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DEVELOPMENT OF AN APLICATION OF WEB SERVICES FOR THE ENCAPSULATION OF A HUMANOID HANDS´ FUNCTIONALITIES AS INTEGRATION MECHANISM FOR DUAL ARM ROBOTICS

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ABSTRACT

Jesús Martin de la Cuadra Vila: Developement of an aplication of Web Services for the encapsulation of a Humanoid Hands' functionalities as integration mechanism for Dual Arm Robotics
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As years go by, the automation industry keeps pushing deep into factory operations. Which provides many benefits to the production line, the main one being the avoidance of human labour. Furthermore, it provides precision on the operation and control on the workflow. This continuous development of the automation within the Industry leads to a higher difficulty of tasks to be solved by a robot. Which, sometimes, cannot be performed. Maybe, because the task to complete isn't physically the same each time or because there needs to be a human interpretation on each cycle.

This document focuses on the physical part of the task. Where there must be a resemblance between a human operator and the robot. And here, there must be some thought on what truly makes a human replaceable by a robot. On some cases it's a decision. Let's say, size, shape or color, for example, but on others it's the complexity of the task. On this last point, it is key to resemble the human contact with the process it is replacing, and this leads us to the use of hand-a-like grippers and with it some terms such as dexterity and anthropomorphism that will be explained on the literature review. To approach this scenario, this thesis studies the implementation (in this case via Web Services) of and humanoid end-effector in order to mimic the gestures and poses required for any given task.

This thesis aims to provide a set of services to adequately make use of the humanoid robotic hand to, afterwards, tackle any given situation where a human is performing a task that requires some dexterity normal grippers cannot achieve. Filling another little gap on the list of tasks that are still performed by humans due to the dexterity needed on the field.

Keywords: Humanoid Hands, Web Services, Robotics and Automation.

The originality of this thesis has been checked using the Turnitin OriginalityCheck service.

PREFACE

Thanks to my family for everything they have done for me, not only the support received within my studies, but also for the environment they created for me to grow in.

Jesús Martín de la Cuadra Vila

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LIST OF FIGURES

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LIST OF SYMBOLS AND ABBREVIATIONS

CAD	Computer Aided Design
CPS	Cyber Physical Systems
ERP	Enterprise Resource Planner
FIPA	Foundation for Intelligent Physical Agents
GND	Ground
HMI	Human Machine Interface
HTML	HyperText Markup Language
H2M	Human-to-Machine
ICT	Information and Communication Technologies
IFR	International Federation of Robotics
IoT	Internet of Things
ISO	International Organization of Standardization
JSON	JavaScript Object Notation
MEDC	Most Economically Developed Country
MES	Manufacturing Execution Systems
PLC	Programmable Logic Controller
REST	Representational State of Transfer
RTU	Remote Terminal Unit
Rx	Receiving Channel
SCADA	Supervisory Control and Data Acquisition
ST	Structured Text
Tx	Transmitting Channel

1. INTRODUCTION

1.1 Thesis Background

On the last decades, automation has won a significant role on industrial processes, allowing the companies to substitute human labour by automated equipment. With this, companies increase their productivity as the programmable automated machine replaces the operator and, furthermore, decreases the chance of an error on the given task. With automation, there is also a big production flexibility, as it adapts easily to other similar task with a few tweaks to the program and/or the machine itself. The use of automation has mainly been involved on mass-production, as it performs non-stop and reduces the defects on the production line.

With all these advantages, and, of course, including the decrease of work-related injuries, it is clear automation is the way to go in order to achieve a more efficient and safer work environment. And so, over the years automation has been getting involved in the industry processes as well as on other topics not related to manufacturing processes. The main example of this relationship in between industry and automation, is the case of Ford, December 1913. Henry Ford studied the process of building a car and divided it into sequential tasks that where always performed by one operator as well as building machines to stamp parts automatically. By doing this, workers had only one task in mind, and by so reducing probability of injurie or error on the task. With all this in place he then mounted parallel rails to as guide for the wheels and so creating the first moving-chassis assembly line.

Of course, this case has nothing to do with the technologies dealt with nowadays. These times are considered as the fourth industrial revolution “Industry 4.0” [1]. This term first appeared in 2011, as a high-tech strategy for this year (2020) and grew in popularity at and industrial fair in Hannover, Germany. Its name comes as the fourth stage of industrialization being the first three: mechanization, electrification and information. The goal of this initiative, proposed by the German government, is to transform the industry through integration of information and communication technologies (ICT). With it, it aims to make a flexible production model that involves the business, the manufacturing processes the suppliers and the customers.

The plan developed by Germany mainly consists of: building a Cyber Physical System (CPS), which connects all the factory devices to the internet, researching the combination of ICT and smart devices, integration of horizontal, vertical and end-to-end communication and eight objectives as reference and guidelines.

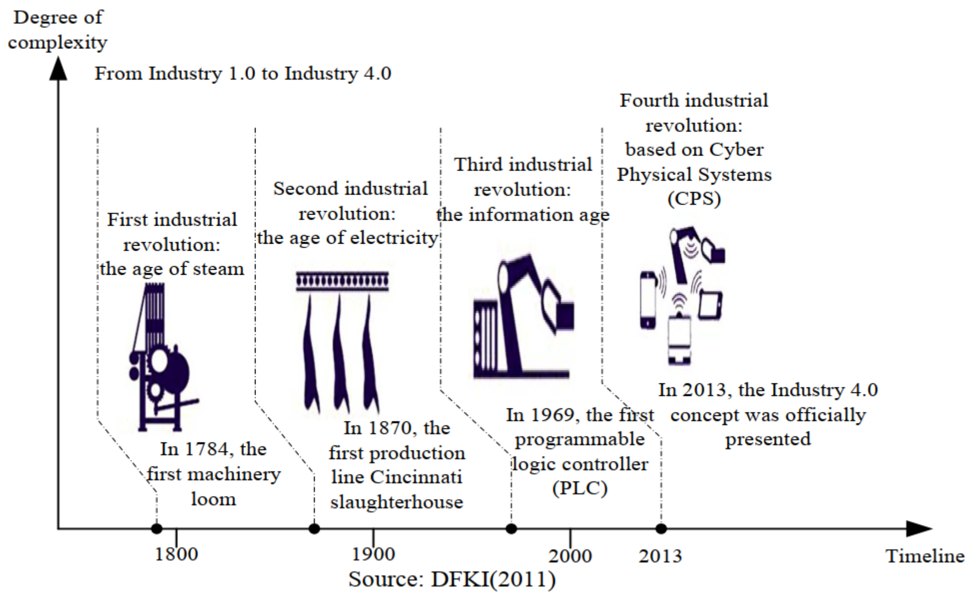


Figure 1. *Stage of industrial revolution*

With these horizons opening each day towards the use of automation, let it be with the physical robot or end-effectors themselves or with the ethereal technologies such as cloud computing or Internet of Things (IoT), there are enormous variety of fields to cover when researching. This Master Thesis focuses on robotics, specifically on humanoid end-effectors and its capabilities, which afterwards are meant to be attached to a Dual-Arm robot in order to simulate possible tasks and movements that mimic the human operators labour at the factory floor, as well as opening the spectrum of possibilities for the end-effector as its similarities with the human hand can help research how humans interact and coordinate their movements in order to grasp objects.

As first steps towards researching how the human hand can solve industry related problems, the purpose of this project is to research this field as well as to provide a real humanoid hand the possibility of moving and knowing its position and interconnecting it via web services so future programmers can make use of this end-effector on a comfortable way.

1.2 Objectives

With the automation industry updating daily it is the job of the educational institution to asses these new advancements and requirements accordingly, not only to support the necessities of the companies but also to contribute to the research on the topic that is tackled.

With this acquisition the department is aiming to go deeper on the research possibilities of grasping objects with a human alike end effector and adding a tool which students can use in future assignments to learn on up-to-date topics. To provide the lab this tool, the main objective is to program the hand so it can be used afterwards in a programmable friendly way and, additionally, research on the capabilities of the hand. After this, if the scope is increased, these humanoid hands may be attached to a Dual-Arm robot including then the full range of motion of a human, as, even though the hand offers a huge variety of degrees of freedom, the orientation provided by the robotic arm is key when approaching objects and grabbing them.

1.3 Outline

This document structure includes, besides the introduction chapter, background information at the literature review, and approach chapter, the core chapter of development and implementation and the conclusion chapter.

The state of the art furnishes the readers mind with background information on the topic that is tackled on the document. Providing knowledge about the state on the Automation Industry and, particularly, with humanoid hands as end-effectors. It also boards how real-life hands move, coordinate and move along. And it’s here where the topic of dexterity is discussed, as this term is commonly used how well system works.

Following this chapter comes development and implantation, where the core part of the Thesis comes in. Here comes in the end-effector itself and the issues attached to it. Not only the connection and communication issues of the hand, but also the services that must be provided so that the use of the hand is facilitated for other future works or assignments the FAST-Lab has.

The last chapter, which precedes the programmed code at the Appendix, is the conclusion chapter. This last chapter ponders on how useful the humanoid hand can be and how the set of services can be used, with regard of its limitations, on the industry while also introducing future trails for research

2. LITERATURE REVIEW

This chapter provides the reader some knowledge on the topic of robotics, focusing on the last link of the robot arm, the end-effector. This component of the arm is the most critical one as it is the part which is going to be contacting the object. In this case, the end-effector that is dealt with does not have a specific function, as most end-effectors do, but it can probably mimic most of them. As it is a humanoid robotic hand.

2.1 Robot Automation Industry

Before immersing onto the currently used robots and its end-effectors, a short review on history is going to be made on behalf of general knowledge. The word "*robot*" comes from the Czech word "*robota*", which translates to hard or arduous work. It was first used on a science fiction play in 1920 where the characters of the play acted as cyborgs. In any case, and even though the term "*robot*" was not attached to the idea of what we know consider a robot, there were previous inventions that resembled what we consider a robot nowadays [2]. In 1739, the French inventor Jacques de Vaucanson manged to assemble a digesting duck (Canard Digérateur) which seemed to be able to flap its wings, eat grain and, afterwards defecate to seem "alive". This resembles, in a way, what we now consider a robot, as it could perform a physical task and was reprogrammable. Two centuries later, in 1954, George C. Devol filed a patent for a machine that had a mechanical arm with a gripper attached to it, it was mounted on a track and the operations it had to perform where encoded by means of magnetic patterns on a rotating drum (programming).

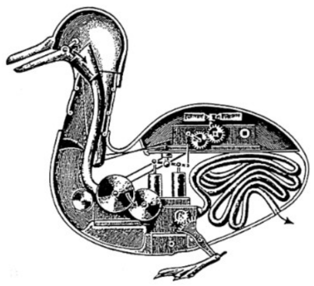


Figure 2. *Vaucansons Duck [2]*

From here on huge developments have been made on the field of automation. There are now various types of robots, such as mobile robots, service robots, field robots, humanoid robots and the most obvious ones, manufacturing robots. All of them providing humanity with huge amenities that fulfil the required necessities, them being faster production techniques or artifical medical limbs for patients.

