A REVIEW ON HUMAN ROBOT COLLABORATION AND ITS APPLICATION IN THE HEALTH CARE SECTOR

Final work of the master course of study to get the academic degree “Master of Science in Industrial Engineering”

by

Jon Irujo Aizcorbe

from

Pamplona, Navarra, Spain

The topic was elected from the subject “Human-Robot Collaboration” and done at the faculty of Industrial Engineering of the Hochschule Niederrhein in Krefeld

First Examiner: Prof. Dr. Engineer Hans Buxbaum

Second Examiner: Engineer Sumona Sen

Summer semester, 2020

Acknowledgements

First of all, I would like to thank the professors of the faculty of industrial engineering at the University of Niederrhein, Sumona Sen and Hans Buxbaum, for the attention and understanding shown throughout this unusual semester. Despite not having been able to develop the research project in the university's laboratories expected for this Master Thesis due to the coronavirus pandemic, thanks to the interest and total availability of Sumona, the development of this final work has been very enriching and rewarding.

I would also like to express my gratitude to all the staff of the international student service of the Hochschule Niederrhein who have been willing to help me at all times, solving doubts, taking an interest in my situation and making me feel at home.

I must not forget to thank my cousins Maite and Sara, and my girlfriend Laura, the three nurses, for their collaboration in this work. They have given me ideas and shown me some of the needs of the health sector. I must also thank my cousins Ana and Toño for their help with the language.

I would also like to thank all the volunteers who have participated and shared in the survey.

Finally, I am deeply grateful for all the support received throughout this semester from my family, I thank my parents for the unconditional support, which they have not only given me during this semester, but throughout all the years of study, I thank my sister Maialen who has helped me a lot in this work and I also thank Laura who has always been there when I have needed her.

CONTENTS

FIGURES

Fig. 42 Appearance of the robots 73

GRAPHICS

1. ABSTRACT

Europe is usually named as “The Old Continent”, and looking at the demographics, the nickname is starting to become a reality. The population in Europe is getting older. In 1950, only 12% of the population was over 65 years old. Nowadays, the proportion has doubled, and projections show that in 2050 more than 36% of Europe´s population will be over 65 years old. In the next ten years around 30% of the population in Germany will be over 65 years old, and eight percent will even be over 80. In Spain the same trend will follow, the population over 65 years old, which is currently the 19,2% of the total population, will reach 25,2% of the total population by 2033.

It is therefore predictable that the number of people in need of care will increase rapidly. Today, what still seems like dreams of the future and provokes fierce ethical debates will probably become an integral part of our social reality: the use of robots in health care. One circumstance that makes this development even more probable and which is hardly mentioned in the current debate is that the health care industry is particularly affected by the consequences of demographic change in two ways. While the number of people in need of long-term care is rising, fewer people are choosing to enter the nursing profession; at the same time, older nursing professionals are leaving hospitals and nursing homes early due to the high physical and psychological strain.

Healthcare robots are intended to support and relieve the workload of nursing staff. They bring medicine, food and beverages to the sick and elderly patients, help them to lie down and stand up or alert the emergency services. Although health care robots are currently in most cases prototypes, they are an important issue in politics, society and science.

The development of health care robotics benefits significantly from the knowledge and experience of industrial robotics, in particular, human-robot collaboration (HRC) systems can be transferred.

Industrial robots have been used in production worldwide for four decades. Their significance for our current production systems is immense and the industrial sector would not exist as it is without them. However, the general idea of these systems is characterized by powerful mechanical constructions that perform tasks with high speed, enormous power and special accuracy that a human worker either do not want to perform for ergonomic reasons or simply cannot perform with such precision. Such systems, which usually do their work behind fences and without any human intervention, are not suitable for healthcare applications.

A new category of robots, the so-called cobots (short for collaboration robots), has been developed recently. Cobots are designed to work together with humans. Of course, such an HRC only works if cobots may act in a common working environment instead of being locked up behind fences. Complex tasks that can neither be economically nor technologically fully automated could be broken down into subtasks that are partly

performed by humans and partly by robots. For example, a cobot in an industrial application can hand a component to the worker for assembly, or the cobot can powerfully and precisely insert a component selected and tested by the worker to be assembled.

Since these systems are designed for safe cooperation with people, they are also conceivable for applications in the health care sector.

This master thesis aims to show that it´s possible to take advantage of all the advances, and development of HRC in the health care sector. Although most of this advances and development have taken place in the industry sector the aim is to show that there is a way and many reasons to use them also in the health sector.

