications for these devices to be developed. Finally, cloud services are nowadays a new trend in the AR field which may lead to a new standard of AR computing. Moreover, the use of cloud services is very tempting because it enables the utilization of powerful computer vision algorithms with low requirements of hardware, as the majority of the calculations are done remotely. Therefore, if the tracking is done in the cloud, a smoother rendering can be achieved with the same hardware. However, cloud technology also presents some drawbacks, such as the need of continuous connection to internet for the cloud processing and an appropriated bandwidth for the targeted cloud service.

3. AR Applications – Drivers and Challenges

3.1. Industry and Military

Industry is one of the fields that may take more advantage of AR technology than other fields, as it can be applied to the whole life cycle pipeline, starting from the design of the product and going through the workers' training, the product manufacturing and the maintenance of the facilities. Figure 1 shows a block diagram of the current possibilities of AR in the product pipeline. These possibilities are explained in this section, except the marketing of the product that will be explained later in a separated section.

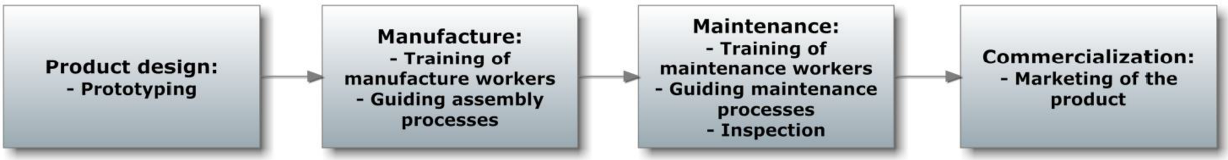

Figure 1. Product pipeline and the uses of AR.

Product design is usually an expensive process for the majority of companies, as either a physical prototype (in fact, several iterations of prototypes) or a Virtual Reality model displayed in a Cave Automatic Virtual Environment (CAVE) like system is needed. The use of AR technology allows designers to create real scale virtual prototypes that would be very expensive to build (e.g. cars, heavy machines, etc.) and analyse and present them augmented in a real scenario with a low cost solution. Thus, AR can be used at an early stage prototype design phase to reduce costs and provide means of design interaction either in a real size or in a desk size environment [19]. Designers may get interested in AR not only for saving costs, but also for some additional features like tangible interaction [20], [21], the easiness of visualizing changing variables like size, colour or textures [21] or the possibilities of usability evaluation [22].

Although the use of AR for training purposes is discussed later in this paper, it is worth to mention that AR may bring standardization of the manufacturing training which in the end would reduce costs and training time and allow workers to learn at their own pace [23]. During the training phase, the real devices can be augmented to guide the trainee through the different steps to follow, highlight some specific parts of the devices or point out dangerous parts and/or procedures that need to be avoided, for citing some examples. Several studies have already shown positive results when using AR for guiding the assembly process (e.g. [24], [25], [26]). The results from [27] show that the use of AR for assembly provides faster and more accurate performance for psychomotor phase activities. Although these studies have been carried out for small size prototypes, benefits like higher accuracy with fewer errors and shorter assembly times depict a promising future for larger scale projects. For example, [28] presents a first phase to create a large scale AR assembly process in the aerospace industry. Moreover, AR can be also used for final inspection of the manufactured products [29].

Maintenance is probably the most active research field in AR for industry and there is a large number of studies that have described the benefits of using AR for maintenance (e.g. [30], [31], [32]). Some of the benefits are faster maintenance interventions with fewer errors and more efficient and safer procedures. Furthermore, remote guidance and supervision from an expert is also possible by means of AR [33]. Several AR prototypes have been already implemented for maintenance in different sectors, such as aerospace industry [31], remote handling [34], photovoltaic pumping systems [35] or acid treatment industry [36] for citing some recent examples.

The great majority of research studies are prototypes aimed to solve a specific problem. However, the use of AR in industrial environments requires flexibility [37]. This flexibility means that the AR tools should be easily reusable to adapt to different devices and procedures with little effort. The solution to this issue could be the standardization of the patterns to be recognized by the system, like the unique identifiers proposed in [38], and the implementation of authoring tools that allow facilities to create their own AR applications without the need of dealing with low-level AR programming.

Military field has also started to research actively the use of AR technology not only for training (e.g. [39]) and maintenance (e.g. [40]) but also for simulation of actual military operations, like the prototypes presented in [41] and [42].

One of the main drawbacks of utilizing AR in industry and military fields is the accuracy of the virtual elements positioning. For instance, when using AR for the product design, the accurate placing of the prototype models is difficult to achieve [19]. Sometimes the low accuracy comes from the tracking algorithm itself which sometimes relies on environmental variables such as light conditions. Another important drawback of AR is that the recognition and tracking can be time consuming processes which complicate the direct use of the in-place objects for tracking in real time. Although some studies have shown good results in this direction (e.g. [31], [34]), a standardized method for markerless-based AR systems for large facilities is still far from the status of current technologies. Due to this fact, it is common to use marker-based AR systems which can provide a robust real time performance for large projects. However, this approach is not always convenient as the placing of markers in the facilities may not be possible or desired [31].

Despite the advantages mentioned through this section, it is still not clear for the industry whether the use of AR technology would return the investments made in the implementation of the system [23], which may be the major impediment in the generalization of AR applications in industry environments.

3.2. Training and Education

According to [43], AR is one of the ten most important emerging technologies for humanity, especially when it is used in educational environments. The reasons of this asseveration usually rely on the inherent characteristic features of the technology, i.e. immersive environments and interactivity.

The combination of real environments with virtual objects creates an immersive feeling for the user. As stated in [44], immersion in a digital environment enhances education in terms of multiple perspectives (i.e. changing frame of reference), situated learning (i.e. learning in the same context where the knowledge is applied) and transfer (i.e. the application of the acquired knowledge). AR is also a highly interactive technology which makes it suitable for the concept of "learning by doing" [45]. The interaction possibilities range from the basic interaction with virtual objects (e.g. moving 3D models, playing videos, scaling objects, etc.) to complex interactive features, like an embedded intelligent virtual tutor [46] or interaction between physical and virtual objects (i.e. tangible interfaces) [47], [48].

Moreover, AR brings further features to education and training. Collaborative applications have shown to be of great interest in this field and several studies have already shown the benefits of creating collaborative AR environments (e.g. [49], [50], [51]). AR is not only a means to educate and train people, but also to entertain while acquiring new knowledge. Students usually find concept acquisition more interesting when using this kind of systems [52]. Last but not least, AR technology has a fast learning curve, which means that users are able to start utilizing the applications with very little prior information [53], [54].

AR can be used in almost any educational subject, as it has been demonstrated in the large variety of examples that can be found in the literature, such as mathematics [55], [56], physics [57], [58], chemistry [47], [50], languages [59], medicine [60], Earth and environment learning [51], [61], natural sciences [54] or music [62], [62]. The applications can be targeted to a wide range of ages, from preschool students [54] to University students [49]. AR can be also used for training professional workers in several fields, such as training on clinical breast exam [64], planning brain surgery [65], [66], bread production in a bakery [46], full-body movement [67], myoelectric prosthesis [68] or escape guidelines for nuclear accidents [69].

There is no common standard on how to deploy AR applications for education and training. However, there are some common approaches that are followed by a large number of studies. One of the most common approaches is to use AR to augment the content of books where traditional educational or training material is explained in the form of text and images. The content used for the augmentation may cover a wide range of multimedia elements (3D models, animations, videos, webpages, etc.) and also several means of interaction that provide an added value to the books. Starting from one of the first AR books, the widely known MagicBook [70], where users could immerse themselves in a virtual world, researchers have been augmenting books for different subjects with all kind of educational material to enhance the learning process (e.g. [71], [72], [73]). The inherent interactivity of AR technology leads to a common and widely used approach where hand-sized markers are handled by students in order to analyse complex 3D representations that are not easy to understand when seen as printed images or to interact with the learning content in educational games. Another common approach is to introduce virtual characters in the AR scene to act as teachers, tutors or training guiding characters (e.g. [46], [74], [75]).

As it can be seen from the previous considerations, there is no unified procedure for the development of AR applications, as the variability of needs is large in the educational and training fields. Moreover, there is a gap between application developers, mainly from programming and IT fields, and educators and trainers who provide the educational value. Several approaches have tried to fill this gap by providing authoring tools to educators and trainers (e.g. [76], [77], [78]). Another approach is the one proposed in STEDUS [79] where a common platform provides access to educational AR applications that have been developed by programmers from the specifications designed by educators.

Despite the large number of research studies in this field, the level of acceptance is still limited. Some reasons may be that as an emerging technology, people are not used to utilize the technology or they even do not know what AR is. This applies not only to educators, but also to students who, as reported in [80], may feel overwhelmed with the large amount of information and the complexity of the educational tasks. In that paper, the authors also point out that some educators are unwilling to let the students experiment with the AR applications by themselves fearing that they may get lost in the process. Another problem may be, as stated before, that the majority of the applications are developed by programmers without the appropriate pedagogical point of view which may lead educators to ignore the potential capabilities of the technology.

3.3. Travel and Tourism

The travel and tourism industry is one of the fastest gowning industries across the world. For instance in Europe, it comprises 1.8 million enterprises, many of these being SMEs, and contributes to more than 5% of European GDP [81]. Tourism includes the activities of persons travelling to places outside their usual environment for recreation, leisure, business and other purposes. The tourism market relies heavily on information and technology plays an increasingly pivotal role not only in the delivery of it but also in the overall enhancement of tourists' and travellers' experience.

Among the various technologies employed in this heterogeneous industry (which includes tourist attractions, accommodation, bars and restaurants, transports, tourist offices, etc.), AR can be used across the value chain. In particular, AR can be used to access information about physical objects "on-the-go" via mobile AR browsers which deliver information through spatially registered virtual annotations and can function as an interface to (geo)spatial and attribute data [82]. For example, one can browse the history of Greece, see the Berlin Wall and other historic sites as well as see information about nearby business, e.g. the today's menu of the restaurants nearby. AR browsers have achieved more than 20 million downloads from mobile app stores [83] and some of the most common examples are Wikitude (launched in 2008) [84], Layar (launched in 2009 by SPRXmobile) [85] and Junaio (launched in 2009 by Metaio) [86]. Other, less popular, AR browsers are Sekai Camera (launched in 2009 by Tonchidot) [87], Tagwhat (launched in 2010) [88] and Argon (launched in 2011 by Georgia Tech) [89].

