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Learning environment for robotics education and industry-academia collaboration

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Abstract

It is expected that by utilizing digital technologies, advanced robotics and artificial intelligence, the manufacturing base of Europe will become stronger and allow production re-shoring from other trade areas to take place. The European competitiveness is tied to better competences of the workforce and fast implementation of new technologies. This requires new approaches for formal and non-formal education. For this, we propose a new robotics learning concept and collaboration scheme to support both MSc level education, but also non-formal education with industry. The non-formal education example could be a combination of an education package followed by rapid experimenting with a robot system. In order to facilitate the learning process, we have established the Tampere RoboLab and joint academia-industry education modules for both formal and non-formal education. The Tampere RoboLab operates with similar principles as e.g. Fab Labs (fabrication laboratories), but the focus is on indoor stationary and mobile robotics. Aside from education, the concept allows system interoperability testing and pre-competitive research to be done in the same premises as well as field robotics by providing the state of art localisation and perception sensors, and computation and communication devices. This paper will introduce the concept, used hardware and software configurations, education modules and the forms of industry-academia collaboration.

1. Introduction

Manufacturing value networks are becoming more complex, versatile and global [8, 2]. Manufacturers deliver their products to customers through digitalised supply chains, acting in global manufacturing networks, covering both extended or confined geographic regions [11]. The manufacturing industry does not only produce products, but also life-time services for the products. In order to cater the needs of the customer, the designers, engineers and manufacturers must adopt and master the new emerging technologies required by the customers. These emerging technologies include recent and fast developing advances in artificial intelligence (AI) and robotics.

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It is expected widely that robotics technologies will become dominant in the near future. Robotic technologies in general have the potential to transform lives and work practices, improve efficiency and production quality, improve safety, provide enhanced levels of service and create jobs [6]. Artificial Intelligence (AI) is gradually emerging as a general-purpose technology that could have far- reaching effects in several sectors and cause disruptive changes in value chains and business models. The development of AI in Europe relies on a highly educated labor force and excellent research institutions [3] . According to the Cedefop (2015) the EU's skills and supply and demand are continuously rising [1]. In the EU, most job opportunities (around 24%) until 2025 are forcast for professionals (high-level jobs in science, engineering, healthcare, business and education), followed by around 16% for service and sales workers, and around 13% for both technicians and associate professionals (occupations applying concepts, operations and regulations in engineering, healthcare, business and the public sector) and elementary occupations (jobs traditionally requiring low-level or no qualifications). Shortage of skilled professionals is already visible in the job market, and it is our aim in this paper to present our effort in building an effective learning environment to address current and near future needs [1, 8, 11]. In order to mitigate the skill shortage new types of education modules and systems need to be developed. Considering ways to improve the competences of the workforce and the fast implementation of new technologies, the research question addressed is in this paper is "What formal and non-formal education in the field of robotics is required to keep the European companies competitive?".

2. Theoretical background

In order to facilitate more efficient learning, different teaching factory concepts such as problem-solving, reflection, learning from errors and boundary-crossing different learning methods have emerge [13, 8, 14]. The common goal of the learning factory concepts is to provide an industrially relevant production and/or operational environment for education purposes that supports both teaching and learning concepts.

There exist several different learning and teaching factory concepts. Flexible Manufacturing System (FMS) Training center in Finland was established in 1997 and is still operational. FMS TC learning environment focuses on education about flexible manufacturing systems, factory operations and energy and resource efficiency, and is targeted for vocational, BSc and MSc level education, company staff and customer education [8, 14]. Rentzos et al. (2014) introduced the teaching factory concept with the focus on providing engineering activities and hands-on practices under industrial conditions for university students while taking up the research results and industrial learning activities for engineers and blue-collar workers [13]. The teaching factory environment has been operational since 2009. Wagner et al. [16] described the LPS Learning factory that focuses on process optimisation, lean management, resource efficiency, and for users to learn factory operations for management and organisation perspective for students. Elbestawi et al. (2018) introduced a SEPT Learning Factory, that focuses on teaching how to apply modern manufacturing approaches such as Industry 4.0, IoT, IIoT and additive manufacturing methods for students [5]. Lanz et al [9] introduced a cyber-physical factory to support both education and industry-academy collaboration in the field of ICT and factory automation. One of the newest learning factory concepts was established in company premises for introducing Lean practices for mining industry employees [10].