This categorization is not a strict one, as some robots may be considered of more than one type. An easy example are the cleaning robots we see nowadays (Figure 2.a). These service robots are also considered mobile robots, as their task depends on the position they are in and the path taken. Field robots, are also pretty relevant, thus the human labour it demanded on the past was very arduous. This does not only apply to crop fields, but also to the animal industry (Figure 2.b).

Figure 3. a) *Mobile-Service Robot [1] ,* ***b)*** *Field Robot (Robotic Milker) [4]*

Manufacturing robots are the main descendant of the first generation of robots. Even though not all have the same shape and size, most of them are arm-based robots attached to a platform which perform the same repetitive task over and over again. This category of robots can now cover a wide variety of tasks and , furthermore, can be modified and reprogrammed to tackle other task if necessary. With these robots in place, it is much easier to control the status of the work-plant, as the robots can also provide feedback on, for example, their position or their energy consumption during the process. This leads to a more efficient and interconected factory line which, with the pass of the years, will improve and will implement other mechanisms to achieve that so called "Smart Factory".

Smart factories are the end-goal of the Industry 4.0 revolution. These factories aim to capture the whole process within them, starting with the digital to physical conversion and ending with the relationship with the customer.

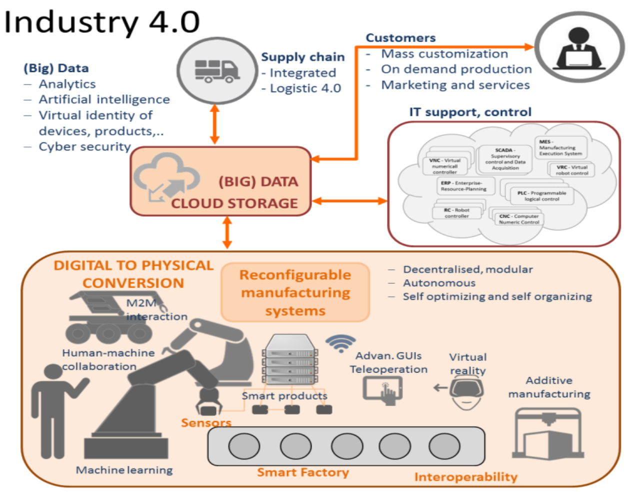


Figure 4. *Smart Factory [5]*

In these smart factories, the product itself also has a virtual identity (not only physical) as it must be monitored during its lifecycle. This information is stored on the cloud and the product information may contain any necessary documents such as its 3D model, standards (ISO, FIPA…) or even a historic of where it came from and how it got there. This information leads to bigger connectivity which allows Machine-To-Machine interaction (M2M), as well as the traditional Human-To-Machine (H2M), which interact and communicate independently to achieve a common goal. The communication done here is done via IoT (Internet of Things), which is a combination of CPS and the factory environment.

Before advancing to the physical robots themselves, the software and structure of the system must be explained. Industrial automated production plants are divided into five different layers [6]:

- Layer 1 (Field Devices): This layer has a naturally distributed control level and is the layer where the physical interaction with the production line are done, via sensors and actuators
- Layer 2 (Control Level): This is the layer where Programmable Logic Controllers can be found (PLC) and acts as the translator so the next layer can interpret and use the information provided by the field devices.
- Layer 3 (SCADA): In this layer the factory floor is monitored, and it recaps the information in order to supervise the process. The most common example is Supervisory Control and Data Acquisition (SCADA).
- Layer 4 (MES): Manufacturing Execution Systems provide support with the huge variety of operation performed in the factory such as scheduling, product tracking maintenance or performance analysis. It is the layer that performs the managing of the factory floor besides communicating with last layer of the pyramid.
- Layer 5 (ERP): This is the last layer, and the one with most long-term relevance, as the Enterprise Resource Planner includes aspects like managing the supply chain, accounting or even human resources.

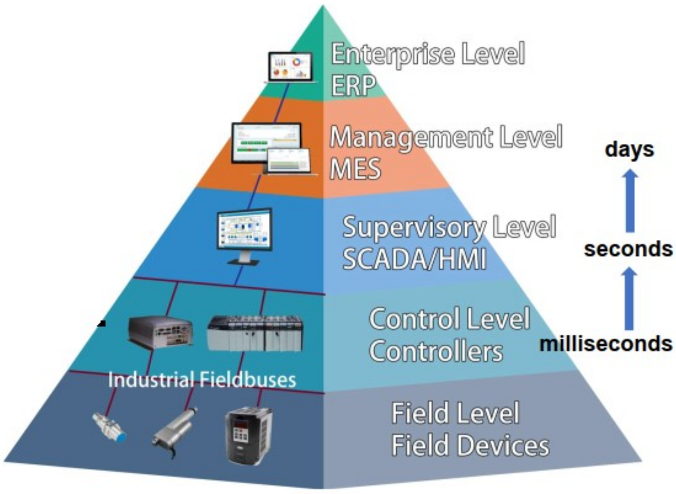


Figure 5. *Automation Pyramid [2]*

This pyramid serves as guide for the integration of automation on the industry, which opens new windows for production or enhances existing ones (e.g. just-in-time production). According to [7], Industry 4.0 may decrease production costs around 20%, logistics costs by 10 - 30% and management costs by 10 - 20%, while also shortening the processing time of an item as well as making a more efficient use of the energy and resources [6].

All these advantages led by automation have caused significant changes on the industry, not only regarding human labour, but also on specific ones like the automotive. First topic to cover is how robots have substituted labour in recent years. To approach these four classes have been taken into account, following the Foote and Ryan occupation classification. These four groups are: Nonroutine Cognitive (management), Routine Cognitive (sales and office occupations), Nonroutine Manual (mostly health support and services) and Routine Manual, which includes the most common type of jobs that can be easily replaced by robots.

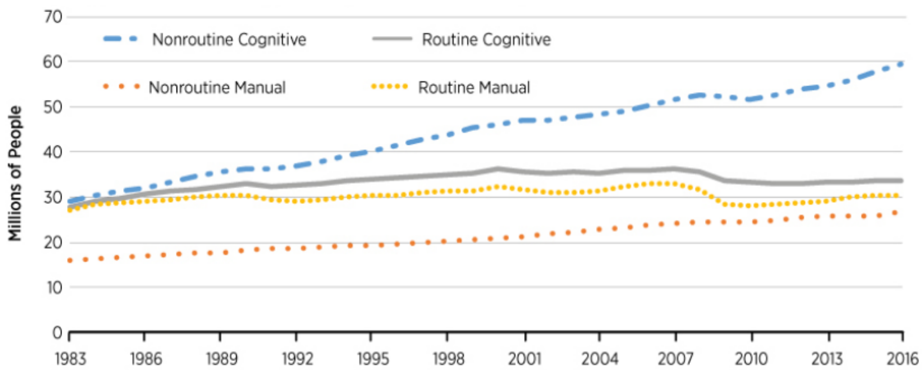


Figure 6. *Employment by Occupational Group (Source: U.S. bureau of Labor Statistics)*

As seen above, the only occupational group that has grown is the Nonroutine Cognitive group, thus the logic involved in those kinds of jobs have too many variables to take account of as well as the human factor. As for the other groups, robotics has had a mayor impact in them. Thanks to the International Federation of Robotics (IFR), statistics can be shown on how robots have accessed the industry and how it has grown, Figure 8 shows the evolution of robot stocks of some economies of the MEDC´s around the world.

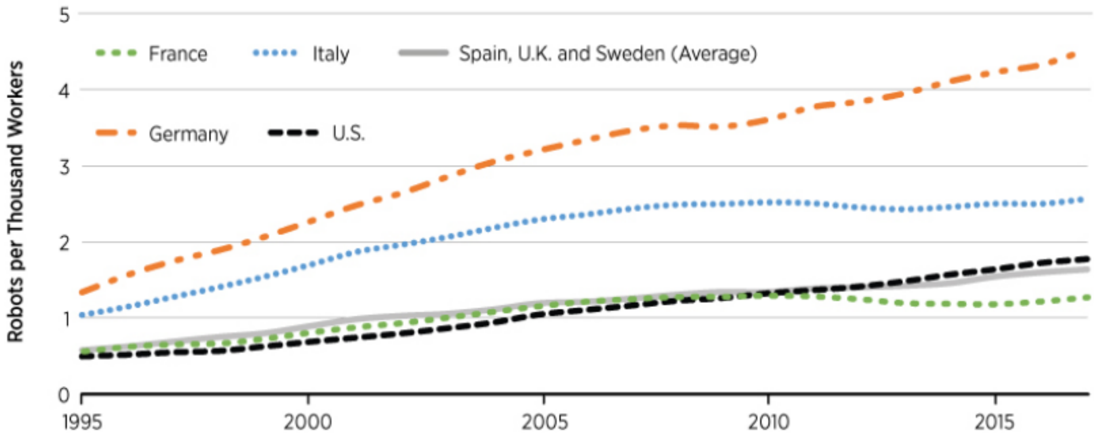


Figure 7. *Evolution of the Stock of Robots in Advanced economies (Source: International Federation of Robotics)*

These large amount of robot acquisitions are made by various markets inside the industry, being the most relevant one the automotive industry. As it is known, automotive industry has grown massively on the last decades, as there is more and more demand on cars. This demand has also had an impact on automation itself, as the factories search for faster and more efficient techniques in their line, they pass these requirements to universities and research groups which day by day, append new intellectual property to the field. Figure 9 shows the difference in between the robots used on the automotive industry compared to other manufacturing industries.

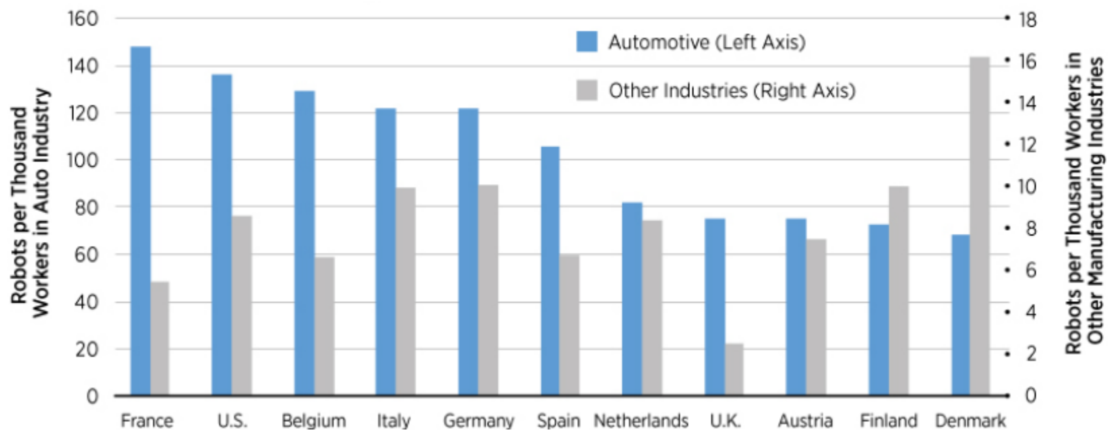


Figure 8. *Robots in Automotive / Manufacturing comparison (Source: International Federation of Robotics)*

2.2 Industrial robots and end-effectors

Even though robots have made its way deep into industry, not all of them operate the same way or even have the same specifications, but they do have some requirements in common. As defined by ISO 8373, and industrial robot is *"an automatically controlled, reprogrammable, multipurpose manipulator programmable in three or more axes, which can be either fixed in place or mobile for use in industrial automation applications"*. This definition may be a bit heavy for someone who is not familiar with the topic as, when imagining an industrial robot, most people just think of a articulated robotic arm (which is included). Besides this type of robot, industrial robots also include many others that also fulfil the definition above. The classification by mechanical structure is as follows: Linear robots, SCARA robots, Articulated robots, Parallel robots and Cylindrical robots [8]. To understand their functioning a few concepts must be introduced first.