Exploring new places is the most common motivation in tourism and therefore navigation is very important. AR technology can also be used to facilitate access for visitors to and within a destination by overlaying virtual arrows on the live view in real time that indicate the direction the user should follow. Currently, there are many mobile applications available that utilize AR; few focus exclusively on pedestrians (e.g. [90]) or drivers (e.g. [91]), while a larger number focus on several modes of commuting or travelling (e.g. [92], [93], [94]). Moreover, the automotive industry is also interested in in-car AR as a means of enhancing drivers' safety. For instance, Mercedes-Benz is developing an In-Vehicle Infotainment System based on AR for its in-car navigation system which would have a split-view display in order to minimize distraction for the driver. Apart from navigation, the translation of information (e.g. menus and signs) is also very important in the tourist sector and AR can be utilized to instantly translate foreign text by pointing the mobile device's camera at the text (e.g. [95], [96], [97]).

AR can be used in cultural institutions for engaging visitors and enhancing their experience through interactivity. For example, the Digital Binocular Station (DBS) used in Canterbury Museum is based on a traditional binocular station, but adds a layer of interactive, 3D stereoscopic digital content between the user and their view [98]. Stedelijk Museum in Amsterdam used AR to install artworks in a local park [99], the Royal Ontario Museum used AR to add flesh to the bones of dinosaurs [100] while the Asian Art Museum recently unveiled a new AR application for its Terracotta Warriors exhibit [101]. AR applications have been also developed for further promoting tourism in particular regions. For instance, Tuscany+ [102] and DiscoverHongKong-City Walks [103] applications offer visitors in Tuscany and Hong Kong, respectively, an interactive, real-time AR-based guide for experiencing city's vibrant living culture while AR city tours are offered in Seville [104]. There are also mobile tourist guides which utilize AR but are not limited to a single region such as GuidePal [105], mTrip [106], and GeoTravel [107].

Despite the increasing use of AR in tourist-related mobile applications, there are several obstacles reported in the literature which prevent the wider adoption of this technology. One such problem is the lack of interoperability across mobile platforms which affects both application developers and content aggregators [108]. Moreover, many apps often require Internet connection which can limit greatly their use considering the high cost of data roaming [109] (although the effect of this is likely to decrease in EU when data roaming charges may get unified across Europe). Other major factors hindering the adoption of AR applications for tourism are the scarcity of available content, the poor quality of the user interface and user experience, as well as issues with battery life likely caused by the variety of sensors involved [110]. For example, many of the existing marker-less smartphone AR applications do not support extensively value-adding functionalities for mobile tourism such as Context-aware push of information, m-Commerce, Feedback and Routing [111]. In addition to technical limitations, aspects such as information abuse or oversaturation for marketing reasons and data privacy could also affect negatively the adoption of these in applications in the tourism sector [112].

In order to facilitate the adoption of AR in tourism, a number of critical design issues have to be addressed. For instance, according to [109], the criteria that need to be taken into account when developing an AR application specifically for tourism are (a) efficacy (e.g. does the system work as it was planned for and does it provide the required information to the right users?), (b) efficiency (e.g. are the AR application functions fully exploitable?), and (c) effectiveness (e.g. does the new AR system provide better tourist support?). AR app developers focusing on tourism also need to take into account future trends in this sector such the shift of demand from mass tourism to more tailor-made customized tourism for individual travellers [113]. All in all, innovative AR solutions can become the key to the promotion of tourism or tourist regional development therefore. However, it also important for relevant stakeholders to come along on this move toward innovative strategies, knowing that it will cost money, require a lot of training, and take time [114].

3.4. Medicine and Healthcare

Medicine is one of the most important industries for human well-being and health. The technological development has enhanced the quality and possibilities of medicine. Many illnesses and abnormal conditions that earlier caused constant pain or death, such as cardiovascular diseases or many cancers, can now be cured by modern technologies, pharmaceuticals and surgery.

The possibility of using AR and VR in medicine was recognized already in the late 1990s [115]. Benefits of using AR in medicine include a possibility to increase the (virtual) transparency of the patient, higher accuracy and precision with fewer risks, possibility of diagnosing the patient's condition during surgery and guided surgery within less time [116]. AR is especially useful in surgery. Together with 3D visualization and modeling, AR can be used to provide a virtual transparency of a patient and thus, help surgeons to conduct minimally invasive surgery that provide greater benefits to patients [117]. AR supports Minimum Invasive Surgery (MIS) approach, aiming at the least possible inconvenience for the patient. AR may also prevent patient and operator from other risks such as exposure to radiation in some procedures [118]. In orthopedics, VR training applications for shoulder and knee operations have been used with good results [119], [120], [121].

Augmented reality has proven to be useful in after-stroke re-education (e.g. [122], [123], [124], [125], [126]). Luo et al. [125], [126] got promising results by creating an AR training environment for rehabilitation of hand opening in stroke survivors. They used mechanical devices to assist finger extension. However, the patient required a therapist to assist wearing the equipment. A musical AR game has been created to develop patients' motor coordination, providing a natural fingertip/toe tipbased interaction [127], [128]. An AR-based rehabilitation system for daily practice, using a 2-D web camera and fiducial markers was proposed by Alamri et al. [129]. A table-top home-based system proposed by Mousavi Hondori et al. [123] rehabilitates wrist, elbow and shoulder by tracking the patient's hand and creating a virtual audio-visual interface for performing rehabilitation-related tasks that involve wrist, elbow, and shoulder movements. The system can be used by the patient and a therapist may follow and modify the exercise as the system sends the real-time photos and data to the clinic for further assessment.

Presurgical cranial implant design technique that develops custom fit cranial implants prior to surgery using the patient's computed tomography (CT) data was pioneered in 1996 [130]. In 2004, it was shown that virtual 3D cranial models based on patient CT data can be created in a haptic AR environment, thus, using force feedback to simulate a sense of touch, which is essential while creating realistic and reliable models [131].

Despite the numerous benefits of AR in the medical field, some issues have arisen, including, for example, incorrect visualization of interposition between real and virtual objects [132], [133]. A challenge in surgery is that the position of organs and tissues cannot be estimated but the surgeon must know them exactly. AR projections do not always correspond the reality because of the structure of tissues in human body and patient's subtle movements, such as aspiration and other tissue function [115], [134]. An attempt to provide more realistic real-time data was made by Konishia and al. by integrating laparoscopy and 3D-ultrasound images, i.e. combining images inside and outside a body, provided by two different imaging methods [134].

As described earlier, AR is beneficial also in training doctors, as well as in medical education and while explaining patients their condition and treatments. AR provides a realistic method to train medical skills, as well as objective feedback, without a presence of an expert supervising the exercise [136]. AR aids medical trainees to acquire proficiency in required procedures [137]. The enhanced reality compared to traditional learning methods enhances memorability of the procedures and thus, the efficiency of training and the speed of learning [138], [139].

3.5. Retail and Marketing

The retail industry involves the sale of products and merchandise online or from a static location, such as a physical store. It is also coupled with marketing activities undertaken by a retailer with the purpose of promoting awareness of the company's products and increasing sales. While e-commerce has improved dramatically over the last 20 years since Amazon was founded, still a large percent of all retail commerce is being done in the brick-and-mortar world. As an attempt to bridge this gap, many retailers, small and large, have increased their investment in their e-commerce divisions but one of the biggest challenges they face when entering the online shopping space is the lack of interaction with physical products. Moreover, retailers have traditionally relied on print advertising campaigns or other media to promote products. With the increasing use of tablets and smartphones, the use of augmented reality technology could completely transform the way traditional retail and marketing activities are done [140].

In the retail industry, AR can bring major benefits both in the online and brick-and-mortar sectors by enabling the interaction with virtual objects and enhancing the shopping experience with capabilities offered by the Internet, respectively. Specifically, there are many advantages in using AR in the retail industry [141]: It can improve the conversion rates and reduces returns for clothing stores via the use of virtual fitting rooms. Such rooms allow customers to sample products online as clothes are automatically overlaid on the consumer`s real-time video image through their webcam. For example, both Bloomingdale and J.C. Penney have tested the use of virtual dressing rooms, which let customers "try on" outfits that appear when they are looking at themselves on a large screen. In addition, the clothing retailer, American Apparel, is also adopting AR technology with the aim of bringing the online experience offline. By using a particular application, in-store patrons can scan the item to see the product in different colours and read reviews by other customers who have bought that item [142].

Besides clothing, AR allows customers to try a product before they buy it with the use of a 3D preview, as in the case of Lego. Major beauty retailers also plan to offering customer a new way to try out new makeup with the help of 3D AR Makeup and Anti-Aging Mirror which was unveiled at the 2014 CES conference by ModiFace. Moreover, the assembly of models can be digitally displayed on products, such as furniture, that require at-home assembling. This increases convenience and perceived flexibility to the online shopping experience. For instance, IKEA has utilized AR for visualizing the 2014 product catalogue and providing a virtual preview of furniture in a room. In 2014, Matterport, along with a growing and diverse list of companies, will start selling software to the public that can create a 3-D rendering of indoor spaces such as the inside of a house. People can view the rendering on a computer screen, explore the house as though taking a video tour and add objects to rooms. Such application could be also be utilized in construction, home improvement and insurance industries. Furthermore, AR can be used to optimize the warehouse space resulting in the reduction of time needed to process orders. For instance, Vuzix and SAP have created a partnership with the aim of developing AR applications for data collection and warehousing.

With the help of AR technology, additional information can be displayed about products in order to enrich the shopping experience, enable customers to search for nearby deals and attract them inside a store. Yihaodian, China's largest food e-commerce retailer launched in 2012 a chain of 1000 "virtual stores" with an AR mobile app that allows customers to shop in public places across the country. Glashion, a fashion app recently released for Google Glass allows users to purchase fashion items online as soon as they spot someone else wearing it. Pocket BargainFinder, a handheld device for augmented commerce allows customers to physically inspect products while simultaneously perform a price comparison online [143]. Another AR application, called TrackMyMacca, was lunched in Australia with which customers of McDonald's could see what their meal is made of [144].