The Fab Labs concepts started to appear in late 2000's. Fab Labs are 'place[s] to make (almost) anything' [7]. By the original vision, the Fab Labs could be used for teaching, professional development, applied research and research services with strong focus on prototyping. Most of their spaces include small, simple to operate and relatively safe machines that can be used with brief introduction and without pre-existing skills. Fab Labs aim to offer access to a range of low-cost fabricators and they are based on a commons-based peer production approach [15]. The main difference of Fab Labs and teaching and/or learning factories is that the Fab Labs are educationally unstructured/free-form spaces for individualised learning, to learn how to manufacture a narrow set of physical objects. While, the teaching and learning factories have pre-defined mission to facilitate the learning. Based on the literature review, the environments focusing on manufacturing and design processes are rather common. However, the learning environments focusing on different fields of robotics are rare.

3. Pedagogical foundation for the robotics learning environment

By growing needs for new teaching methods and enhanced learning in technology rich environments, the Tampere University's academic board defined the common learning outcomes summarised in Table 1. The learning outcomes were based on also the needs collected from the industry and society. These are the preliminary performance requirements for establishing a suitable learning environment for robotics education. These high-level goals have to be met in curriculum wise, not in one MSc or BSc level course alone.

Table 1. Learning outcomes.

Learning outcome	Explanation
Learning skills and critical thinking	The student is able to evaluate and develop his/her know-how and learning methods continually and is able to solve new and complex problems and make decisions even in unexpected situations. He/She gathers, processes, evaluates, analyses and uses information in a versatile, critical and ethical way and is able to evaluate and develop his/her information gathering processes further. He/She is able to cooperate and construct information, and understands the importance of sharing information, scientific thinking, reasoning and explanation.
Ethics	The student is familiar with the principles of sound scientific practice and acts accordingly, and complies with the research and professional ethics.
Employability skills	The student is able to act as a member of a work community and promote the community's and his/her own well-being. He/She takes into account the diversity of actors in the work environment, functions appropriately in complicated situations, and understands the importance of networks in working life and has the ability to develop his/her own networks.
Information technology and digital skills	The student is able to use ICT, and understands the importance of digitalisation, and utilises the digital operating environments available in the field. He/She promotes the development of digital operating environments, and knows the risks associated with these.
Innovation	The student implements R&D activities by using existing knowledge and methods, and produces new knowledge and methods for the field. He/She finds and creates new customer-oriented, sustainable and economically viable solutions, and is able to think creatively and sees alternative solutions.
Interaction and communication skills	The student is able to engage in constructive and expert social debate. He/She is able to discuss research-based knowledge and understand the status of different presentations and media texts. Student is able to communicate and work with people from different cultures in his/her field.
Social understanding and economic and leadership skills	The student has sufficient economic and leadership skills in his/her field and a willingness to expand this know-how. He/She is able to capable of plan and manage workload, targets, work independently and in team.
International outlook and global responsibility	The student actively follows up on the international developments in his/her field and understands the effects and opportunities. Student is familiar with sustainable development challenges and knowledge creation, and is able to critically specify and analyse these aspects.