A robot is formed by two basic components, links and joints. Links are rigid objects which are connected to joints, which allow a relative motion with the link connected to the other side of the joint. These joints can either be prismatic (allow sliding) or rotatory (allow rotation) and determine the number of axes the robot can use. The first link is connected to the base frame, that may be mobile or not, and the last one is connected to the end-effector [9], that has a huge role thus it is the contact point in between the object the robot is handling. Some common examples are welding gun, screwing gun or a gripper designed for the process.

With these basic terms, the classification of robots can be explained. The first one that comes to mind is the articulated robot, with 3 rotatory joints that simulate the shoulder, elbow and wrist. Next one in the figure (Figure 10) is the SCARA robot, which performs greatly on the electronic manufacturing industry as, by having two rotatory and on last prismatic joint, can approach and act with great speed at a constant work plane. As for the cartesian robots, they are very similar to a 3D printer, as they have prismatic joints that act as the common "*x-y-z"* axes. These robots have a very user-friendly use as the coordinate system is more familiar to the programmer. Lastly, Figure 10 shows the parallel robot, whose arms have parallel or rotatory joints (in this case rotatory) and are also very common in tasks where speed is key. Cylindrical robots are named after its work envelope, which obviously has cylindrical shape. It consists of two prismatic and one rotatory joint which provide reach an volume in space with a cylindrical shape.

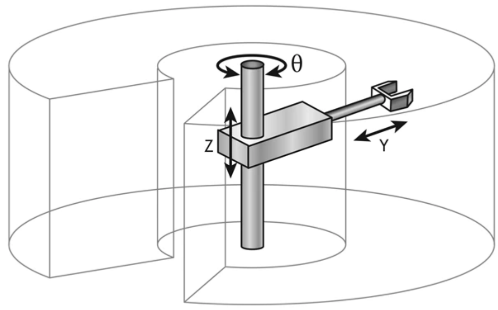


Figure 9. *Cylindrical Robot [12]*

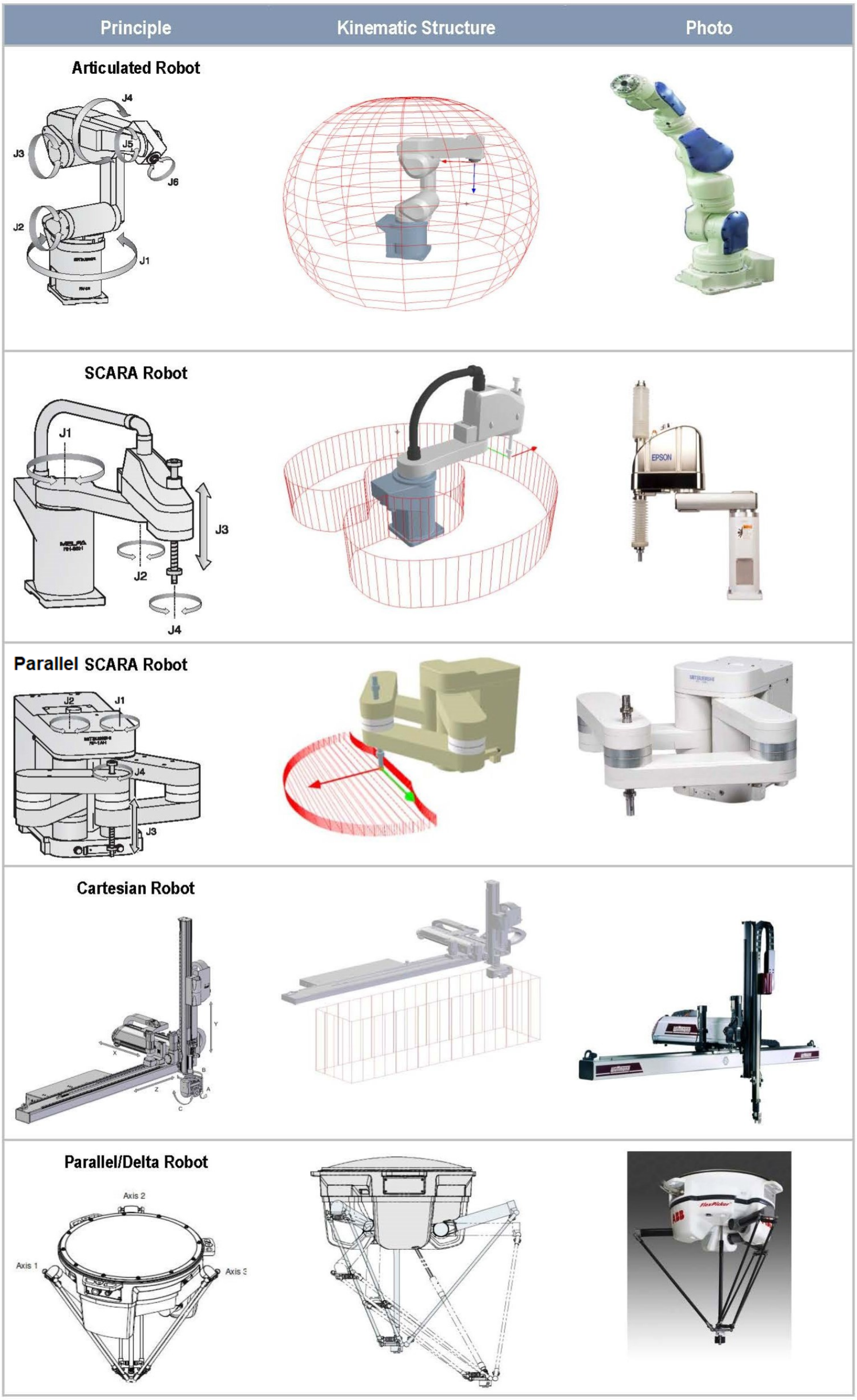


Figure 10. *Classification of robots (ISO 8373) [8]*

With all these kinds of robots, there is no doubt the range of tasks they can be implemented on is enormous. And it is here were the end-effectors come in. For every process where a robot is involved, one or more end-effectors are also involved. In most cases the robot performs a repetitive task such as welding or painting, and the end-effector is never swapped. But on others, the robot may have a multi-use end-effector which provides the workstation with more capabilities. This is mostly the case of multi-grippers, which, by means of machine vision, can be used to grip objects depending on their dimension or shape. Of course, the variety of shapes and dimensions it can grasp depends on the design of the gripper, as most of them are made by Computer Aided Design (CAD) to ensure the perfect geometry which, besides offering the appropriate grab, may only be useful towards that object in particular. Making it necessary to design another one if a different object comes into, for example, the conveyor line.

As most processes on the industry are studied in-depth to optimize the use of resources (being time the most critical one most of the times), it is common to avoid the use of multi-grippers as the time required for one robot to manage 2 type of resources is bigger than buying another robot and make it an equal ratio so each robot can handle one resource. Moreover, the design of these grippers can nowadays be approached by 3D printing (cartesian robot) and modified easily with the use of modelling tools and then reprinted again. With this, it is very easy to test and satisfy the factory line needs, always having in mind the physical properties of the gripper, as it may break, melt or even cause an electric failure if not insulated correctly.

On the other hand, robots which are not on the manufacturing robot’s calcification, do not have the same limitations or even requirements as the ones on the industry, where time, money and safety are key factors on the production line. Mobile robots, for example, may not have end-effectors, but just another device that acts went required (like a radar). Service robots can vary a lot, as the needs of the human vary a lot. A cleaner device just needs a vacuum and a spinning brush, but a kitchen robot may need a great variety of end-effector to perform adequately. Lastly, there are humanoid robots, which don’t have a general purpose but are applicable to many fields, from health caring to military purposes (which have always played an important role on technology development). These robots aim to mimic human motion and interaction, which besides being applicable to high risk situation where, can also be applied to tasks that have not yet been replaced by robots.

As an example, and a discussion topic, the handling of cables is a key concern in the industry. Cables deform easily can are hard to model, and this uncertainty of the movement of the cable makes the process different each time as the cables hardly are always on the same exact position.

2.3 Robotic Hands

Once highlighted the relevance of the last link of the chain, it is logical to think about which would be the best end-effector on the market. Of course, there is no ideal answer, as it always depends on the scenario and environment. If the operation is painting, it is clear a spray gun will fulfil the necessities, but when grasping objects there may be other considerations to it.

Humans are trained naturally since birth on hand coordination, without noticing the skill involved when touching, grabbing or even pressing. Its precisely this improvement of skill that makes the human capable of interacting with all type of shapes, the so-called dexterity. Dexterity involves the interaction of muscles, articulation and neurological functions to make precise movements in order to adequately place each extremity where desired. Certainly, human hand also performs other tasks that do not involve movement of the phalanges, such as measuring roughness or temperature. With all these capabilities it is natural to think the human hand is the ultimate end-effector, as it can do it all. From the automation side of view, the modelling of the hand with all its function is very complex, as there are too many variables to have in mind when mimicking the human hand. This is also a challenge to the research community and that is way it has been a research topic since the early day of robotics.

When tackling the robotic hand topic, dexterity, which was explained above, and anthropomorphism are two key concepts to have in mind. Anthropomorphism is a term used to represent how similar the object is to the human nature, in this case, to mimic fluently the hand movements as well as the shape and size, not just mimicking the positions the hand can get to. These two concepts do not need each other to achieve its maximum level, as a high dexterity may be achieved without the need of high-quality external properties. Therefore, dexterity is usually the main concern when approaching robotic hands. Nevertheless, anthropomorphism must be considered as it the resemblance with the human hand is, in some cases, very useful towards completing the task. For example, in human-oriented environments, where the tasks can be either performed by humans or robots, the interaction with the surroundings is designed in a hand friendly manner. Also, when considering interaction with other humans, it can be required to give the, for example assistance robot, a human-like aspect. Lastly, prosthetics must be mentioned, where both, dexterity and anthropomorphism are key in order to give the patient the right substitution. In order to value how anthropomorphic a hand is, three concepts are related to it:

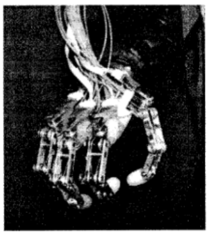
- The existence of the main phalanges of the hand (fingers and palm)
- The contact surfaces, as this is key when grasping
- Size, as it must resemble the human hand in as many physical ways possible

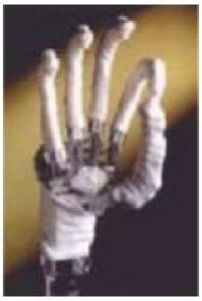
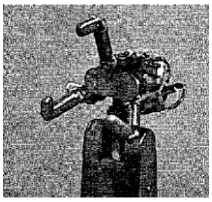
Obviously, some tasks do no need the full hand to perform while others need the resemblance but not the functionalities of all of them, it depends, of course, on the scenario. Multi-fingered robots have been in robotics since the early days, as the human itself has always found inspiration in nature. This approach has led from to the simple two-fingered end-effector to fully functional hands which are used nowadays in many applications. With the spectrum of robot manipulation applications widening, there is no doubt the use of robotic hands is the best alternative. Besides its use on industrial applications, it is also being applied on other fields such as services and household work.