It´s about finding out why the HRC hasn´t been implanted yet in the health sector, which are the problems that arise, whether they are technical, security or ethical issues.

The characteristics of cobots will be described, a review will be done about different issues considered of interest for the present paper such as human factors, situation awareness, safety and robot acceptance.

Then, HRC will be looked at from the perspective of the healthcare sector. First there will be a review of the state of the art of robots in this sector, the term “Healthcare 4.0” will be introduced establishing a connection with “Industry 4.0”. The following is a brief description of the current situation of the health system due to the coronavirus crisis and focuses on this crisis as an opportunity to introduce the HRC in the health sector showing that it could be of great help. Two possible applications of HRC will be described to illustrate this.

Finally, attention will be paid to the restrictions that arise when it comes to implanting robots in the health sector, because, if they could be so helpful, why are they not yet implanted? Security reasons will be mentioned, but particular attention will be paid to the ethical dilemmas that arise when introducing robots in the health sector. A web-based survey will try to clarify this kind of ethical dilemmas. The survey consists of questions on many of the topics discussed throughout this work. And by analysing the answers, conclusions will be drawn to help in dealing with the ethical dilemmas that arise when introducing collaborative robots into the health sector.

Altogether, this Master Thesis explored the Human Robot Collaboration in the healthcare sector, its restrictions, its opportunities in different applications and its acceptance by society.

2. INTRODUCTION

2.1. HISTORY OF ROBOTS

Karel Capek in 1921 introduced the notion and the term robot in his theatre play Rossom's Universal Robots. The word robot comes from the Czech word ''robota'', meaning ''labour''. In this theatre play, robots looked like humans and were far more efficient in what they did than their human counterparts. In fact, in this play the robots eradicate humanity. As will be discussed later, even if it is only a play, the image of robots potentially contributes to society's distrust of them, as it does in films such as Terminator or Matrix. However, there are also more friendly versions of robots, like in the Star Wars saga with C3PO and R2D2.

Later, in 1942, Isaac Asimov inspired by Capek's works defined the term ''robotics'' and wrote his famous Three Laws of Robotics in his books *Runaround and I Robot*. The laws are:

- A robot may not injure a human being or, through inaction, allow a human being to come to harm
- A robot must obey the orders given it by human beings except where such orders would conflict with the First Law
- A robot must protect its own existence as long as such protection does not conflict with the First or Second Laws

Although robotics is a relatively new term, autonomously operated machines can be dated from 400 BC when Archy-tas of Arentum developed a steam-driven, self-propelling wooden bird capable of flying 200 m. However, the first robot that imitated human movements of the jaw, arms and neck was designed by Leonardo da Vinci in 1495 and was named the Metal-Plated Warrior (Fig. 1) (Kalan et al, 2010).

Fig. 1 Metal-Plated Warrior by Leonardo da Vinci (Kalan et al, 2010)

This invention served as an inspiration to Gianello Torriano, who created a robotic mandolin-playing lady in 1540. Later, the robot called ‘’The Writer’’, developed by Jaquet-Droz in 1772, was the first one with a programmable wheel used to write whatever the user desired. ‘’The Writer’’ was able to make complete sentences, spacing between words and lines, and even place full stops after sentences, replicating a task previously only performed by humans.

It wasn’t until 1960 that the first robot that was perceptive and mobile appeared. Aptly named “Shakey”, it was slow and twitchy. But it could navigate a complex environment on its own, although not very confidently. Shakey was developed at the Artificial Intelligence Centre of Stanford Research Institute and it is shown in Fig. 2. (Nilsson, 1984).

Fig. 2 Shakey the Robot. (Photo retrieved from https://www.computerhistory.org/)

Honda started a humanoid robotics program in the mid-1980s, the P-series. P3 was unveiled in 1997, which was a robot that could walk very well and even wave and shake hands. This progressive development would ultimately culminate into ASIMO, one of the most famous robots to date, which is currently displayed the Miraikan museum in the Japanese capital city of Tokyo. Honda announced that it was stopping the development of the ASIMO project in June 2018 and now plans to put the technology behind ASIMO to be in areas such as physical therapy and self-driving vehicles. Fig. 3 shows the ASIMO robot (Sakagami et al. 2002).

Fig. 3 ASIMO (Photo retrieved from https://www.honda.mx/asimo/)

Increasingly sophisticated machines may already be with us, but for robots to be really useful, they will have to become more and more self-sufficient. It is impossible to program a home robot to grip each and every object it might ever encounter. This is where artificial intelligence (AI) comes in.