In order to answer to the needs defined by industry and society, while taking into account the vision created by our academic board, we have developed the Tampere RoboLab concept and physical learning environment that supports different needs students may have. In this concept the learning is considered from both passive learning mainly done in the typical classroom setting and active learning via exercises, illustrated in Figure 1. In general, the amount of the traditional lectures is decreasing, and being transformed to more flexible and interactive learning methods such as video lectures, flipped classroom, workshop sessions, digital exercises including both reading material and examination. The amount of active learning events in the physical environment is increasing. In Tampere RoboLab the main idea is to increase the amount of both supervised and un-supervised exercises that aim to strengthen the problem-solving, learning from errors and reflection skills of the students, which were found highly relevant from an industrial perspective [9]. The active experimentation aims to connect industrial cases, their products, to the prototype development or feasibility testing done in the Tampere RoboLab. The concrete experience means the testing facility where students can (dis)assemble products, modify and combine these. The exercises might be on the system integration level, where the functional mechatronic modules are integrated or in a component level where for example an older model robot is retrofitted with new controllers. All exercises must have reflection and reflective observation where students either show what they have accomplished to other students or the supervisor demonstrates the correct use of
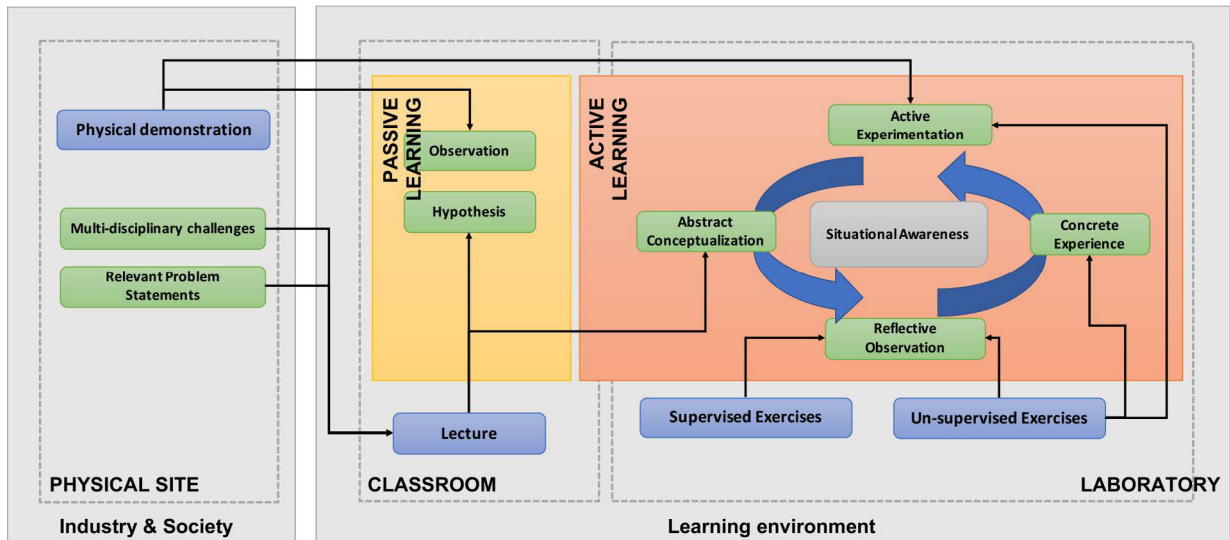
Fig. 1. Learning principles in Tampere RoboLab (adopted from [2]).

the robot system. This can be done in supervised exercises or un-supervised exercises. The active learning is supported with concrete problem statements, multi-disciplinary challenges and equipment. In reflection to the goals set by the academic board, this learning environment and concept aims to increase the learning skills and critical thinking, employability skills, information technology and digital skills, innovation, and interaction and communication skills. In future the other learning outcomes will be considered further. The Table 2 shows what type of activities are currently running in the learning environment.

Table 2. Learning outcomes.

Type of activity	Example	Target group
BSc theses	BSc theses with industrial robotics and signal processing	BSc. Level students
MSc level laboratory courses for Robotics Major, and minor in Industrial Robotics	MSc level education: Phenomena based and highly problem-solving oriented laboratory courses with industrial case problems and modern industry robots	MSc. Level students
MSc theses	Hand movement tracking with depth sensors and motion duplication with robot arm, Learning motion generating dynamical systems from human demonstration, Evaluation of Human-Robot Collaboration (HRC) in light-weight assembly task	MSc. Level students
Transfer Education	Robot system design focusing on industrial robotics, off-line programming, virtual commissioning, directives and occupational safety	Industry (continuous education, re-education)
D.Sc. thesis/academic research	Vision-Based Mobile Manipulation, Vision based safety system in HRC	PhD/D.Sc. level students, Industrial partners
Pre-competitive research	Feasibility testing of HRC capabilities, feasibility test on manipulation of small and flexible parts, Technology transfer	Industrial partners