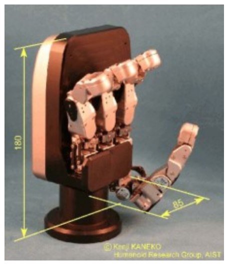
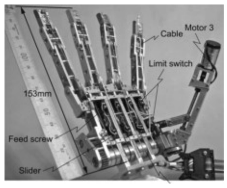
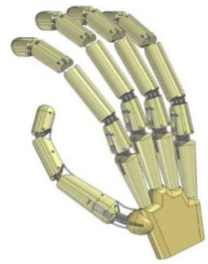
It is in rehabilitation applications where both dexterity and anthropomorphism must be on point, as the user must feel the prosthetic as close a to a real hand as possible. On the services field, familiarity is key. And, as humans are used to interact with other humans, the cooperation in between both must be comfortable for the human which is handling a shared object with the robot. A pause must be done here to name the use of collaborative robots (Cobots), where not only the similarities are physical, but these also have safety protocols (as well as safety pads) which act when a collision happens.

Table 1. *Historical review of some robotic hands [11]*

Name	Year	Fingers	Joints	Actuations	Image
Okada Hand	1979	3	11	11	

JPL Hand Standford	1983	4	9	9	
MIT Hand Utah	1983	4	16	16	
Barret Hand	1988	3	8	8	
LMS Hand	1998	4	16	16	
DIST Hand	1998	4	16	16	
Robonaut Hand	1999	5	22	14	
DLR-Hand	2000	4	17	13	

Karlsruhe Hand	2000	5	20	20	
Ultralight Hand	2000	5	18	13	
Gifu Hand	2001	5	20	16	
Shadow Hand	2002	5	23	23	
High Speed Hand	2003	3	8	8	
Universal Hand	2005	5	20	16	

Multi fingered Hand	2007	4	17	13	
Anthropomorphic Hand	2009	5	13	5	
UB Hand III	2010	5	20	16	

2.4 Manipulation Taxonomy

Since birth, humans train daily on their dexterity, as the hands are one of the basic tools to interact with the environment around us. This improvement of skill is afterwards required to perform specific tasks on the industry, as well as on day-to-day life. This human-level dexterity is achieved with 21 controllable degrees of freedom on each hand [11], which equal the same number as both arms, wrists and one together. With these characteristics and the interaction of muscles, nervous system and the neural network, the level of dexterity of humans is very sophisticated.

The research on the human grasp, has been essential on manual labour production lines, as the faster the operator performed the task, the faster the product went out of the factory. One of the most valuable contribution has been the study on how the task requirements relate to the objects shape in order to determine the grasp. For example, an egg can held with the index and thumb fingers, as to showcase it, but it can also be grabbed by wrapping all our fingers around it and pressing it gently into the palm, as a protective measure. This study has led to a grasp taxonomy, which has its seed on [12], where workers on the metal industry where watched and interviewed on the grasping techniques. Even though the study was mainly focused on single-handed tasks, it has been observed that two-handed tasks usually require the same grasps as the ones of single hand.

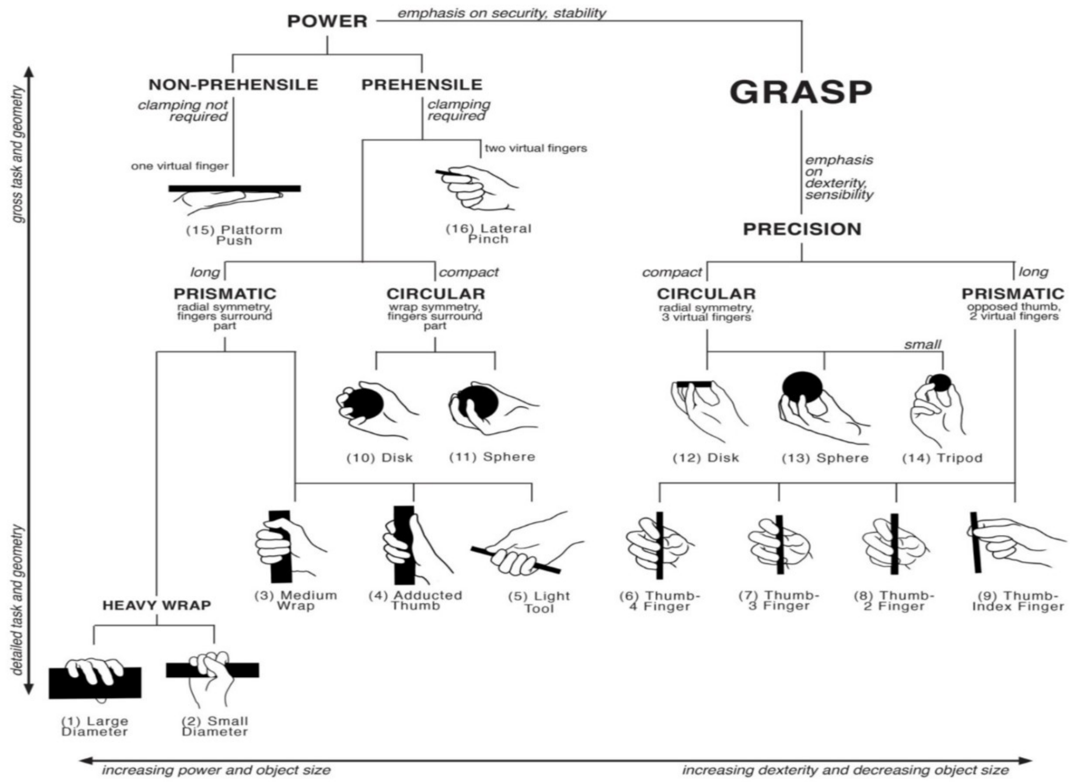


***Figure 11**. A Partial Taxonomy of Human Grasps [12]*

As stated on [13], there are 3 main concepts which can be also used to classify the grasp, these are:

- Power, Intermediate and Precision Grasps: which refers to the horizontal axes on Figure 11. The main idea was developed by Napier´s work [14] and advanced in [15] by Landsmeer who differentiated in between two main types of grasp, “precision handling” and “power grip”. In the power type the hand basically acts as a clamp in order limit the movement of the object. It this type there is a close relation with the arm movement as usually most of the movement of the object is done by the arm. Therefore, being a static grab, where the objects distance from any point of the hand is always the same. Intermediate grasps have been described in [16] as a mid-point in between both, yet the basics precise and power grasps remain as the basis in the dextrous manipulation concepts.
- Opposition Types: When securely grabbing an object, the force can be applied in three posture configurations [17]: Pad Opposition, Palm Opposition and Slide opposition. Pad Opposition happens in between surfaces that are parallel to the palm, and Palm Opposition when these are perpendicular. And Side Opposition when the contact surfaces are transverse to the hand.

- Virtual Finger: By definition, fingers belong to a virtual finger if they act in synergy or apply forces on the same direction. This concept is illustrated on Figure 14 with the examples of Opposition Types included.
-

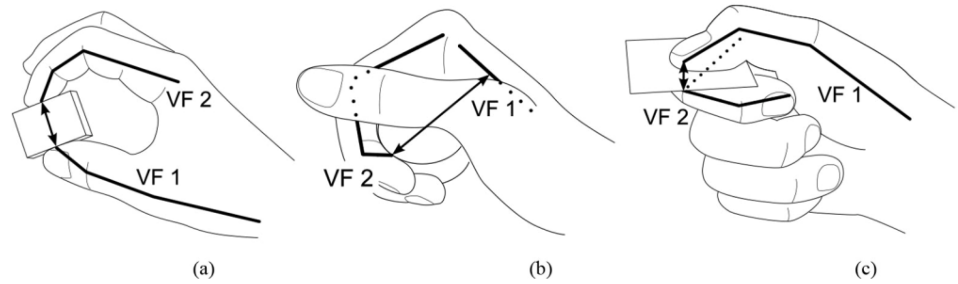


Figure 12. *a) Pad Opposition. b) Palm Opposition. c) Side Opposition [13]*

Besides this classification, there are also some basic terms which are relevant on the manipulation taxonomy field by describing the way the hand interacts with the external objects. These include Contact, Prehensile, Motion, Within hand and Motion of Contact. These terms belong to [11] and are briefly explained by Figure 15.

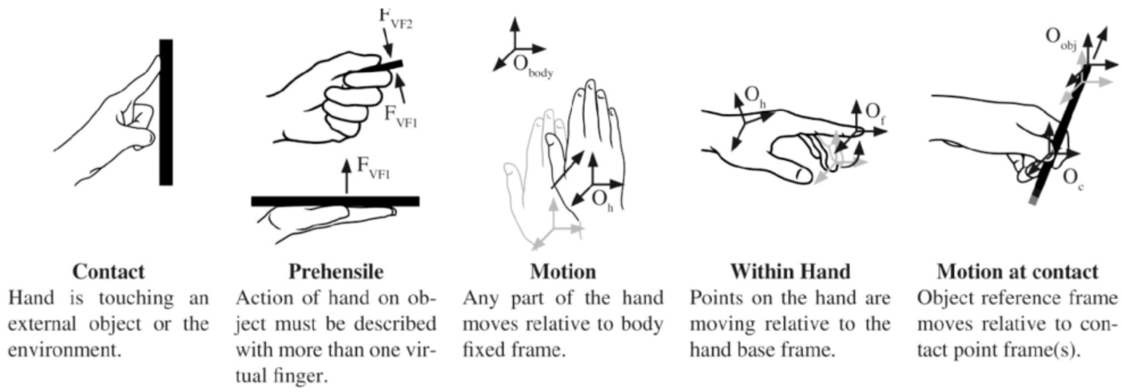


Figure 13. *Example of terms in taxonomy* ***[12]***

The definition of these terms favors the creation of a manipulation taxonomy tree based on them.