AR technology can also be regarded as an effective marketing to enable a new form of visualization and interaction. In particular, AR can enhance brand recognition and empowers advertising campaigns. For example, Accenture has developed an app for Google Glass that allows customers to explore Toyota showrooms and check out new cars. Another example is Unilever, a global hygiene and personal care brand, launched in Buenos Aires an interactive AR campaign to promote one of their products [145]. AR, which has been used in marketing campaigns, can be seen as a form of experiential marketing because it focuses not only on a product/service, but also on an entire experience created for the customers [146], [147].

While the use of AR in retail and marketing is increasing, there are still several obstacles preventing its mass adoption. Specifically, only a fraction of consumers with Internet access have a webcam and the majority of mobile handsets are unable to support AR activities or have a limited computational power. Also, awareness is low and not every product is outfitted with the ability to display the interactions [148]. Therefore, relevancy of idea with the product should be taken into consideration when designing AR applications for the retail and marketing sectors.

4. Analysis of Drivers and Bottlenecks

AR has been an active research topic during the last decade and its importance will likely increase in the future as technological advancements (e.g. new hardware devices, more computational power, etc.) could fuel further the development of AR technology as well as help overcome existing bottlenecks. Several benefits and bottlenecks regarding the use of AR in five different domains have been discussed in this paper. Such approach enables us not only to identify the domain-specific benefits/bottlenecks but also to expose potential commonalities. One of the most commonly encountered benefits of AR across the examined domains is the reduction of various types of costs. For instance, as a tool for learning and guiding (e.g. in maintenance tasks, in medical procedures, etc.), AR helps to learn faster and reduce errors which leads to increased time savings, safer procedures and less operational costs. Furthermore, AR can also reduce fixed costs such as those related to the purchase of various items as virtual objects can replace physical ones (e.g. using virtual robots instead of real ones for the path planning phase). Moreover, the use of virtual objects is also beneficial in terms of reduced damage costs (i.e. virtual items cannot be damaged by misuse) as well as development costs (e.g. in product development, the use of virtual prototypes can be employed in the design phase to fine-tune the development of the final physical prototype).

AR is still an unknown technology for many people. Although this is still a problem for the expansion of the technology, its fast learning curve and the curiosity make it already suitable for many contexts, like education, training, or leisure activities (e.g. tourism). Moreover, the use of AR also allows users to visualize content that cannot be easily viewed otherwise. For example, it is possible to see the 3D disposition of the planets in a desk-size environment, recreate in-place 3D environments of historical moments, view the interior of the human body or understand 3D objects that are usually printed as images in books. Although the visualization of 3D content has been done for several years in VR field, the possibilities of tangible interaction and in-place visualization (mixing reality and virtuality) that AR provides, together with the fun side of its use, make AR a solid alternative that can overcome traditional VR applications in several fields. However, as it has been explained in this paper, there are also some common problems that still prevent AR from being a mainstream technology.

Nowadays, there is no standard for the use of AR technology. Although the creation of an all-purpose standard would be a very challenging task, defining several standards for different purposes would be a more realistic approach to follow. For example, the standardization of AR use in the tourism field has already shown some progress when considering the related AR browsers. However, the content of these browsers is still not common as it could be, for instance, in traditional web browsers. For this reason, the majority of existing applications are still of prototype level with the lack of flexibility being often a common denominator. Nonetheless, several tools have been already developed to help overcome the flexibility problem, but the efforts need to be still increased.

From the technological point of view, there are two main problems nowadays which hinder the adoption and diffusion of AR; these are the lack of accuracy (e.g. light conditions affect to the right alignment of virtual objects) and the time consuming algorithms (which may be an important bottleneck in some devices with limited computational power). While both of these problems have been tackled during the last years and some progress has been made towards achieving higher alignment accuracy and reducing the algorithms' complexity, the demand for more robust AR applications is yet to be met.

In the recent months, a new bottleneck has arisen as a major issue: the compatibility with social practices. As we have described before, there is a current trend on new devices in form of glasses or HMDs. Although the majority of these devices are used in specific environments (e.g. training rooms, maintenance facilities, etc.), some of these devices are beginning to appear as common accessories in everyday life (e.g. Google Glass). The possibilities of these devices in their daily use are unlimited and their use could boost the development of AR technology. However, the use of these devices is still far from being socially accepted. Apart from the inherent problem of getting distracted by the virtual content displayed on the glasses while establishing social relationships, one crucial problem is the privacy issues that may appear, as stated in [149]. In that paper, they explain that a new technology may create privacy concerns at the beginning but this may change when we get familiar with the devices and with the real value of using them. Despite this fact, the problem of social practices may become so important in the early stages of the product commercialization that even Google has release a list of "do's and don'ts"

[150] targeted to the users that are currently testing the device.

Last but not least, there is a risk to overwhelm users by a large amount of information. Therefore, it is crucial, to carefully analyse the information before presenting it to the users (e.g. shops in an AR city application or instructions for maintenance) in order to ensure that the amount of information conveyed is sufficient for the application's purpose, but not too much or more than needed as it may distract the user and limit the outcome of the application use.

If we analyse the drivers and bottlenecks presented here with Rogers' innovation diffusion theory (mentioned in the introduction), we can conclude that three out of the five characteristics are already fulfilled by AR, as it is shown in Table **1**. AR shows advantages over VR and other multimedia technologies, it implies low complexity in its usage and it is relatively easy to try nowadays (although not all devices are prepared for AR technology). However, there are still two aspects that are not met yet. Although technically AR can be used nowadays, there are still some compatibility issues in terms of social practices for some devices (e.g. AR glasses). On the other hand, the observability of the benefits of the technology is not clear for all potential users.

Table 1. Roger's theory applied to AR.

Roger's theory applied to AR	
Relative advantage (the extent to which it offers improvements over available tools).	Compared to VR, AR offers new advantages (e.g. Visualization of virtual worlds mixed with real environments)
Compatibility (its consistency with social practices and norms among its users).	Some devices are not socially accepted yet due to privacy issues.
Complexity (its ease of use or learning).	AR is easy to learn and to use.
Trialability (the opportunity to try an innovation before committing to use it).	AR is easy to try nowadays as many applications are freely available (especially for smartphones, tablets and consoles). However many users do not have the required devices to test the applications.
Observability (the extent to which the technology's gains are clear to see).	The benefits are not clearly seen from the consumers' point of view. Some users are not aware of the benefits of the technology while others need more information to know if AR would return the investments made in the implementation of the system (e.g. investment in AR maintenance systems, investment in marketing and retail solutions, etc.).

In today's economy, network effects due to technology standards are very important because there is a high degree of interrelation among technologies [10]. A technology has a network effect when the value of the technology to a user increases with the number of total users in the network. Network effects in adoption can arise from two different but related reasons, often characterized as direct and indirect. Direct network effects are present when a user's utility from using a technology directly increases with the total size of the network. Specifically, in AR direct network effects are relevant when considering e.g. the user-generated content in AR browsers where the higher the amount of content is available, the more probable it is to attract new users or in the case proposed in [79], where a larger number of users implies a larger number of available applications. Indirect network effects also arise from increased utility due to larger network size, but in this case the increase in utility comes from the wider availability of a complementary good [10] such as smartphones, tablets, head mounted displays and AR glasses.

5. Conclusions

As a conclusion, this paper has presented an overview of AR and related technologies and has introduced the benefits and most common problems of its use in different fields. Table 2 presents a summary of the drivers and bottlenecks analysed in this paper.

Table 2. Summary of drivers and bottlenecks in the adoption of AR.

Drivers		Bottlenecks	
Reduction of costs	Costs can be reduced by using AR in several manners (e.g. reducing costs in manufacturing processes, reducing errors, safer procedures, etc.)	**No standard and little flexibility**	There is no current standard for AR applications. The majority of applications do not allow their use in other domains and thus, the creation of new applications is usually required with the additional effort and time that it entails.
Fast learning curve	The technology is intuitive and easy to use. Therefore, the adoption from newcomers is easier than in other technologies.	**Limited computational power**	Many AR applications require complex computer vision algorithms to work. These algorithms tend to be time consuming for current devices (especially for mobile devices).
Curiosity	The idea of "expanding" the real environment with virtual content usually catches the attention of users that feel tempted to use the applications.	**Inaccuracy**	Some of the techniques are still not accurate enough to provide a robust localization of the virtual content to be displayed in the augmented view.
Tangible 3D visualization	Visualization of 3D content in real life and the possibilities of interaction offer an added value.	**Social acceptance**	New devices (especially glasses) are in their first years of existence and they have not been fully accepted in social practices.
Fun	The technology offers a component of fun in many cases that can be useful in several fields (especially in education and tourism).	**Amount of information**	The amount of information to be displayed in the augmented view may exceed the needs of the user. This problem may become critical when advertising becomes popular in AR applications.

From the aforementioned considerations, it can be concluded that AR technology is not mature enough to be mainstream (at least not as mature as VR is nowadays), but the steps followed by developers are pointing in the right direction. Also, changes in the perception of the technology from the users in terms of social practices and the perception of the benefits from its usage are needed to enhance the acceptation of the technology. Finally, an increase of the number of users and devices may create a network effect that can boost the implantation of AR as an everyday life technology.

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VI

AUGMENTED REALITY AIDING COLLIMATOR EXCHANGE AT THE LHC

by

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Augmented Reality aiding Collimator Exchange at the LHC

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Abstract

Novel Augmented Reality techniques have the potential to have a large positive impact on the way remote maintenance operations are carried out in hazardous areas, e.g. areas where radiation doses that imply careful planning and optimization of maintenance operations are present. This article describes an Augmented Reality strategy, system and implementation for aiding the remote collimator exchange in the LHC, currently the world's largest and highest-energy particle accelerator. The proposed system relies on marker detection and multi-modal augmentation in real-time. A database system has been used to ensure flexibility. The system has been tested in a mock-up facility, showing real time performance and great potential for future use in the LHC. The technical-scientific difficulties identified during the development of the system and the proposed solutions described in this paper may help the development of future Augmented Reality systems for remote handling in scientific facilities.