Humanoid robots will also increasingly interact with humans, to the point where they may eventually become unrecognizable to us. Hansen Robotics already built a human-like robot called Sophia in 2016. It is a robot that can speak autonomously on various subjects, since it is permanently connected to the Internet, it can surf and search for different subjects at will. It can perceive the speaker's mood from facial expressions, and in turn can make more than 50 different facial expressions by itself. Eventually, the goal of Hansen Robotics is for Sophia to look and act surprisingly human through continuous machine learning, another of the most popular terms in this field. (Fig. 4 shows the face of Sophia). Another example of these humanoids that are almost indistinguishable from humans is the Geminoid robot shown in Fig. 5. The Geminoid HI-4 is a humanoid robot designed in the image and likeness of its creator Hiroshi Ishiguro, who holds a doctorate in engineering and is the director of the Robotic Intelligence Laboratory at Osaka University, Japan.

Fig. 4 Sophia (Photo retrieved from https://www.hansonrobotics.com/)

Fig. 5 Geminoid HI-4 and its creator Hiroshi Ishiguro (Photo retrieved from http://www.geminoid.jp/)

Other famous robots throughout history have been, Leonardo, ICat, Nexi, HRP-4c, Albert Hubo, CB2 or Robomaid, among others.

At the end of K. Capek's play, 'Rossum's Universal Robots', almost all humans had been killed apart form one, Alquist, whom the robots had chosen to spare from death because they recognise that "he works with his hands like the Robots". Two robots, Primus and Helena, develop human feelings and fall in love. Alquist realises that they are the new Adam and Eve and gives charge of the world to them. As we near the centenary since this play was first performed, the question of whether robots will develop into a master race of consciousness and high intelligence is one that won't go away.

2.2. Appearance of Robots in Factory Environments

It is also worth taking a look at the world of industry. Before the Industrial Revolution, the manufacturing process was done by hand and tools were only an extension of the physical skills of the craftsmen. Then came the development of mass production and among its features, technology combined with a well-defined division of labour, clear rules, increasing overall efficiency and the maintenance of product quality.

Henry Ford introduced the concept of the production line at the beginning of the 20th century and revolutionized the manufacturing industry. A production line is a system consisting of multiple workstations, and each workstation refers to a location in the factory where a well-defined task or operation is carried out by an automated machine, a combination of man-machine or man-tool (Cencen et al., 2015).

Today, industry trends to increase flexibility and capacity for change in order to achieve a more efficient production. This is where the role of robots in the industry comes into play. It is believed that flexibility can be increased by maintaining productivity through so-called "collaborative frameworks", where workers and robots share a workspace.

2.3. Human Robot Collaboration

Human Robot Collaboration (HRC) is an interdisciplinary research area comprising classical robotics, cognitive sciences, and psychology. Overall, robots are gradually leaving highly structured factory environments and moving into human populated environments, thereby they need to possess more complex cognitive abilities in order to achieve higher levels of cooperation and communication with humans. The design of robot behaviour, appearance, cognitive, and social skills is highly challenging, and requires interdisciplinary cooperation between classical robotics, cognitive sciences and psychology (Bauer et al., 2008).

To make possible the collaboration between robots and humans there must be an interaction between them, it is important to differentiate the concepts HRC (Human Robot Collaboration) and HRI (Human Robot Interaction). The HRI concept is much more general and broader than the HRC concept, the collaboration is a type of interaction, so the HRI concept includes within it, the HRC concept.

Cencen et al. (2015) argue that for human-robot interaction to be possible it is required that the human and the robot are in physical contact or close to each other, thus the authors distinguish four different roles that the human can have in this interaction, shown in Fig. 6: remote controller, supervisor, co-worker and teammate. The role that would correspond to the HRC is that of teammate.

Time / Space	Simultaneous action	Sequential activities
Human&Robot in separate area	*Remote controller*	*Supervisor*
Human&Robot in same area	*Co-worker*	*Teammate*

Fig. 6 Human Robot Interaction Roles (Cencen et al., 2015).

In contrast, Onnasch et al. (2016) distinguish only three types of interaction between humans and robots, and define them as follows:

- Coexistence: Episodic encounters between a robot and a human. Interaction partners do not necessarily have the same goal. The interaction is limited in time and space.
- Cooperation: Interaction partners work towards a higher common goal, but actions are not directly linked and do not follow a clearly defined and programmed division of tasks.
- Collaboration: There is direct interaction and collaboration between human and robot with common objectives and sub-objectives. There is a coordination between the tasks of each one in a continuous and situational way. This type of interaction is an example of synergy.