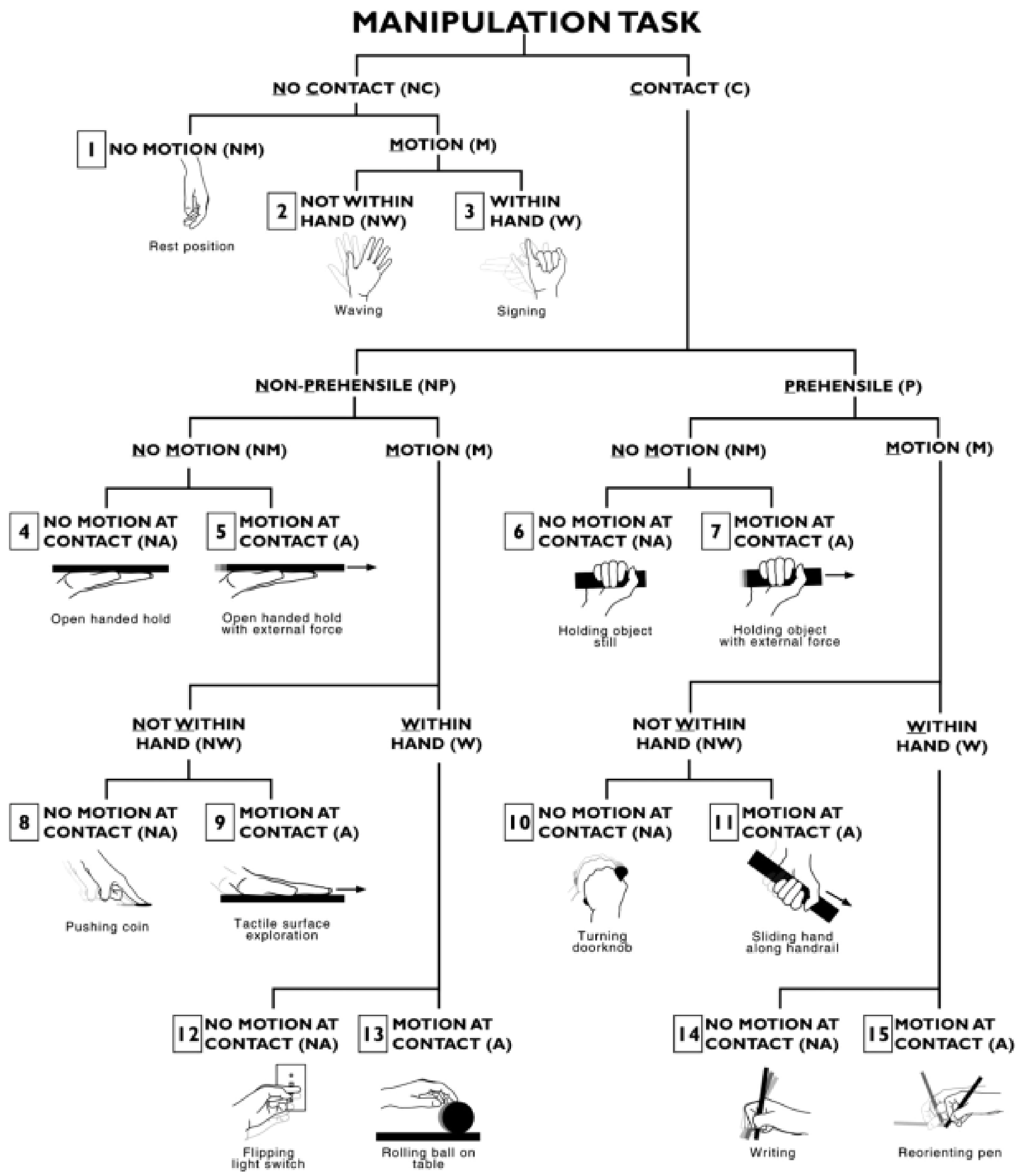


***Figure 14.** Task Classification according to [18] (Source: [12])*

When applying robotic hands in manufacturing, dexterity was debated as a feature on factory floors that would reduce times and also decrease the use of custom equipment in assembly tasks, [20] and [21]. Where the most dexterous hand would be able to fulfill the a wide variety of operation in the factory environment. Wright [21], also managed to present a comparation in between various operators' dexterous capabilities as a way to correspond different operators with different dexterous tasks. Afterwards, Okamura (in collaboration with Cutkosky) noted [22], once he had correctly studied the environment with its planning strategies and physical parts, that dexterous operations required a transition in between grasps, thus extending the kinematic limits of the system.

In order to model the grasping of objects, many concepts must be analyzed. The figure below shows how Cutkosky most relevant factors when modeling the grasp.

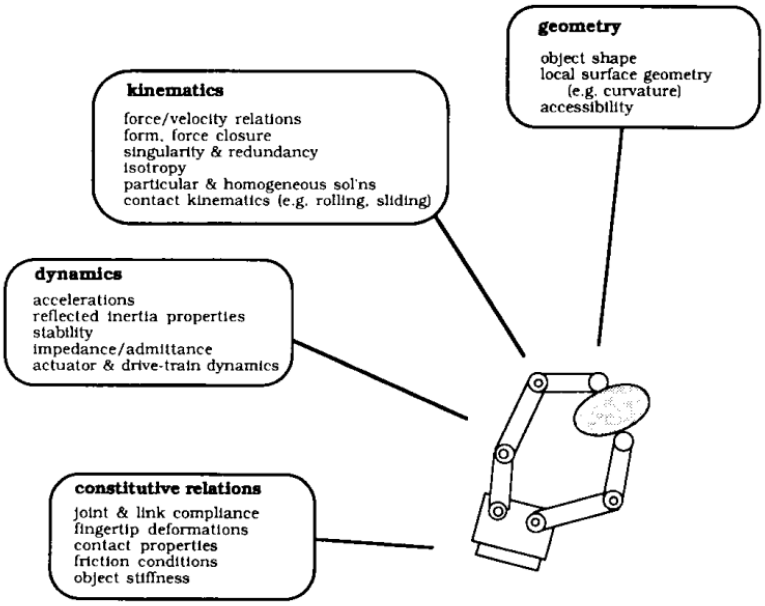


Figure 15. *Issues in the modeling of grasping and manipulating [23]*

In addition to the issues on Figure 17, the contact circumstances must also be studied, as the gripping involves how soft or elastics the object/fingertips are as well as the drivetrain and the actuations used in order to grab. To keep the analysis tractable, Cutkosky made the next considerations, which are also considered in current analysis of dexterous manipulation:

- Rigid-body models with only contact points
- Linearized Kinematics
- No inertial or viscous terms involved
- No sliding or rolling of the fingertips
- No redundant Degrees of Freedom (DOM > DOF)

In order to qualify the grasping, Cutkosky also introduced some quality measures that include [23] : compliance, connectivity, force closure, form closure, grasp isotropy, internal forces, manipulability, slipping resistance and stability. These measures describe the properties of the grasp, but do not entirely suitable for all tasks, as the placement of the object is key, as not al surfaces of the object are reachable (they may be in contact with the surface the object is standing on). This constrain, besides others can be shown of the next Figures 18, [23].

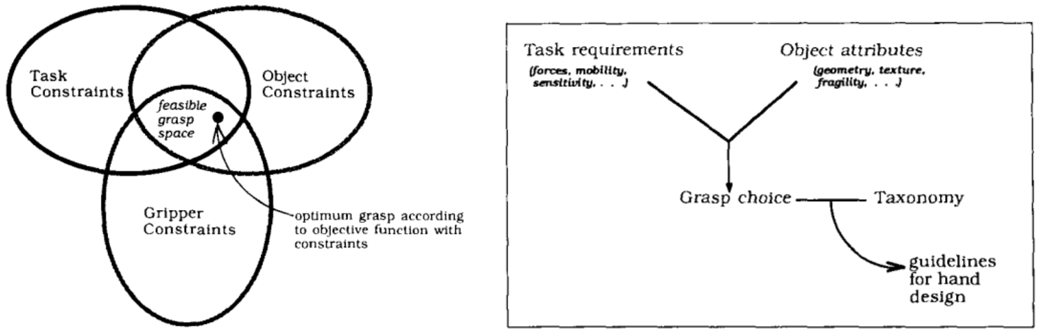


Figure 16. *Grasp selection depending on task object and gripper constraints and task attributes to decide grasp choice [22]*

This study by Cutkosky was preceded by ones Schlesinger [24] (1919) and Napier [15] (1956). Where Schlesinger categorized grasps into six types, which where cylindrical, tip, hook, palmar, spherical and lateral while Napier divided, not as much as Cutkosky did, into precision and power grasps, but some grasping techniques where no clearly defined.

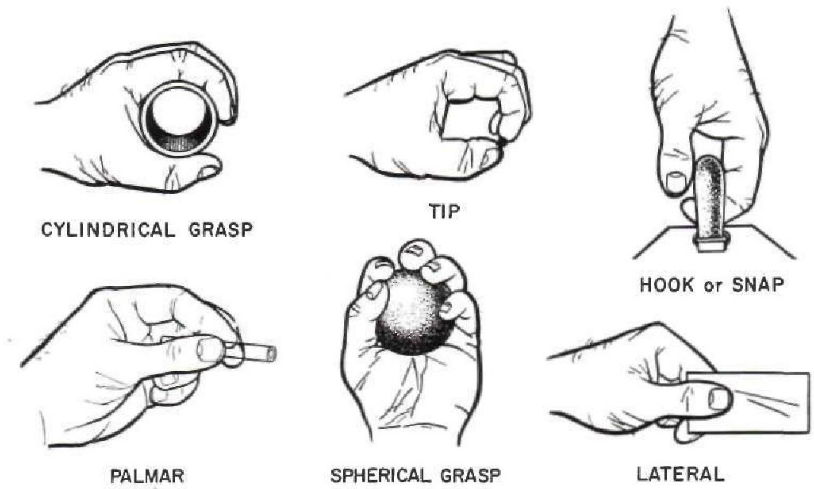


Figure 17. *Schlesinger grasp types [24]*

3. APROACH

3.1 Proposal

As the industry searches, via automation, for new approaches towards a more efficient work plant, Universities also aim to add some value to them, as well as to the research community. Most of the times there is a cooperation between the University and the company which provides any possible help to the research group to ensure a step forward towards the common goal.

Nevertheless, there is not always the need of the backup of a company to advance on a topic, in this case Humanoid Hands. For such research a space is needed at the university.

The FAST-Lab (Factory Automation Systems and Technology Laboratory) is located at the Tampere University of Technology and its purpose is to help the student community learn the basics of Automation, as well as the more complex and up to date methods with a various types of equipment including some recent acquisitions.

3.1.1 Humanoid Hand exploration

This Master Thesis starts with the initiative of the Automation Department for the research on the Humanoid Robotic Hand and its capabilities. As stated previously on the document, new horizons are opening with these end-effectors which can “mimic” the human hand and its movements.

It is here where the exploration starts. As a recent acquisition, the FAST-Lab obtained two new Humanoid Robotic Hands (AR-10). These end-effectors, which will be explained in detail afterwards, serve as the ground for future development of the topic as not all the Humanoid Hands that where researched are connected or even work the same way. In this case the hand movement is performed by servo motors and has 10 degrees of freedom (two per finger).

3.1.2 Programming Services

In order to give a utility to this end-effector, a programmer need a basis from where to start. Disregarding how the hand is physically connected, there must be a way in which the movement of the hand relates to the written code.

It is here where Web Services come into play. Using a RESTful approach, this Master Thesis provides aims to provide a set of services/methods with which a programmer can adapt the hand to the required task. To approach this, the hand must be modelled to give a more approachable way of communicating, not only with a servo, but also with any finger or the whole hand.