Keywords: augmented reality, collimator exchange, remote handling, maintenance, radioactive equipment

1. Introduction

Particle physics is a branch of modern physics that studies the smallest known constituents of matter. Particle physicists try to find out what the Uni-

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verse is made of and how it works. By studying what happens when fundamental particles collide at high energy levels, physicists learn about the laws of nature.

The study of the basic constituents of matter necessitates large and complex scientific instruments. The instruments used at particle physics laboratories are particle accelerators and detectors. Accelerators boost beams of particles to high energies before they are made to collide with each other or with stationary targets. Detectors observe and record the results of these collisions [1, 2]. The largest and highest-energy particle accelerator is the Large Hadron Collider (LHC) at CERN in Geneva.

The circulation and collisions of high energy beams in the accelerators and detectors have an undesirable consequence, namely the radiological activation of some of the components of these facilities [3]. This activation affects differently to the constituents of the accelerators and is more pronounced in some components than in others.

One constituent of a particle accelerator are collimators. Collimators are special devices that mechanically narrow the beam of particles that is accelerated. In modern accelerators, collimators are highly technological devices that are cooled and can become highly radioactive [4] and must be good absorbers [5], extremely robust and work as precision tools [5–7].

Because of their complexity, eventual maintenance and/or replacement operations however have to be foreseen. As the collimators will be among the most radioactive components in the LHC, their maintenance and exchange has to be studied in detail [8], and all possible tools for optimization of the operation have to be considered [9].

The LHC collimators, especially if installed in the beam line facing the tunnel wall are objects difficult to reach for maintenance work. During design, this was already kept in mind, and to provide a fast exchange a plug-in system was developed, ensuring an efficient installation and removal of the device. However, additional equipment is installed close to the collimator. This additional equipment is complicating the maintenance proceedings and not facilitating the accessibility. Herefore, Augmented Reality (AR) could become a very important tool.

The AR concept refers to the merging of real images with virtual content in real time. Figure 1 shows AR with respect to the real environment and to virtual environments, as they can be found in CAD programs. In this Reality-Virtuality continuum, defined in [10], AR appears as an intermediate state between reality and virtuality.

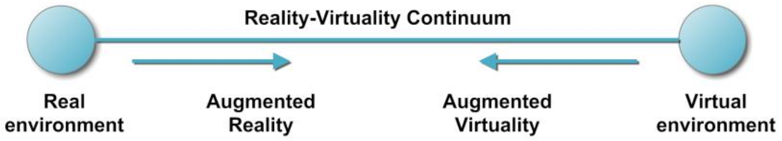


Figure 1: Reality-Virtuality Continuum.

There are several fields, such as medicine, education, entertainment or tourism, that have taken advantage of AR showing good results [11–14]. It has also shown solid results for maintenance of complex technical equipment [15–20]. The majority of those works is oriented to human intervention maintenance, where virtual information is displayed in a suitable fashion for the aid of the maintenance worker. The results provided in these publications are that AR is an easy to use tool for maintenance [17, 18] that enhances the task efficiency [17–20] and decreases the accident risk [19]. Moreover, AR has already shown good results in terms of training maintenance workers in hazardous facilities, such as nuclear power plants [21].

The results obtained in [18] show that AR enhances the task localization in terms of time saving and head and neck movements (minimising head and neck movements could potentially reduce overall musculoskeletal workloads and strain related to head movement during maintenance tasks). They compare their AR prototype to a modified version of the traditional system in use in the facility, which they call LCD. The mean task localization time for the AR case was 4.9 seconds against the 9.2 seconds that it took with the LCD condition. The mean translational head exertions were 0.25 metres for AR while 0.68 metres for LCD and the mean translational head velocities were 0.05 metres/second for

AR and 0.08 metres/second for LCD.

In [22], quantitative results of the improvement in efficiency are detailed. In the study, three aspects of the Operations and Maintenance (O&M) procedures with and without the use of AR are compared: time spent on locating the maintenance target area, the time spent on obtaining sensor-based operation data and the time spent on obtaining equipment-specific maintenance information. Here, an average of 51% of the time spent during a task where workers are located in the target areas is saved, while 8% of the time spent during a task is saved while obtaining sensor-based performance data.

In remote handling maintenance, however, the number of AR based works is more limited. There are some cases, such as in hazardous facilities with highly radioactive areas, where the maintenance has to be done remotely for the safety of the workers. The distance factor has to be taken into consideration and the approaches for AR applications have to be different from human intervention. Some issues that have to be taken into account are, for example, the use of remote imaging systems instead of built-in cameras and the need for guiding aids for the control of remote devices.

In [23] some of the possible benefits of the use of AR technology for remote handling in radioactive areas are presented. These benefits range from collision avoidance to recording of the work carried out for later review. All these benefits can be translated into a safer and more efficient maintenance performance.

[24] presents a case study of AR applied to remote handling in an ITER mock-up scenario. In this work, a template based matching algorithm is used to detect and track the Water Hydraulic Manipulator in the video feed. The accuracy achieved in this work is high and the tracking is done in near real-time. However, the markerless tracking used needs around 0.3 seconds to detect one object in the scene. If we think of a large number of different devices (like the different types of collimators), this approach cannot be used until the required time for the markerless algorithm is reduced to allow the detection and tracking of several devices in real-time.

The work proposed in [25] presents a series of experiments that aim to improve the depth perception of teleoperation procedures. The target of their experiments is to enhance teleoperations at ITER by overlaying depth cues to the real view. From the different experiments, the results obtained show that the best performance using virtual cues was obtained by using stereo tracking.

The structure of the remainder of this paper is as follows: section 2 details the developed system from the architecture to the features and difficulties found. Section 3 discusses the results. In section 4 the conclusions from this work are discussed and the possible lines for future development are proposed.

2. Materials and methods

The system proposed in this paper is intended to be used for remote handling and remote maintenance in the CERN environment. The developed AR system for remote collimator exchange relies on marker detection and provides multimodal interaction and augmentation capabilities. Markers have been the solution selected for the recognition process to ensure the performance in real-time. A database system has been used to provide flexibility for the development and maintenance of the final application.

2.1. System description

Figure 2 shows the UML component diagram of the system. Every component inside the component diagram corresponds to one module of the system.

The main actor (i.e. the user) is in charge of defining the configuration of the camera to be used for the current session. This configuration is fed to the acquisition module which starts the camera with the provided configuration and begins the acquisition of video frames. The frames are fed to the marker detection module and to the rendering module.

The marker detection module receives the frames and starts the recognition and tracking of the markers visible in the image. This module provides two outputs: the unique indentifier of the markers and the position and orientation of the markers in the 3D world. This information is fed to the database module and to the rendering module respectively.

The information about the content (e.g. virtual elements associated to every marker identifier, the path of the files, the information to display in the menu, etc.) is located in the database module. All this information is provided to the multimodal augmentation module and to the menu module, according to the information received from the marker detection module.

The multimodal augmentation module receives the information of the content data and processes the files before the actual rendering. This pre-rendering step is needed as the virtual elements to be rendered come from very different sources (e.g. videos, images, audio files, etc.). Therefore, they have to be read by the system and unified for the final rendering. When the content has been unified, it is fed to the rendering module. The multimodal augmentation module is also in charge of receiving the interaction of the user with the system and react accordingly to this input.

The system also provides the option of displaying a menu over the final augmented view. The menu module communicates with the database module to obtain the required information to display in the menu, including the information related to the current maintenance step and provides layer to be displayed to the rendering module.

Finally, the rendering module receives the inputs of the rest of modules (i.e. the video frames, the tracking information, the rendering information and the menu layer) and renders the final augmented view that is displayed in the screen.

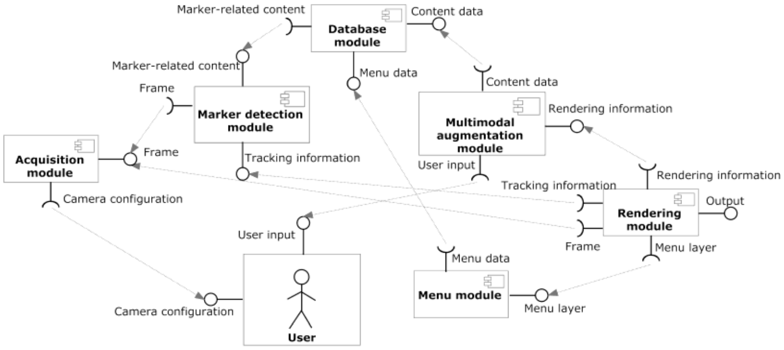


Figure 2: UML component diagram of the proposed system.

The great majority of AR applications make use of USB or embedded webcams to acquire the live feed of the target scene. However, AR applications for remote handling maintenance are meant to be used from a separate location than the actual maintenance location, making difficult the use of cameras that are attached to the computer. For this reason, one suitable solution is to use IP cameras that can be accessed from distance. For the prototype proposed in this paper, a calibrated Pan-Tilt-Zoom camera (AXIS PTZ 214) has been used. The camera can be manipulated remotely and the video feed can be acquired by the implemented system and processed for the marker recognition and for the augmentation. In the future, the collimator exchange system is expected to integrate up to four cameras in the new crane with an optical fiber transmission of the video feed. We plan to use one (or more) of those cameras for the final AR system.

Nowadays there are several ways of implementing the recognition of the scene that can be divided into two big groups:

- The first group comprises those systems that use black and white images (fiducial markers) to track their positions and use this info for the final augmentation. Several researchers have made use of this approach with different marker configurations [26–28].

- The second approach (usually called markerless) tracks natural features ranging from planar images to 3D objects. This second approach has also been used in a large number of works [29–31].

Although a markerless approach may look more natural, there are a number of disadvantages compared to fiducial markers approach. Markerless techniques need to detect and track featured points in the input image, which is a slow process compared to fiducial marker detection. Markerless detection also requires more memory use and the previous training of the natural features. For the proposed setting (collimator intervention), a markerless approach may be problematic as there are different collimator configurations with similar appearance. This means that the markerless approach may mismatch the detection of the collimator, showing the maintenance steps for the wrong model. Fiducial marker detection is more robust than markerless techniques in this sense. Due to the previous considerations, a fiducial marker approach has been used in the proposed system.