Bauer et al., in their work *Human-Robot Collaboration: A Survey (2008)*, collect and argue interesting information that can be useful in the present Master Thesis. According to them, collaboration means working with someone on something that achieves a common goal. Humans and robots should form a team and a team is characterized by a small number of partners with complementary skills who are committed to a common purpose, a performance objective and a mutually responsible approach.

Hans-Jürgen Buxbaum (2020) explains that the aim of HRC is to maintain the human being with his abilities as an active member of the production and at the same time to increase productivity through automation. Both man and the collaborative robot have special skills that must be harnessed in the HRC. Buxbaum states that the advantages of the human lie in the fast detection, evaluation and reaction. The free mobility and the possibility to compensate tolerances and to detect errors at any time are also advantages of the human being. People are capable of learning, reasoning and face new situations. On the other side, Buxbaum states that the advantages of the collaborative robot are precision and repeatability. Robots are able to handle heavy or dangerous objects and tools. Ideally, monotonous and repetitive tasks can be transferred to robots.

Bauer et al. (2008) argue that just as in any collaboration between several people, in collaboration between robots and humans, a plan is also required for all partners to meet a common goal. Thus, the interesting term joint intention appears. The intentions of the team members and what they are doing have to be known in order to obtain a joint intention. Based on that knowledge the robots can plan their own actions that will lead them to the common goal. Therefore, they need to be able to perceive and understand their environment, make decisions, plan their actions, learn and reflect on themselves and their environment.

In order to collaborate, partners agree on a joint intention, derived from the unique estimated intentions. The joint intention provides a common goal. Action planning is used to find a series of actions that will lead to that common goal. Finally, joint action is taken (Bauer et al., 2008).

In HRC it will normally be the human who sets the goal, while the robot's task is to help the human and take over the human's intention as its own. The robot's intention becomes to help the human to reach their goal.

In order to agree on a joint intention, communication is indispensable. The main ways of communicating one´s intention listed by Bauer et al. are shown in Fig.7. Some of these intentions are communicated explicitly and some are communicated implicitly and sometimes unconsciously, indicated in grey. This complexity that exists in the forms of communication, as will be discussed later, will be one of the challenges that exist in the world of collaboration between humans and robots

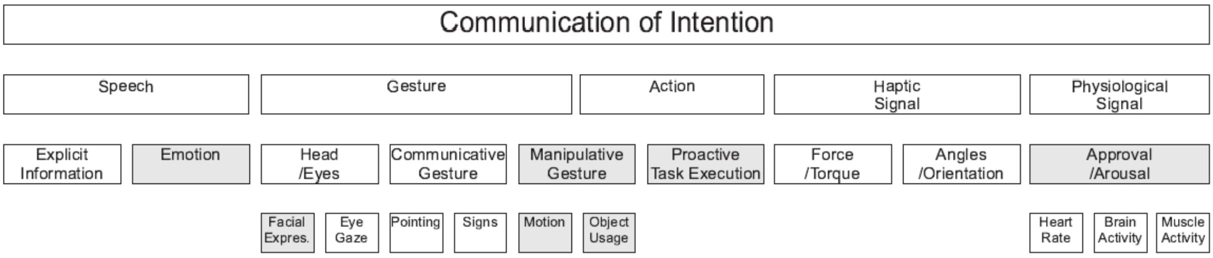


Fig. 7 Main ways of communication (Bauer et al., 2008)

In addition, the intention may change during the course of the action. This further complicates the interaction between robots and humans, as the exchange of information must be as continuous as possible. Thus, the ability to estimate the intention of the other partner is crucial to achieve a proper joint intention that is the basis of the whole HRC.

After determining the joint intention, when planning the actions to be carried out, the possible problems may appear. Bauer et al. (2008) define a problem as a set of states that result in a set of possible associated actions. These actions can cause a transition from one state to another. Ideally, this transition is caused from the current state to a desired state that is derived from the joint intention. The general problem with planning is deciding on a series of actions that will lead to the desired goal, given the current state. In real-world problems, the environment is not always static and there will be uncertainty in the outcome of actions and the transitions from one state to another. These complications have to be taken into account when planning for HRC.