4. Robotics education in close collaboration with industry and society

The close collaboration between different educational disciplines such as mechanical and automation engineering, ICT and signal processing, provides diverse flavour in terms of both content and implementation. It can be seen after the first implementation year that is has attracted students from different study directions. The philosophy of Robotics education at Tampere University is to be generic enough, such that it can serve students of different

Fig. 2. (a) UR5; (b) Franka Panda; (c) Tampere RoboLab (center); (d) KUKA Iiwa; (e) Sensor rack.

backgrounds and provide a holistic view to the subject. Students can then focus their studies at certain direction by elective studies or majoring in a different discipline in the different fields of robotics. To support this a specific major in Robotics was formalised. A student majoring on Robotics will achieve knowledge of and ability to analyse fundamental computational methods relevant to robotic manipulators and mobile robots, including modelling, planning, localisation, and control, and experimentation on real robot platforms. The courses in this major in general train the student to use SW tools such as Robot Operating System (ROS), Matlab and Simulink. Regardless the selection of additional/complimentary courses, all of the participants will design and implement a simple robotic system including hardware and software solutions.

This Tampere RoboLab offers a place for students to work with robotic equipment and experiment without major restrictions. Robots and related technology are for example industrial manipulators (Kuka Iiwa, Flexfellow, Universal robots, Franka Panda, PRob), mobile robots (turtlebot, MiR100, in-house developed robot), a multitude of sensors (2D/3D ToF cameras, LiDAR, GNSS, IMU, etc.) and different processing platforms (PCs, embedded PCs, Raspberry Pi, Nvidia TX2). The learning environment differs from FabLabs and other learning/teaching factory environments in such way that the lab is available 24/7 to all students interested in robotics. The lab is also located in the main lobby of Mechanical Engineering building. three out of four walls are glass, providing increased visibility to the activities and robots. Access to the lab is granted after a specific safety training is completed, and students can keep the access up t two years. Students can also work with their own robotics topics within this environment and use the floor tracks or removable walls to test their solutions.

The use of the Tampere RoboLab shows its working principles in laboratory courses. "Robotics Project Work" course topics are introduced by different professors or companies, and students choose some of the topics and work in a team to complete their project. A team is then responsible to manage, plan, revise, and do the project under the supervision of the project responsible. Example projects of this year are such as building a Lego house from virtual models with machine vision and UR5, building a mobile manipulator (MiR100 + Franka Panda) and performing a use case, and developing user interface for Hololens for controlling UR5 and electric gripper. The project work topics and arise from research needs or directly from industry. Robotics' students use Tampere Fab Lab when building their projects. The industrial partners are involved in contributing case products and equipment, but more importantly, they frequently visit the lectures and give problem statements and evaluate the results from the student work.

5. Conclusions

Manufacturing has been a pioneer in using robots such industrial manipulators and automatically guided vehicles (AGVs), though traditionally in closed fenced spaces. The trend has changed dramatically and flexibility and connectivity are key factors for this shift. Robots working alongside humans is expected to become more common. Many other industries from work machines (mining, harbour, etc) to transportation (self-driving cars and trucks) and service sector (e.g. hospitals) are being transformed by the emerging robotics technologies. Education thus must to adapt to these as well. The paper introduced a new learning concept and environment focusing on robotics formal and non-formal education. The developed environment supports both formal and non-formal education and industry-academy collaboration in research. From the education perspective the robotics learning environment was developed to facilitate the learning process and to allow different robotics projects originating from industry to be carried out. From the society's perspective the accessibility and visibility to the environment was made as easy as possible yet ensuring the safety of the users. The novelty therefore lies in the establishment of the Tampere RoboLab that it offers students and industry professionals multiple choices of education modules and with principles similar to traditional Fab Labs. In the future, more co-creation services and activities are planned to boost the industry-academia collaboration and facilitate the life-long learning among different industrial branches.

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