From all fiducial markers, binary-based markers seem to be the most robust [32]. The marker detection module proposed in this paper has been designed to detect binary-based markers, using ARToolKit [33] as the base library. These markers are represented as 3x3 matrices of black and white squares (see Figure 3 left). Each square represents a binary number, creating thus a number that uniquely represents every marker. One advantage of this approach is that the markers require no previous training and that it allows lower processing times as markers do not need to be tested against an increasing number of patterns. Table 1 shows results obtained from [27], where processing times for fiducial markers and binary-based markers are presented. Thus, by using binary-based markers the system can be scalable as the processing time does not increase significantly when a larger number of markers has to be used. Figure 3 shows an example of a marker (left) and the collimator and collimator crane with the attached markers (right).

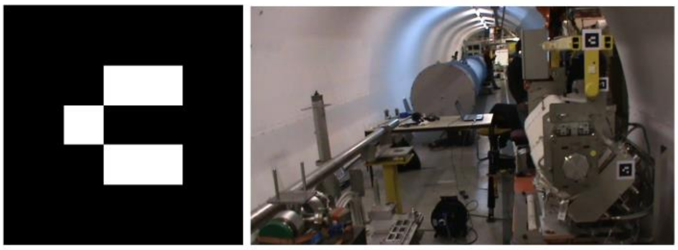


Figure 3: Left image shows an example of a binary-based marker. Right image shows the real device to maintain (i.e. the collimator) with the attached markers.

Table 1: Values of processing time (ms) for different cases for fiducial markers and binary-based markers. The values have been obtained from [27]. The number of markers loaded affect only to fiducial markers, as the binary-based marker approach does not load any marker in memory before the actual data processing. Therefore, binary-based markers are affected by the number of visible markers only while fiducial markers are affected by both factors: the number of markers loaded and the number of markers visible. As it can be seen in the table, for a low number of markers loaded and visible, both approaches have similar processing times. However, for larger number of markers visible the processing times of fiducial markers increase rapidly compared to fiducial marker case. It can be also noticed that the processing time increases quickly with the number of markers loaded for the fiducial marker case.

Conditions		Fiducial marker	Binary-based marker
Markers loaded	Markers visible	Processing time (ms)	Processing time (ms)
100	15	17,5	15
	30	40	37,5
500	15	75	15
	30	175	37,5
1,000	15	175	15
	30	315	37,5

The two main aspects in the development of an AR application are the marker/markerless positioning system (explained in the previous paragraphs) and the rendering system. The rendering system used in this work uses OpenSceneGraph [34] as base library. The multimodal augmentation module is in charge of unifying the Human Computer Interaction (HCI) capabilities of the system. It is in charge of the pre-processing of the virtual content (e.g. 3D models, images, videos, plain text, browsers and voice instructions) and of the user input by means of keyboard, mouse and/or touch screens.

There are around 100 collimators along the LHC tunnel (this number could increase up to 152 in future) with up to eight different configurations [35]. For this reason, the number of different 3D models and other virtual elements may be relatively large. Instead of hardcoding the paths of the virtual elements inside the application as a large number of AR systems do (e.g. [36]), a database system has been used in order to create and maintain the system without code modifications. The database contains all information required to properly load and display the virtual elements in the augmented scene. Moreover, the steps definition process has also been moved to the database system, so that the different steps can be added, edited or modified without the need of recoding the application. The database system has been designed to contain three levels of the maintenance process: maintenance, job and task or step. Maintenance is the top level and can comprise one or more jobs. Each job can contain one or more tasks (steps) which are made up of one or more virtual elements (see Figure 4). In the database, every maintenance, job and task has its own name, identifier and description. All the info about the elements to be displayed (file path, size, position respect to the marker, etc.) is also defined in the database. The database has been used locally, but it can be seamlessly used as distributed database with distributed virtual elements. As a result, the virtual elements can be stored and managed in a centralized system or split into different computers and accessed from any device connected to the same network.

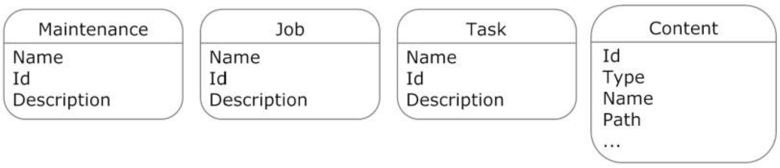


Figure 4: The data base scheme as used for the current implementation. It contains three levels of the maintenance process: maintenance, job and task or step. Each level has a unique identifier as well as a name and a description. The identifier is used for a proper registration of the progress of the maintenance. The name and description are displayed to the operator in those places where it is needed (e.g. in the starting window, in the HUD, etc.). Every task (step) contains a number of virtual elements (i.e. the content) that are also defined by a unique identifier and a large list of fields defining all the required information.

The AR view comprises the video feed from the camera and the virtual elements augmenting it in real time. There are some elements that do not need to be included in the 3D world (i.e. they do not need to be associated to any real object). For those elements, a head-up display (HUD) like menu has been designed and included into the AR view. The HUD is semi-transparent and can be hidden at any time by the operator. The goal is to offer as much information as needed in the way that is helping but not disturbing the operator. Figure 5 shows an example of the final layout of the HUD menu.

Help

SHIFT+H: Show/hide menu
SHIFT+(N/B): Next/Previous Step
SHIFT+S: Start demo
N: Next image
B: Previous image
F1: More help

Lift the crane up using the highlighted control.

Figure 5: Application layout. The HUD menu is displayed over the AR view.

2.2. Novel features of the proposed system

The AR system has been designed as a step-by-step guiding tool for the maintenance operator. The maintenance comprises two jobs (collimator removal and collimator installation) and each job has several tasks or steps. When the operator launches the application, he or she decides which job is going to be performed and automatically the first step appears on the screen. Each step is different and may contain one or more virtual elements, as well as text or voice instructions. The virtual elements may be goals to reach or helping content for the particular step. When the system detects that the step has been accomplished, either by automatic detection or by operator input, the elements of the old step are removed and the new step is displayed. The operator is able to navigate back and forth through the steps by using a keyboard if needed. Table 2 details the steps to follow and the information provided by the application to the operator in the augmented view and in the HUD for the collimator removal job.

Table 2: Steps and provided information in the augmented scene and in the HUD for collimator removal.

Steps	Augmented info	HUD
Follow the path	- 3D model of spreader part - Path and 3D keypoints - Collimator hook	- Text description
Reach the keypoint(s)	- 3D model of spreader part - 3D keypoints (one at a time)	- Text description - Image of controller
Approach	- 3D model of spreader part - Collimator hook - 3D animation of alignment	- Text description - Zoom video
Remove collimator	- 3D model of spreader part - Path and 3D keypoints - Collimator base	- Text description
Lift collimator	- 3D model of spreader part - 3D keypoint	- Text description - Image of controller
Reach the keypoint(s)	- 3D model of spreader part - 3D keypoints (one at a time)	- Text description - Image of controller
Approach	- 3D model of spreader part - Collimator base	- Text description - Image of controller

The collimator exchange intervention implies the movement of the collimator in an environment where sensitive equipment is surrounding the target position (Figure 6). For this reason, the intervention has to be performed with great precision, avoiding possible damages to other equipment. In order to cope with this limitation, a path guiding system has been developed for the procedure. The AR view shows key points that the collimator has to reach. Those key points are spheres located in the same 3D virtual environment as the collimator is and they draw the virtual path that the collimator has to follow. When the collimator (or some specific part of it) reaches the key point, the intersection between both 3D models (collimator and sphere) is detected. This intersection means that the key point has been reached and then the next key point in the path is displayed in the AR view. If the operator follows the key points, the probability of collision with the rest of the equipment is reduced.

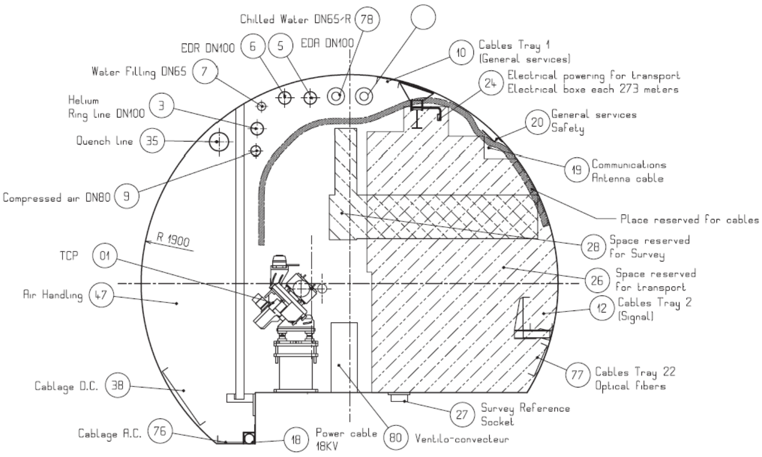
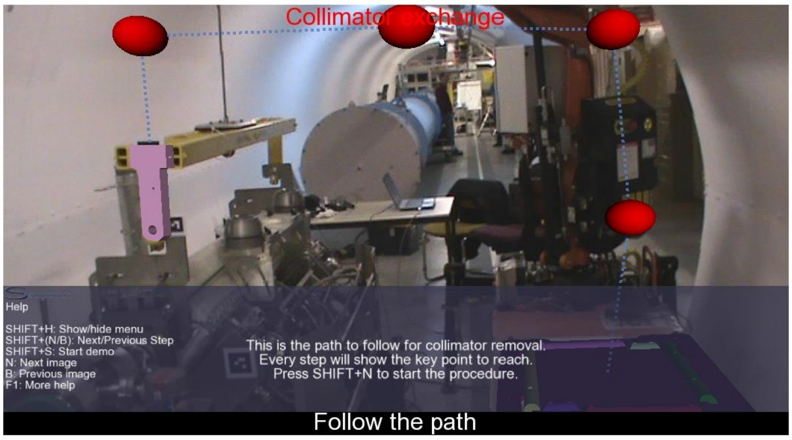


Figure 6: Transverse section through the tunnel around the collimator, showing the various services [8].