3.1.3 Implement on FAST-Lab

A key factor on the selection of the topic of this Master Thesis has been the future use of the humanoid hand on the FAST-Lab. Not only because of the interest on new methods on the industry, but also for a recent partnership on a research which tackles the jobs done on the industry with human labour due to their dexterity with the fingers.

Of course, the humanoid hands must be attached to a robot that provides that right orientation, as the hand is just the last step of the process of grabbing. Here, the importance of the three arm joints (shoulder, elbow and wrist) must be highlighted when approaching an object, as it can be grabbed in many ways but with the aid of the joints the task of grabbing eases very much. As well as the importance of the arm, depending on the tasks, it is also relevant the interaction with other hand, as the big scope objective of the industry is to replace the tasks performed by humans with automation.

Therefore, the acquisition was made for two hands, so that tasks involving both can be approached, and, with means of the existing Yaskawa Dual-Arm robot, attached to the end of each arm to have a complete robot for future research.

3.2 Scenario

In order to give a visual representation of the proposal, a use case diagram has been developed to show the basic relationships between the user and the robot via an HMI which is controlled by the user.

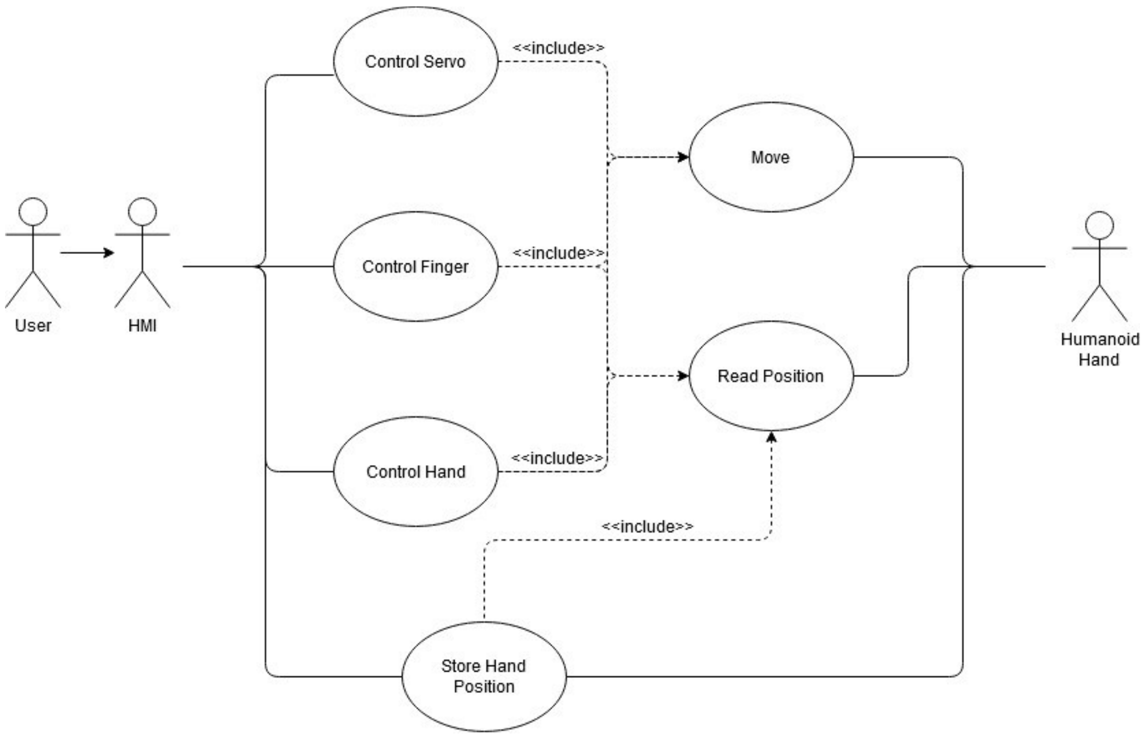


Figure 18. *Proposal Use Case Diagram (Own Source)*

As illustrated above, the user deals with the HMI to afterwards send the desired commands to the hand. This can be done just to one servo (which represents one of the two phalanxes of the humanoid hand), a whole finger or the full hand.

To approach this, an object-oriented approach was taken, not only because it is a topic covered on the Industrial Informatics course of the Automation Department, but also because the physical constitution of hand favours its use due to sublevels of the hand (phalanxes, fingers and hand).

Of course, these are also sub-levels of the bigger scope. As the hand is intended to be attached to a robotic arm which also provides the wrist, elbow and shoulder joints which, as stated previously, provide the right orientation for the grasping of the object. This need to seek for the right orientation is not tackled on this paper thus the main focus is the programming and implementing of the hand on the laboratory and to test the capabilities it offers.

To provide the reader with a more graphic approach to object-oriented programming, a Class diagram is shown below with the relationships between the 3 different classes, besides the attributes and methods of each one.

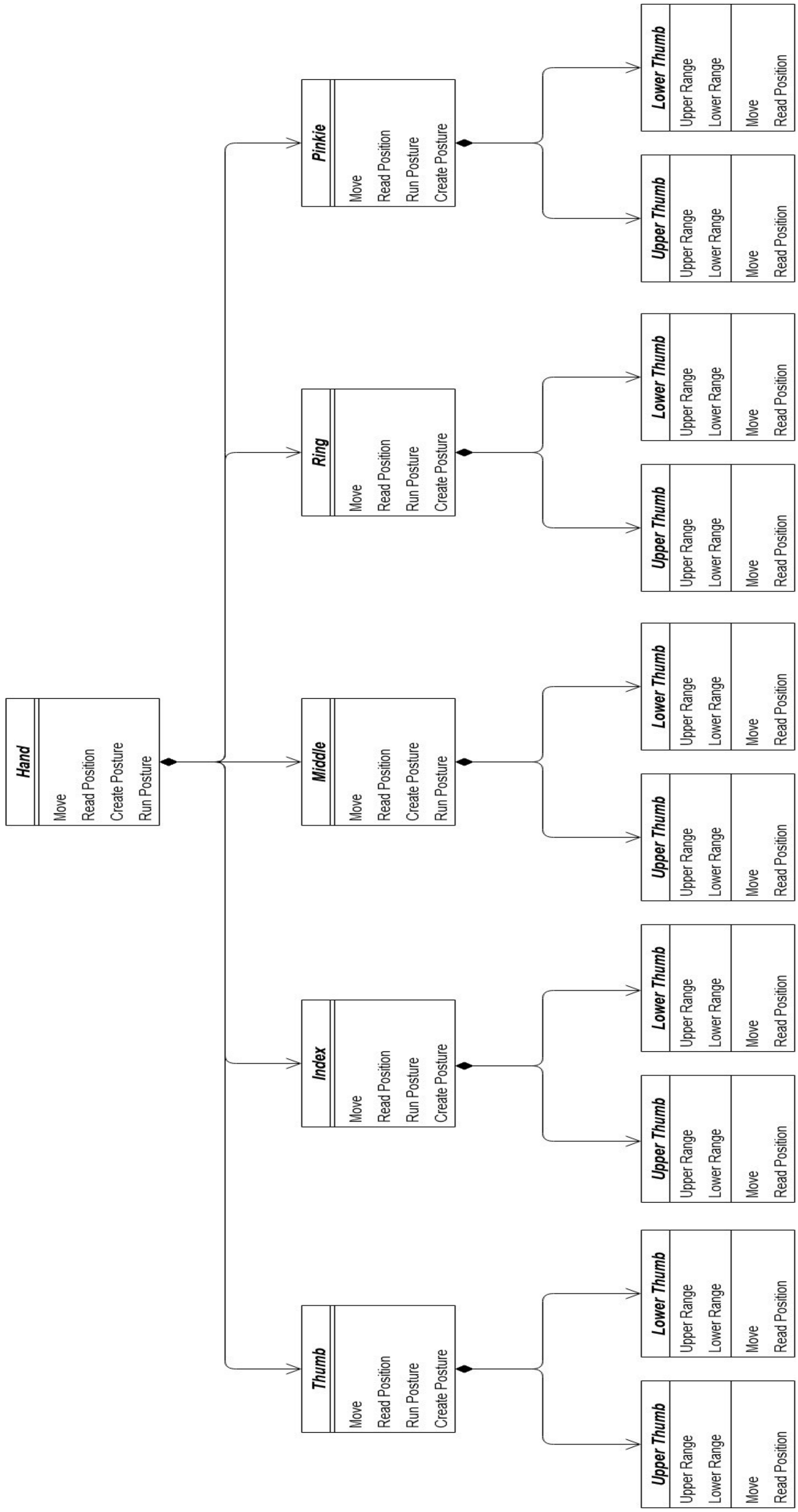


Figure 19. *UML Class Diagram (Own Source)*

4. IMPLEMENTATION

4.1 Humanoid Hand (AR10)

First item to be assessed in the implementation of humanoid hands on a robot is the physical end-effector itself. It is also key to evaluate the scenario and the purpose of the hand. In this case, this Master Thesis is part of the development of the FAST-Lab as well as a tool to communicate and use hand alike end-effectors that lead to future researches.

For this purpose, the selected model was the Humanoid Robotic Hand AR10 (produced by Active8Robots). The model is mainly meant for educational and research purposes, as, besides having a strong structure it is not as robust as industry end-effectors, and, furthermore, it only offers two servo motors per finger. Not mimicking the full mobility of the hand, thus it lacks the fingertip phalanxes.

Figure 20. *AR10 Humanoid Hand [24]*

As seen on the image above, the model significantly resembles a human hand. Its movement is performed by 10 prismatic servo motors which are controlled by a microcontroller powered by a DC-DC Step Down Regulator placed at its base. The fingertips are 3D printed.

Each 6V actuator (Firgelli PQ) incorporates a linear potentiometer and a controller that makes it operate as a linear servo, and each one of them is connected to the controller board with a 4-wire ribbon cable.

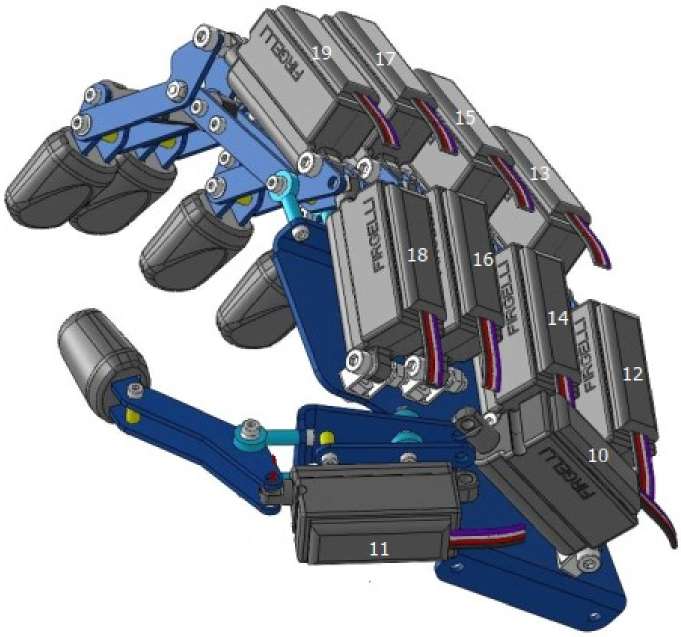


Figure 21. *Back view AR10 Model [24]*

The managing of these actuators can be done either via USB cable, Serial communication or internal scripting from the microcontroller, even though the first time, the hand must via initialized by USB connection. All of this is done by the Pololu Maestro Mini 24 USB Servo Controller (seen below), which is a commercial controller board commonly used in mechatronic projects.