The final targets, such as the plate on the crane where the collimator is placed, are also displayed as 3D models augmenting the real object. The target and the key points are flashing during the guiding process in order to facilitate their location from the operator point of view. An example of the path guiding feature can be seen in Figure 7.



This is the path to follow for collimator removal.
Every step will show the key point to reach.
Press SHIFT+N to start the procedure.

Figure 7: Instructions showing the path to follow for the collimator removal. This step is displayed after the hook-spreader alignment and before the actual collimator removal. When the operator press the right key, the first key point starts to flash, showing the order to follow.

The controller used to operate the crane has four main controls to allow the operator to move the four degrees of freedom of the crane. Although the operators are thoroughly trained for operating the crane, in some cases it may be difficult for the operator to know which control is the most suitable for the required movement. For this reason, an image showing the most suitable control to use is also displayed in the right side of the HUD menu during the guiding process (this can be seen in Figure 5).

There are some steps in the intervention where the operator has to be extremely careful. One of those steps is the alignment of the spreader with the hook of the collimator. The tests for the proposed prototype were carried out using a crane without powered rotation of the spreader as a new crane with powered rotation of the spreader was still being built. As a result, the alignment of the spreader with the hook is a complicated task to perform with the current crane, as the control of the spreader is not as precise as desired. The spreader is connected to the crane through a cable, enabling free rotation of the spreader along the cable axis. Due to this, the latch system in the spreader may sometimes acquire the wrong position, making impossible the alignment with the hook. Figure 8 shows both configurations, the wrong one (left image) and the right one (right image). It has to be noticed that the latch system will be removed in the new generation of cranes which include the powered rotation of the spreader. Although this step will be no longer needed in future versions of the system, we describe it here as it was a crucial step for the collimator exchange with the current crane and one important bottleneck in the process.

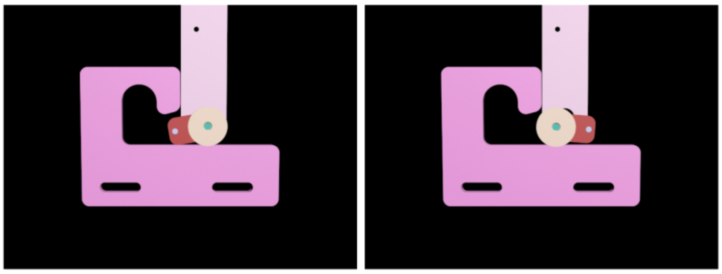
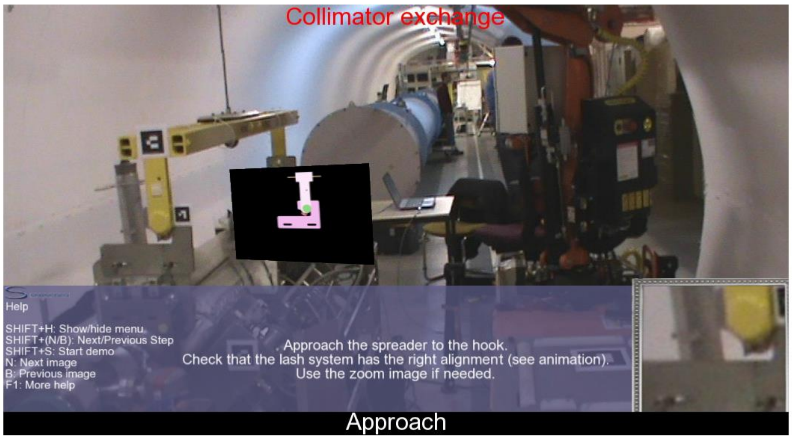


Figure 8: Left image shows the wrong configuration for the latch system, which makes impossible the aligment between the spreader and the hook. Right image shows the right configuration for the latch system during the aligment.

For this kind of steps, additional visual information may help the operator to perform the task. In the proposed system, several visual aids for the spreader hook alignment have been implemented. The first aid is a video displayed next to the collimator showing a virtual representation of the procedure for the step. In this case, a completely virtual representation has been selected instead of an AR representation because the operator needs to properly see the real object in order to perform the alignment. The second visual aid is a zoom area of the hook displayed in the right side of the HUD menu. As it has been explained before, the operator needs to clearly see the area of interest for the approach of the spreader to the hook. The AR view shows the whole maintenance scene, hence, a zoom of the area of interest may help the worker in those cases where the crane movement has to be precise. In the proposed system, the zoom of the same camera used for the AR view has been used. The position of the marker placed over the hook has been used to calculate the region that is segmented from the camera image, which is later zoomed and displayed in the HUD menu. The region segmented from the image has its origin in the main image in $(-100, -100)$ respect to the screen coordinates of the center of the detected marked and the size of the crop is 100×100 pixels. The zoom is a 2X digital zoom using a bilinear interpolation. However, this can be changed and instead of showing the zoom of the same camera, a second camera can be displayed, in those cases where a second camera is enabled and provides a closer view of the area of interest. Figure 9 shows and example of both visual aids.



Approach the spreader to the hook.
Check that the lash system has the right alignment (see animation).
Use the zoom image if needed.

Figure 9: Example of visual aids. In the image, the video showing the animation of the task is displayed beside the collimator. The zoom of the hook area is also displayed in the HUD menu.

2.3. Difficulties and guidelines for AR design in remote handling maintenance

The work presented in this paper focuses on the collimator exchange intervention in the LHC tunnel at CERN. During the development of the AR application for collimator exchange a number of technical-scientific difficulties have been identified. These can be extrapolated to other AR based applications for remote handling in scientific facilities. The analysis and solutions presented in this section may thus guide the development process for future AR applications for remote handling. The following subsections detail the most common problems that may appear during the development of an AR application for remote handling in scientific facilities, and how those problems have been faced in the collimator exchange intervention AR system.

2.3.1. Radiation

In the current case study, the AR system is used to aid the work in environments with ionizing radiation. In the case of the LHC tunnel, the radiological conditions are different when the accelerator is in use, or when the accelerator is down for maintenance. Indeed, during maintenance, when the beam is off, the ionizing radiation only comes from activated material. During operation, the equipment close to the beam is, on top of this, subject to stray radiation directly provoked by the accelerated particle beam.

The proposed AR system is based on marker recognition. The markers need to be present in the final setup in all elements relevant for the AR application, i.e., the collimator and the crane. The crane is removable equipment which means that it is subject to radiation only during the collimator exchange, which is only performed when the accelerator is down for maintenance. The markers that are fixed on the collimator crane are thus not critical with respect to radiation hardness. The markers on the collimators, however, stay in the accelerator tunnel during operation. This means that these markers have to be radiation resistant, have a lifetime that at least equals the collimator lifetime and have to be made from a material that does not become activated itself.

Important hereby is that the colour contrast of the marker stays stable, in order to not make it more difficult or even impossible to detect the markers from the camera image. Conventional sticker markers have an additional limitation, as the glue may degrade with the radiation dose.

In [37], black and white photogrametric targets have been built for collimator survey. Due to the high radiation level of up to 4 mSv/h in the beam cleaning insertions in point 3 and 7 of the LHC, where 37 collimators are present, standard alignment measurements are not possible. Therefore, new targets have been built to be used in such circumstances. The targets are made 100% from anodized aluminium, which has been proven to be resistant to high radiation levels, and provides suitable colour contrast for the detection. As the goal of the prototype proposed in this paper is the exchange of collimators, the current plans for our final system are to use anodized aluminium markers for the collimator, while conventional sticker markers can be used for the crane.

Radiation leads also to problems in electronic equipment. Thus, the cameras used for the AR system cannot stay in the tunnel and have to be movable. During the current case study, the camera is fixed in the tunnel for the tests. However, the camera proposed for the final prototype will be attached to the new crane, which means that it will be subjected to radiation only during the collimator exchange. If the radiation dose would be very high, a radiation-hard camera would be needed. However, this is not expected to be needed in this case and, therefore, there should not be major problems in the functioning of the camera due to radiation issues.

2.3.2. 3D models

Collimators and other scientific equipment are usually designed using 3D software tools before the final construction. However, those 3D models are usually CAD models which file formats are not always compatible with 3D rendering engines. Thus, the need of a format conversion for the 3D models is frequent in order to use them in the AR application.

The models used for the collimator case were created using CATIA V5. These models have been exported to STEP format, imported into 3ds MAX and exported to a suitable format (i.e. IVE files) for the rendering engine. The models designed in CATIA are usually highly detailed (e.g. the collimator model utilised for the prototype contains 2,106,058 vertices and 2,524,451 polygons) as they are the base for the construction of the real equipment. However, those models are not optimised for real-time rendering.

The models used for rendering in real-time Virtual Reality (VR) applications usually contain tens to hundreds of thousands of polygons. Considering that AR not only renders the models but also needs time for processing the video feed, the requirements are more demanding. Therefore, the available 3D models of the devices exceed the reasonable level of detail to be used in a real-time application.

For this reason, the models have been simplified in 3ds MAX by reducing the number of vertices and polygons before the final export (a reduction rate of around 90% of the original vertices has been used). Table 3 presents the values of the vertices and polygons for collimator and crane models in the original model and in the simplified model. The reason behind the polygon reduction is to reduce the size of the file, which will reduce the use of memory by the application, by losing details in the model while maintaining a useful shape of the model. In maintenance-oriented applications, the high detail of the models is not a crucial issue, as the models are only intended to guide the operator. Therefore, polygon reduction will not affect the perception from the operator.

As it can be seen in table 3, the simplified models may be in some cases still too large for their use in real-time applications. Therefore, after the polygon reduction, only specific parts of the models are displayed at a time in the prototype. For example, using the 3D model of the hook (565 polygons) instead of the model of the whole collimator (251,414 polygons) reduces considerably the required memory. Also, the loading time is reduced using the specific parts. The average loading time (including database access and loading in memory) of all models when using the specific parts is around 1 second while it takes an average of 2 seconds when using the full simplified models. Although the difference may not seem too large, it may be significant when the number of involved 3D models increases. However, in any case, this process is done only once at the beginning of the execution and it does not affect the framerate.

Table 3: Values of vertices and polygons for the original and simplified models of collimator and crane.