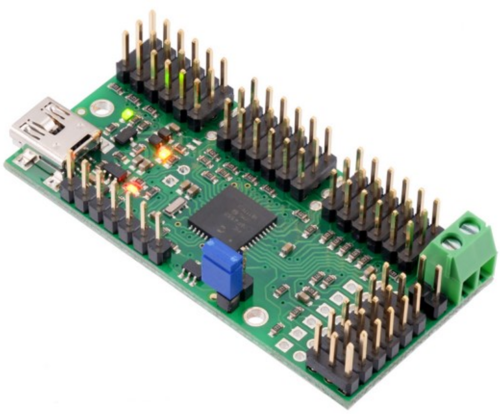


Figure 22.*Mini Maestro 24-Channel USB Servo Controller [25]*

4.1.1 Maestro Control Centre

First contact with the hand is done via USB and supported by the Pololu Maestro Control Centre which gives the programmer an HMI to configure the servos in real-time and modify its settings, as well as basic testing of the fingers. This software can be run in both Linux and Windows, in this case it is applied on windows thus it's the most commonly known operating system used at teaching facilities and also to ensure that future uses of the hand will not need the knowledge of Linux and, therefore, ROS (Robot Operating System).

With the Maestro Control Centre installed and the power inputs connected, a first look can be done on how the hand works. Each servo motor has a range of motion which is set by the upper and lower target limits, which differ for the upper and lower phalanxes of the hand. While testing these limits the hand experiences some stuttering when reaching the maximum and minimum target. This is taken into consideration at the object-oriented programming done on the next chapters by reducing the range of motion of the hand. Even though it decreases the capabilities of the hand it provides a more reliable working when setting the target.

To identify where each servo is on the hand, a channel is assigned to each servo and named accordingly. From now on the channel numbers will be associated with the following parts of the humanoid hand:

Table 2. *Right Hand Channel-Phalanx references*

Right Hand

Channel	Phalanx	Channel	Phalanx
10	Lower Thumb	11	Upper Thumb
12	Lower Index	13	Upper Index
14	Lower Middle	15	Upper Middle
16	Lower Ring	17	Upper Ring
18	Lower Pinkie	19	Upper Pinkie

4.1.2 Serial Communication

Even though the Maestro Control Centre is a great tool for verifying and get to know how the equipment works, it is not on the interest of this Master Thesis to rely on this provided HMI to make use of the hand. The path followed to communicate and, therefore, actuate the hand is going to be serial communication.

The serial communication on the microcontroller is based on binary pulses on TTL (5V), where 0 volts represent the low state (0) and 5 volts the high state (1). Its transmission mode is Full Duplex, which allows simultaneous communication in between the devices by means of the RX (Receiver) and TX (Transmitter) inputs. To adequately use the serial communication some factors must be considered, such as the Baud rate and the data format. The first one is the speed at which bits are transferred from the sender to the receiver, either by the RX or TX channel, measured in bits per second (bps). The data format has a start bit, then 8 data bits followed by one stop bit.

The receiving line, RX, performs as a non-inverted serial, as the line has an idle (not active) state of high, so the start bit is always a low state bit followed the stream of data bits which start from the LSB (less significant bit).

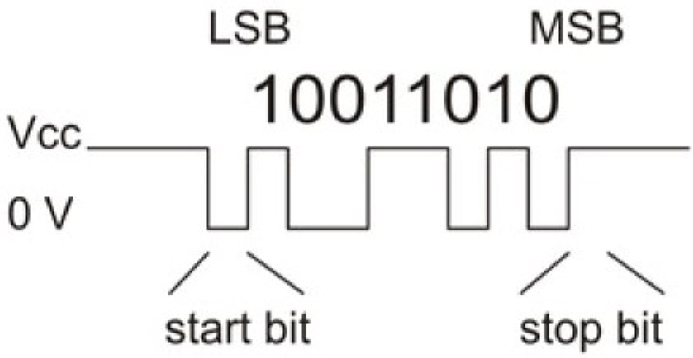


Figure 23. *TTL non-inverted data format [25]*

These packets of data must be sent following a protocol, which, in this scenario is going to be “Compact Protocol”. Which has the following command packet:

Command Byte succeeded by the necessary **Data Bytes**

This protocol and its commands are referenced in “Pololu Maestro Servo Controller User's Guide Chapter 5”.

4.2 Remote Terminal Unit (S1000)

The election of the communication method was due to the availability of RTUs on the laboratory. These devices offer many useful features that make the task of interconnecting the hand with the FAST-Lab communication network easier.

The remote terminal unit in hand, Inico S1000, offers, besides 8 digital I/O, 4 analogue inputs and a CAN port, an RS232 serial port with user programmable protocols to send and receive data from the receiving and transmitting serial lines (RX and TX). As the S1000 also has an embedded Program Logic Control Centre, the data from the serial lines can be accessed by built-in functions supported by an IEC61131-3 Structured Text editor and compiler.

***Figure 24**. Inico RTU used in the research (Own Source)*

With these capabilities, the RTU is used as the Maestro to send commands to the hand without the need of the Pololu HMI provided by the manufacturer and getting rid of the need of a PC. As the Inico S1000 also features communication via web services by with which the logic can be executed remotely, in this case via REST.

To connect the hand with the RTU, 3 cables where dragged from the serial ports of the Inico to the opposition serial pins of the hand. The ground cable (GND), which is connected to the GND pin on the hand, and the receiving and transmitting cables which are connected to the opposite pins in the hand Thus, in serial communication, the receiving line of the device must be connected to the transmitting one of the other, and vice versa.

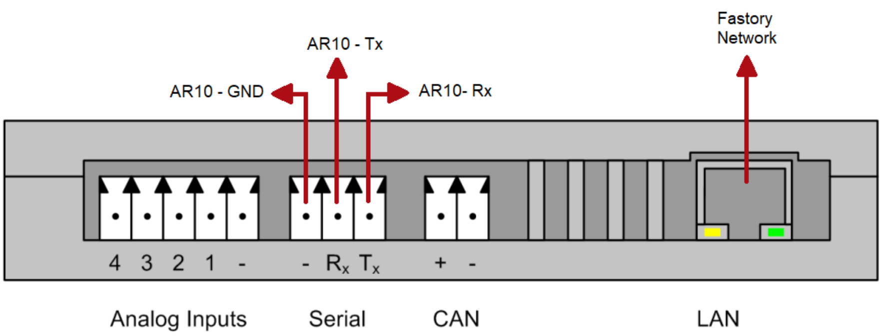


***Figure 25.** Inico S1000 inputs/outputs [26]*

To adequately configure the Serial Ports of the RTU some considerations must be made as the hand's microcontroller has to match the configuration of the Inico S1000. The configuration is as follows:

- Port number: COM0
- **Baud rate**: 9600 bps
- Data bits: 8
- **Parity**: None
- Stop bits: 1
- **Protocol type**: Custom - ST

Once there the parameters are set. The Logic of the RTU can be approached. This logic follows the IEC61131-3 standard. This standard has four programming languages used on the automation industry: Instruction List (IL), Structured Text (ST), Function Block Diagram (FBD) and Ladder Diagram (LD). In this case the device offers Structured Text as the way of programming as it doesn't involve any graphic way of programming and provides a very similar working as in "C" which usually has been taught as a basis in programming.

This language supports BOOL, INT, DINT, REAL and STRING variables that must be declared outside of the program where they are used, on Global Variables, if their content is going to be sent or received by the serial ports. Once cleared the programming parameters, the necessary variables are defined and corresponding ST programs are made to test in which way the bytes must be sent (either binary, hexadecimal or decimal). To achieve these two supporting programs where used: Pololu Serial Transmitter and Putty. With them, the correct functioning of the Logic and serial ports was confirmed to finally connect the hand, without the use of web services, and create a loop which triggered the hand to move the index fingertip up and down indefinitely in a scratch similar motion.

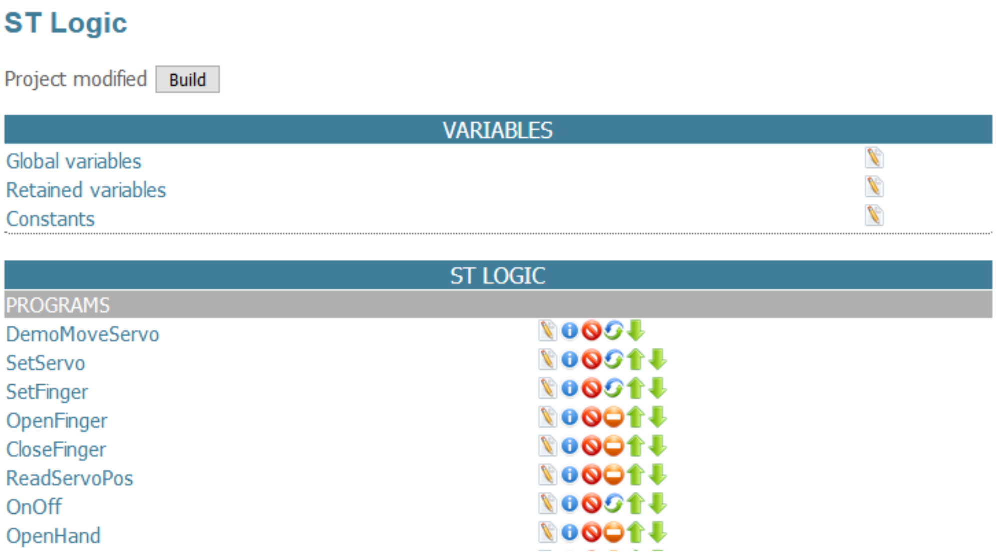


Figure 26. *RTU Logic Tab (Own Source)*

4.3 REST API

With the already functioning RTU serial connection, focus must be placed on how and when the ST programs, and therefore the interaction with the hand's microcontroller, must run. This is done via Web Services and, even though the Inico S1000 provides SOAP features, the development of the APIs is going to be done with REST.

These APIs are used in the Object-Oriented Programming to provide the basic methods of the hand. These methods then use the APIs as a way of communicating in between the programmer and the hand. The OOP was considered due its advantages, thus, by allowing to create classes, the code can be used on either right or left hand.

As stated on the previous chapter, the AR10 is composed by ten servos, two per finger. With this configuration the following classes where made: Servo, Finger and Hand. The Servo Class is the basis from where the Finger Class and Hand Class are created. But when creating a servo, the physical position of it must be considered, as not all the servos have the same upper and lower range.