3D model		Original	Final
Collimator	Vertices	2,106,058	290,966
	Polygons	2,524,451	251,414
Crane	Vertices	101,557	14,410
	Polygons	107,221	10,649

The main challenge in the model preparation process is to properly align the models with the markers to provide a coherent visualization in the AR scene. The position of the marker in the real environment has to be known beforehand, in order to properly align the 3D object and its pivot point respect to the real equipment in order to achieve a realistic augmentation.

The process followed to achieve the proper alignment is the following. Accurate measurements of the real position of the center of the marker respect to a reference point in the device it is attached to (e.g. a corner of the device) are calculated. Later, these measurements are utilised in 3ds MAX to simultaneously align the pivot point of the model with the center of the marker and the origin of the 3D virtual coordinates. With this alignment, the augmented representation is properly aligned with the real device as the units utilised in 3ds MAX are 1:1.

As a conclusion of the issues commented in this subsection, a pipeline involving importing, manipulation and exporting of the models is required before the use in the final application. However, as the majority of the models are already available, the time required for the model preparation is lower than in those cases where the models need to be created from scratch.

2.3.3. Path guiding

One important feature in the work presented in this paper is the possibility of guiding the operator through a virtual path made up of virtual key points. The path shows the positions the collimator has to reach making easier the movement in the equipment-crowded area. However, the position of those key points has to be calculated respect to real known positions. As it has been explained before, the camera has been manually fixed in the tests for the first prototype. Nevertheless, the position has changed during the different tests, as it has been manually moved several times. Moreover, the camera that will be used in the final prototype will be integrated in the crane, which means that it will be movable and its position will be unknown. For this reason, the reference positions have to be calculated from the objects in the scene and cannot be calculated from the camera location, as it is not static.

In the case of the collimator exchange, the suggested fixed positions are the hook of the collimator and the plate of the crane for the collimator removal and the collimator base for the collimator installation.

2.3.4. Illumination and occlusions

The illumination present in the scene may vary from one collimator area to another, as inside the LHC tunnel the light conditions differ from one place to another. For this reason, it is difficult to foresee how the system will react under those conditions. However, the system has been tested against different light conditions inside the mock-up at CERN with good results.

Marker-based AR systems rely in the visual detection of markers in the scene. To achieve the detection, a threshold is applied to a grayscale version of the captured image. The selection of this threshold value depends on the light conditions and therefore, it cannot be fixed beforehand. For the proposed prototype, the method for automatic threshold proposed in [38] has been used. In the tests, the automatic threshold has worked fine and markers are detected under the conditions tested.

It may be the case that at some point of the tunnel the light conditions are too extreme for the automatic threshold to work properly. In these cases, the operator can manually set the threshold used for the marker detection using the keyboard in order to adapt it to the new conditions. With this option, the system will properly detect the markers in the majority of cases, even in poor light conditions.

There can be also cases when the markers are partially hidden or not visible. The reasons may be high reflection over the markers or different objects occluding the view. For those cases, we are currently working in a multimarker setup that will allow the proper positioning of virtual objects if at least one marker of the multimarker configuration is visible. The goal is to integrate this feature in the final prototype.

3. Results

The proposed prototype for aiding the remote collimator exchange in the LHC has been tested in a real collimator exchange in the mock-up facilities. The first results have been satisfactory from the performance point of view. The system is able to work in real time, despite the possible bottlenecks, like the IP communication with the camera, the detection of the markers or the display of the virtual content. The prototype has been tested with two cameras, a webcam for the first tests and an IP camera for the final tests. The specifications of the PC used for the tests are shown in figure 4. The application is able to provide a framerate of 30-35 fps with a resolution of 720×576 while displaying around 10,000 polygons (i.e. when using specific parts of the models). However, if the full simplified models are used, the framerate drops to 8-10 fps with the same resolution and displaying around 175,000 polygons.

Table 4: Specifications of the PC.

Processor	AMD Turion II P560 Dual-Core 2.5GHz
RAM	6GB
Graphics card	AMD Radeon HD 6650M
Webcam	Logitech HD Pro Webcam C910
IP Camera	AXIS PTZ 214

There has been no need to change the automatic threshold for the marker detection during the process and all markers where detected when they were visible in the image. Thus, the 3D models were properly aligned with the real devices. However, it has been seen that the error obtained for points that are far from the marker along the camera axis is large, as suggested in [39]. Although these distant points have not been used in the proposed prototype, solutions for improving the accuracy along camera axis have to be found. One of the foreseen solutions for this problem is to use a multimarker configuration. With the multimarker configuration, the final position of a marker is ponderated by the calculation of the position of multiple markers which may lead to a higher accuracy, as suggested in [40]. Equation 1 shows how the final matrix transformation ($T^{''}$) is calculated from the individual calculations of each matrix transformation respect to a reference marker ($T_i^{'}$) for the N markers visible in the image. The value of ρ_i corresponds to an error rate calculated from variables observable in the image (e.g. diagonals and area of the markers). With this approach, the accuracy of the detection may increase and the system can be able to recover from possible occlusions.

$$T^{''} = \sum_{i=1}^{N} \left(\rho_i T_i^{'}\right) \text{ where } \sum_{i=1}^{N} \rho_i = 1 \tag{1}$$

The path guiding system has worked as expected, detecting the key points intersections in the virtual world. As a result of those intersections, the system has been able to advance through the steps automatically. However, there are still a few steps that need a confirmation from the operator to be classified as performed (e.g. the hook-spreader alignment is not automatically detected by the system due to its complexity and the operator needs to inform the system that it has been successfully performed in order to receive the instructions for the next step).

4. Discussion

4.1. Conclusions

In this paper, a first prototype for an AR based application used for the aiding of collimator exchange process at LHC has been presented. AR has been previously applied for human intervention maintenance applications in the literature with good results. However, there are only very few examples of AR applications for remote handling maintenance. The proposed prototype uses AR technology to facilitate the collimator exchange from a remote location.

A modular system has been developed to acquire the video feed and process it in order to provide a final multimodal augmentation. Due to the special characteristics of the target equipment, several issues, such as camera or marker selection have been taken into account during the development. A database system has been developed and integrated in order to provide a unified method for creating and maintaining the application.

The final view that the operator will use has been designed to be as clear as possible in terms of user experience and different options have been included to allow an intuitive customized view. As a result, the operator can decide which features to display and which features to hide from the view.

The system has been designed as a step-by-step process, which means that the system will guide the operator through the different steps of the maintenance intervention. In addition to more traditional AR features, novel features oriented to remote handling operations (e.g. path guiding) have been developed and integrated into the system.

During the development of the system, the discovering of the main difficulties for this kind of systems, such as radiation dose or 3D model manipulation, has been done. Once those difficulties have been identified, feasible solutions have been designed in order to provide a more robust solution.

The AR prototype has been developed for assisting the remote handling crane operator in collimator exchange process. The main goals of the first prototype development have been to build the modular system and prepare it for the final prototype that would use the crane with powered rotation of the spreader, as well as finding the most problematic issues and providing solutions to those problems. The developed system may be now the basis not only for the final prototype, but also for future remote handling systems.

4.2. Future work

In the presented work a system has been built for the first prototype of AR aiding collimator exchange. The next natural step is to build the final prototype for the new crane with powered rotation of the spreader, attending to its new characteristics.

If the precision of the system can be enhanced, it may allow the reconstruction of the whole 3D environment, which will enable the creation of a virtual view from the rear of the collimator, providing thus a new point of view that cannot be achieved in the LHC due to special restrictions. The virtual view can be displayed in the HUD area, allowing thus to simultaneously provide two views (i.e. the agumented view and the virtual reconstruction) in the same screen. The benefits from this approach many be numerous, as the potential of the AR view can be enhanced by a second point of view that may deal with the limitations of the former view and the restrictions of placing physical cameras in some areas in the proximity of the collimator.

Another important aspect to develop is the implementation of an authoring tool that enables non-programmers to create and maintain the application. As a result of the use of the database system, the application can be modified without the need for recoding. However, a user-friendly application should be created to allow a faster and easier creation or modification of the application, as new collimator models or different instructions may appear.

As it has been mentioned before, the zoom feature is implemented from the main camera. However, in a future it may be suitable to replace the zoom with the video feed from a second camera that provides a new angle or a closer view.

As the number of different collimators is already large and can be increased in a future, a sustainable system has to be designed in order to enable the increase of new models. The database system is the first step to provide the sustainability. A second step may be the integration of an approach like the one proposed in [41] where the number of available markers is larger than using the conventional 2D barcode markers.

Another step after the final prototype may be the performance of user tests to assess the usefulness of the system and to acquire new requirements for future development.

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VII

AN AUGMENTED REALITY PLATFORM INSIDE PURESAFE PROJECT

by

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An Augmented Reality Platform inside PURESAFE project

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***Abstract*—This paper presents the results of a three-year research project inside PURESAFE project. PURESAFE contains 15 research projects and aims to enhance the life-cycle management of facilities emitting ionizing radiation. The research project presented in this paper focuses in Augmented Reality solutions for maintenance purposes. The outcome of the research project is a new platform containing an Augmented Reality engine and an authoring tool for the creation of Augmented Reality applications for maintenance in large scientific facilities emitting ionizing radiation. The platform has been developed and tested in real conditions.**

***Keywords*—augmented reality; maintenance; radioactive facilities; human intervention; remote handling**

I. INTRODUCTION

PURESAFE [1] is an Initial Training Network (ITN) for the training of young researchers, funded under the European Commission's Seventh Framework Programme Marie Curie Actions. The aim of ITN projects is to provide new scientific knowledge and, at the same time, train new researchers targeting to complete doctoral studies.

PURESAFE (Preventing hUman intervention for incrREased SAfety in inFrastructures Emitting ionizing radiation) comprises 15 interdisciplinary research packages that aim to train 15 Early Stage Researchers (ESR) and to develop new means of cost-efficient life-cycle management of facilities generating ionizing radiation. The participants of the PURESAFE consortium are universities (Tampere University of Technology, Universidad Politécnica de Madrid and Karlsruhe Institute of Technology), international research organizations (European Organisation for Nuclear Research - CERN- and Helmholtz Centre for Heavy Ion Research/Facility for Ion and Antiproton Research –GSI/FAIR) and industrial partners (SenseTrix, Oxford Technologies and bgator).

Every research package is focused on a specific aspect of the life-cycle management of facilities. From these packages, research package 11 (RP11) is titled “Augmented reality–based maintenance tool for hazardous places”. The focus of RP11 is to design and develop AR-based tools to aid maintenance workers while performing maintenance tasks.

This paper presents an overview of the research work performed within PURESAFE RP11. The work has been carried out from July 2011 to June 2014. The rest of the text is structured as follows: section II describes the background of the project. In section III, a description of the work developed in the project is presented. The results of the research work are explained in section IV. Finally, the conclusions of the project are presented in section V.

II. BACKGROUND

As mentioned in the introduction, PURESAFE is targeted to infrastructures emitting ionizing radiation. Therefore, human intervention and remote handling procedures may coexist in the maintenance systems of these facilities. Consequently, the work developed in RP11 has considered both types of maintenance.

The use of Augmented Reality (AR) for maintenance has already been considered in several studies (e.g. [2], [3], [4]). The typical approach followed in the majority of the cases is to use the technology to augment the devices to maintain with virtual instructions on the steps that have to be followed by the maintenance worker. The potential benefits are numerous, ranging from increasing the safety of the workers and minimising the accident risks to reduction of working times and maintenance costs.

Although the majority of the previous studies are targeted to human intervention maintenance, the benefits from the use of AR for remote handling maintenance have also been foreseen [5]. However, the studies presented in both maintenance types in the literature are prototypes targeted to solve a specific problem and they are usually not scalable and not flexible enough to be adapted to different maintenance procedures even within the same facility.

As a result of these considerations, scalable tools that combine both types of maintenance (human intervention and remote handling) are needed. Therefore, the approach followed by RP11 is to provide a new solution aiming to overcome this situation.

III. AR PLATFORM

The aim of RP11 is to develop several AR related techniques oriented to maintenance and to integrate those into a unique system that can be used in large scientific facilities. Maintenance in facilities emitting ionizing radiation is usually carried out in two ways: human intervention and remote handling. The purpose is to provide useful AR tools for both approaches. This means that some of the developments are human intervention oriented and some other techniques are remote handling oriented.

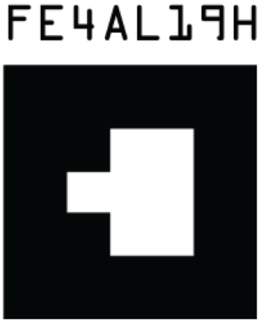
In both cases (human intervention and remote handling), the final application needs to be easy to use while helping the worker in the process of carrying out the work in a faster and safer way thus reducing the costs and risks of maintenance.

As a result of the previous considerations, a new platform integrating the proposed techniques and features has been developed. The platform comprises two main cores. On one side, a powerful AR engine has been developed. On the other side, an authoring tool for the creation of AR applications using the AR engine has also been developed.

The AR engine is mainly based on marker tracking, although it also includes a possibility for tracking images and point clouds. However, marker-based solution has been considered as the most suitable AR technique for the desired purpose, due to the restrictions and characteristics of the target facilities. Although the techniques for markerless AR have improved in the recent years, it is very complicated to provide a robust final solution that includes a large number of devices to be augmented in real time with the current software and hardware. On the other hand, marker-based AR provides a cost-efficient, robust and real-time solution for large scale projects, such as the case of scientific facilities where a large number of different devices have to be maintained.

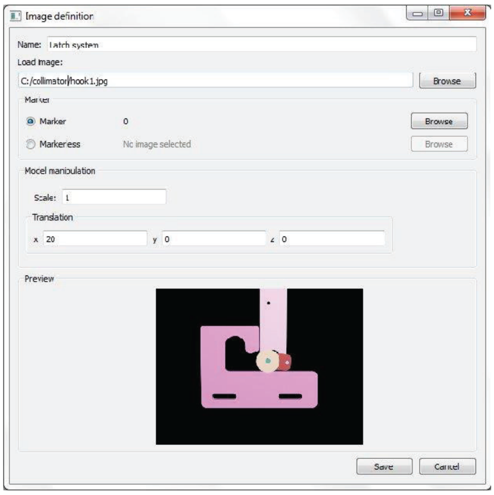
Moreover, a new hybrid approach combining traditional AR markers with OCR (Optical Character Recognition) technology has been also developed and integrated into the platform. Fig. 1 shows an example of the design of the marker used in the hybrid approach. The goal of this approach is to provide a solution that allows the deployment of a coherent system in large scale projects.

Fig. 1. Example of the design of the marker included in the proposed hybrid approach. The marker is made up of a traditional 2D barcode marker and a text code. The 2D barcode marker is used for determining the position and orientation of the objects in the real world while the text code defines the content associated to each marker. The recognition of the marker is carried out by traditional AR techniques while the recognition of the text code is made using OCR.



The authoring tool included in the platform allows non-programmers to develop AR applications targeted to maintenance procedures. The maintenance-oriented features included in the AR engine have been enabled in the authoring tool in order to easily allow users to utilise these features in the developed AR applications. The most relevant features included in the platform are the aforementioned hybrid approach, a step-by-step guiding system including keypoints for guiding remote maintenance and a maintenance-job-task structure of the applications. Fig. 2 shows a screenshot of the authoring tool.

Fig. 2. Screenshot of the implemented authoring tool. The screenshot shows a typical example of image definition to be used in the final augmented scene.



Name: Latch system

Load image: C:/collimator/hook1.jpg

Marker

● Marker 0

○ Markerless No image selected

Model manipulation

Scale: 1

Translation

x 20 y 0 z 0

The platform provides facilities with a design that allows its deployment in large infrastructures. The platform makes use of the aforementioned hybrid approach combined with a database system in order to enable large deployments of AR applications within the same facility. The AR applications follow a maintenance-job-task structure that provides a coherent system for the creation, storage and use of the developed applications.

IV. RESULTS

In this section, the results from this three-year work are presented. As explained in the previous section, the final outcome of the project is a new platform for AR solutions oriented to help in maintenance procedures in large scientific facilities, especially for those emitting ionizing radiation.

The platform includes a set of common AR features as well as new maintenance-oriented features. One important feature inside the platform is the design and implementation of a new hybrid approach (which combines traditional marker-based tracking with OCR technology to achieve more specific recognition) for the deployment of a coherent AR system in large facilities. The details of this hybrid approach can be found in [6].

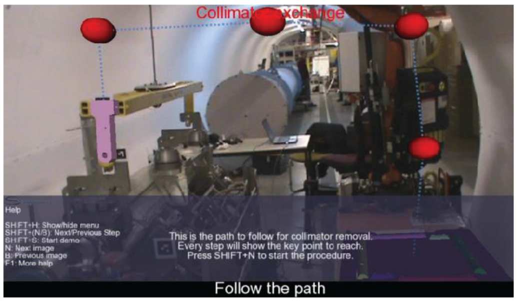
The developed platform comprises an AR engine and an authoring tool. Both sides of the platform are meant to co-work closely and therefore the features from the engine can be used in the authoring tool for the creation of the AR applications. A comprehensive description of the developed platform can be found in [7].

The platform is targeted to human intervention maintenance and remote handling maintenance. Due to the important focus of PURESAFE project towards remote handling and the relatively low number of previous AR remote handling research studies, an important effort has been made in that direction. The developed features have been tested on a real environment where remote handling is required. The use case was the exchange of a collimator inside the Large Hadron Collider (LHC) at CERN. The prototype developed for the collimator exchange was tested on a real scale collimator inside a mock-up of the LHC tunnel. The results of the designed prototype have been detailed in [8]. Moreover, the publication also describes the difficulties related to remote handling maintenance in facilities emitting ionizing radiation, found during the development. To overcome these difficulties, specific solutions are also proposed. The aim is that the proposed solutions may be used as helping guidelines for future designs of similar systems.

Fig. 3 shows an image obtained from the tests carried out with the CERN use case. A crane is used to perform the collimator exchange. The use of the crane is done remotely and, therefore, the operator needs to rely on the visual information obtained by a camera. The information from the camera can be difficult to understand due to the lack of a third dimension. Therefore, additional information provided by the AR view can enhance the understanding of the real situation.

In the image, the AR application provides the operator with a path to follow in order to proceed with the collimator exchange. The path is made up of keypoints that the operator has to follow to reach the final goal (also displayed with a virtual 3D model). When the procedure begins, only one keypoint is displayed at a time to clearly show which the current goal to reach is. The prototype has been tested in the facilities by CERN personnel and it has successfully worked in real time with a standard PC. For more details, please refer to [8].

Fig. 3. Image of the prototype developed for collimator exchange. In the image, a ste-by-step guiding system based on keypoints is displayed in order to aid the operator. When the exchange begins, one keypoint is displayed at a time, showing the goal to reach.



This is the path to follow for collimator removal.
Every step will show the key point to reach.
Press SHIFT+N to start the procedure.

Follow the path

Finally, the platform has been developed to be flexible enough to be adapted to different situations and environments. This flexibility has already been demonstrated as the platform has been successfully utilised to develop a new AR-based educational and training solution, as explained in [9].

V. CONCLUSIONS

PURESAFE is an interdisciplinary project that involves academic and industrial partners. Therefore, the interactions between both partner types allow connecting research results with commercial solutions. The possibilities of interaction between partners also offer a wider view of the problems to be solved and therefore to implement an enhanced solution.

The 15 research packages included in PURESAFE comprise a wide variety of fields, including mechanical engineering, software engineering, robotics, management and innovation models and radiation protection. The final goal is to obtain better solutions for the management of facilities generating ionizing radiation.

One of these 15 research projects is targeted to provide new AR solutions for maintenance in the mentioned facilities. As it has been explained in this paper, the final outcome of the research project is a new platform that comprises an AR engine and an authoring tool for the easy creation of AR applications for maintenance.

At the end of the three-year project, the platform has been developed and tested in real facilities and it is ready for deployment in a real environment. In the post-project period, the platform will be enhanced by including new foreseen features and marketed to potential users in scientific facilities, especially in those emitting ionizing radiation.

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