Table 3. *Servo Ranges*

Phalanx	Upper Range	Lower Range
Upper Thumb	7500	5000
Lower Thumb	7500	5500
Upper Index, Middle, Ring and Pinkie	7500	4500
Lower Index, Middle, Ring and Pinkie	7500	5100

These ranges have been reduced from the limit ones as the movement on the final path is not as smooth as on the mid-range of the hand. With the already created entities (upper and lower phalanxes), the formation of the Finger Class and Hand Class are done and provided with the elementary commands of them. As for the numerical approach of how the movement is done, the election was a percentage in absolute step (e.g. 25 %). Knowing the different ranges of each servo, a relationship is calculated by which the entered percentage relates to corresponding target in between the upper and lower range which is afterwards (if the method used is "Servo.ServoPos(%)") sent via Web

Services to the RTU which applies the corresponding ST program with the sent values (in JSON format). And same is performed vice versa, where (when retrieving the position) the RTU constantly is constantly running a program which sends requests to the AR10 servos than store the values of the corresponding positions and, when requested by a GET method, respond with their corresponding position in a binary format, which is afterwards translated into percentage. The next diagram showcases the communication in between the devices.

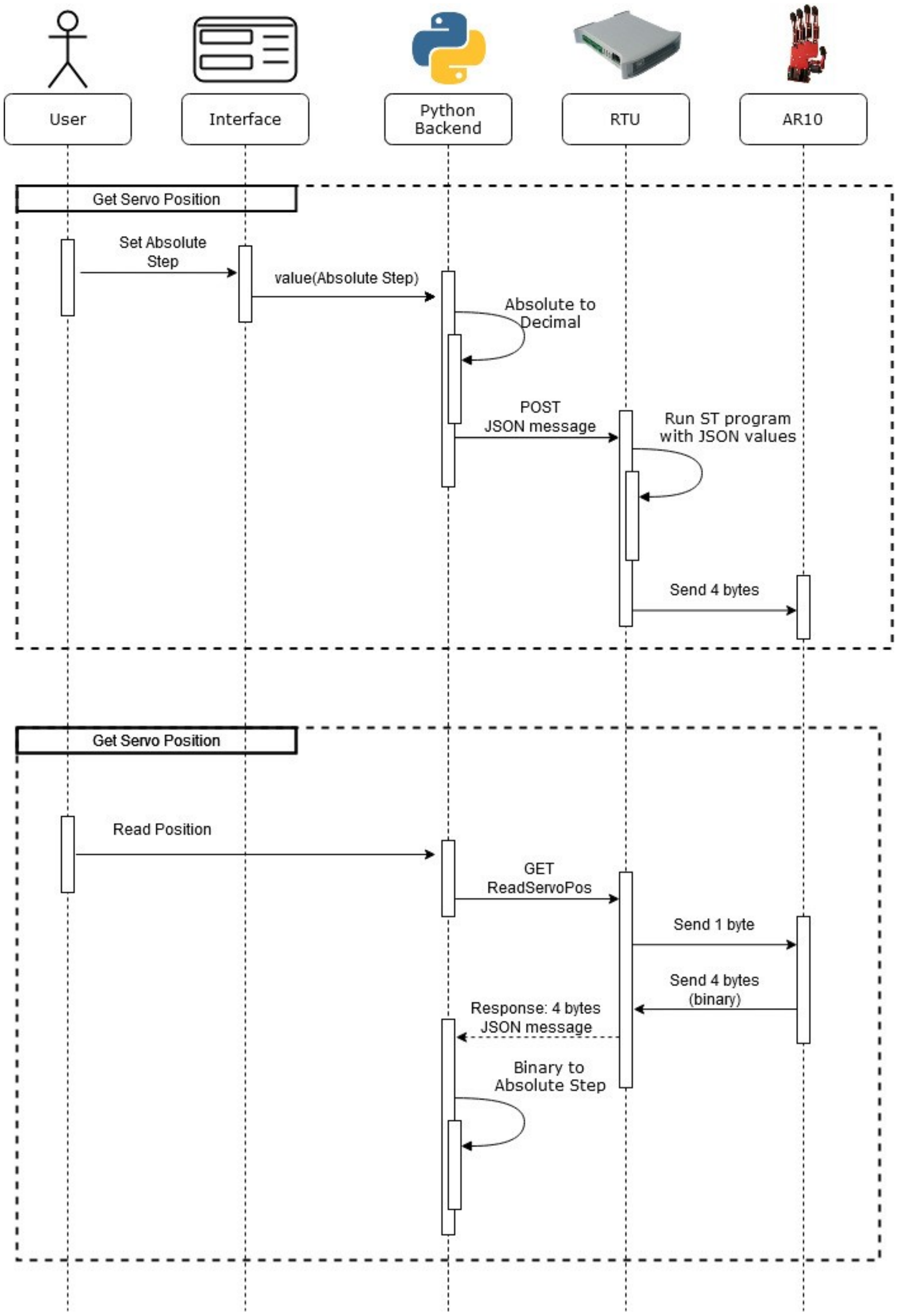


Figure 27. *Sequence Diagram (Own Source)*

4.4 Interface

To showcase the services the hand has been provided with, and with the use of Flask, a server has been created in the localhost and an interface created to interact with the hand.

This interface makes use of the created function to open or close the hand at its range limits, move each individual finger to the necessary position (in absolute step), move all of the fingers at the same time to the targeted percentage and to independently move one servo at a time to get the final hand position which can be saved and, afterwards, retrieved. This interlace has been created with HTML and connected with the Flask via POST methods to various URLs defined on the application.

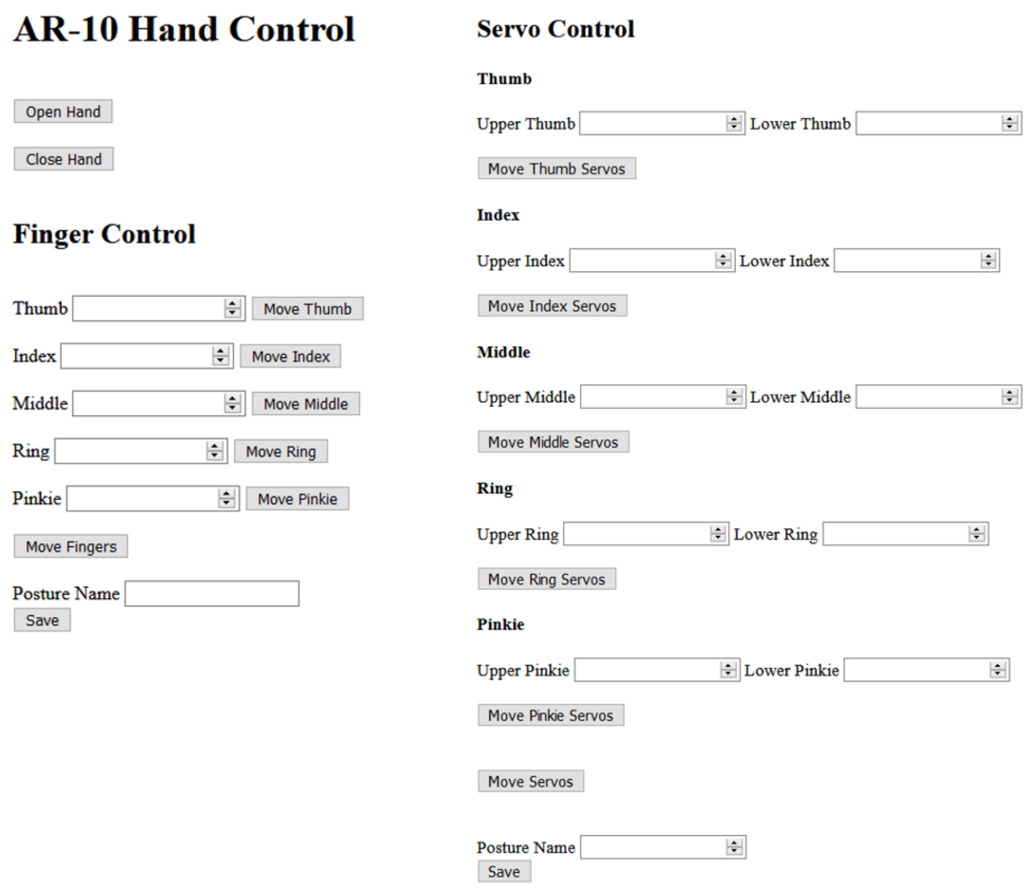


Figure 28. *Interface (Own Source)*

5. CONCLUSIONS

Robotic hands, as well as human manipulation techniques, have been researched and merged in many studies in order to provide many fields, such as manufacturing or prosthetics, with new equipment and skills to perform tasks that were previously performed by humans. Each case differs from each other, as there is not always the need to achieve full grasp taxonomy hierarchy. In any case, the scope the full five fingered robotic hand provides is still in development, and new designs are coming into play.

This thesis, by means of the AR10 - Active8Robots robotic hand, has researched on the hand's capabilities. For it, background literature has been reviewed, with the aim of having the right criteria and knowledge on the topic. The hand has been tested in the grasp taxonomy tree (Figure 11) with some modifications on the hand orientations (fingers facing up) as it was not attached to a robot itself. Even though it reaches most of the positions, it does not provide enough proof of the stability of the grasping, as when having gravity against it, the amount of friction involved on the points of contact gains relevant value on the whole approach. Therefore, the dependency on a robot is key. The orientation at which an object can be reached hugely determines what grasping taxonomy must be used.

These points of contact are a matter that must also be explained. As the "Pad Opposition" concept explained on the Literature review can never be achieved. The robotic hand offers no distal interphalangeal joint (the joint just before the fingertip). This joint plays an essential role on precision grasps, as the detail and dexterity needed on the orientation of the fingers a main technique to increase the area of contact plays a huge role on the task. As for power grasps, there are some limitations in terms of the size of the object it can grab, as the links of the hand (phalanges) have mechanical limitations to them. Moreover, as there are no distal phalanges, the grasps mostly depend on the pressure done amongst it by the possible plastic fingertips that are in contact and the metal plates of which the fingers are made of. These materials, are no ideal in order to avoid sliding or rotating, making the AR10 rely mostly on the power exerted on the object and the position of the fingers in order to balance it.

The implementation of the hand, with the use of the Remote Terminal Unit and the serial communication has been a good approach al around. The RTU allows the hand to receive commands from any request directed to it on the network, without this actor in the process there would have been need of the USB cable which, even though it is an evolved method of communication unlike serial communication, it had many approaches towards it (RoS for example). With serial communication being an option and the available RTUs at the laboratory, the path was clear when the project started, and it has worked successfully.

The object-oriented programming was not always in mind, as the initial way of action was to add some services to the hand by programming it according to its channel numbers, which vary from one hand to the other. It was here were the advantages to OOP came to mind. Of course, the project was going to be implanted on real-life scenario and, as the concepts of the object where nature based, the way to go was to encapsulate each phalange into its finger and then hand. By using this method, the code can be reused to the other hand and therefore, accomplishing reusability. It is also good to notice that, by taking this approach, the structure of the code avoids redundancy as to send a command to move a finger, there will be a reference to the code when servos, reducing the length and complexity of the code, making it easier to understand, use or modify by other programmers with no need of having a high knowledge.

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