The following should also be considered, often new and unforeseen situations arise in HRC, that cannot all be programmed into a robot. Robots need the ability to adapt to unforeseen events, extend their knowledge and abilities, and learn new behaviours, actions and ways of estimating intent. The term “Machine learning” appears here. There are different machine learning algorithms, some predict values from training examples, from previous experiences, others are based on the principle of reward, also there are methods of robot imitation and rhythm entrainment. These machine learning techniques have applications in intention estimation, human-robot communication, action planning, interaction and all other aspects of HRC. In their work Bauer et al. (2008) further develop this type of questions, but the present Master Thesis is not going to focus on them, they are only mentioned to understand the requirements that a collaboration between robots and humans must have.

Besides that, in a collaboration between human and robots, it is very important to have a clear definition of the tasks that each member of the team must perform, so that this collaboration is carried out efficiently.

Thus, according to the division of tasks, Cencen et al. (2015), mention three different roles that partners can take in a collaborative workstation composed of a human worker and a machine:

- Task Initiative (TI) is a role in which the workflow of the task is controlled and monitored. It´s usually the one taken by humans.
- Product Handling (PH) is a role in which the role owner is responsible for the main part of the product which is being assembled or manipulated. Depending on the type of task it is performed by robots or humans. In many cases, depends on the size and weight of the product, the robot usually carries the heaviest loads.
- Component Handling (CH) is a role in which the role owner is responsible for one or more components, but not for the final product.

To summarize, the demands for flexibility and changeability in the industry have led to a change in the mode of operation. There is a growing search for a type of production that allows greater versatility, here is where the collaboration between robots and humans appears. So-called cobots are introduced, which allow situations to be established in which robots and humans work side by side, taking advantage of each other´s skills. These new workstations are flexible and versatile, allowing changes in the type of tasks, working with different products or components and varying load capacities.

As mentioned throughout this section, HRC is a type of interaction between robots and humans in which the partners act as members of the same team, sharing a common goal. They must agree on a joint intention, which triggers an action plan to achieve the common goal. When acting, a division of tasks must be carried out, which determines what each partner in the team must do. Also, to achieve the objective efficiently, communication between team members is indispensable.

Cobots, as already mentioned, work autonomously sharing the workplace with humans, this feature is the main difference with conventional robots, which are installed in factories in closed spaces, surrounded by safety fences, to ensure the safety of operators.

The first idea that comes to mind when you hear the term cobot is that of an articulated arm that allows people to work at their side under a safe environment, but this cobot term does not specify that it must be a robotic arm, there are also cobots composed of two robotic arms like ABB's Yumi robot or humanoid-shaped cobots like the Nextage collaborative robot. In short, the term cobot only indicates that it is a robot that can collaborate with a human at the same workplace in complete safety.

There are different characteristics that substantially differentiate cobots from typical industrial robot models. Unlike traditional robots, cobots can be programmed without advanced programming knowledge. The installation and commissioning of a cobot is really simple. Besides being normally small in size, they are built with very light elements, which favours the mobility of the equipment, they can be moved from one place to another easily.

Thanks to these characteristics the cobots turn out to be very versatile and efficient tools at the time of adapting them to different workstations, they allow changes in the type of work or task, they are very flexible. That is why in industry they are used in so many different industrial applications such as screwing, welding, palletizing, quality control or pick and place applications.

Furthermore, as they have proved to be a key factor in the development of Industry 4.0, many brands that are dedicated to the manufacture of cobots have emerged, such as Kuka, Universal Robots, Omron or ABB. These brands are now offering cobots at a relatively low price that can be quickly amortized.

On the other hand, by using cobots, operator fatigue is minimised, the cobots take over the most dangerous tasks and reduce the risk of injury among workers.

For all these reasons, cobots improve the quality of industrial processes, increasing productivity and making companies more competitive.

In 2015, the German company KUKA presented the first mass-produced robotic arm capable of working safely with people, the LBR iiwa. The LBR stands for "Leichtbauroboter", which means "lightweight robot" in German. The acronym iiwa stands for "Intelligent Industrial Work Assistant". It is no exaggeration to say that this robot has opened the door to a new era in industrial robotics.

The LBR iiwa is equipped with stress sensors in each of its seven axes. This allows the automation of delicate and complex tasks, and its safety technology meets the high standards of industrial robotics. The LBR iiwa robot stands out because of its great versatility and allows to rethink concepts that were impossible until now in the application of robotics to industrial environments. Among other features, the LBR iiwa from Kuka allows simpler gripping systems, programming through manual guidance, the elimination of fences and the possibility of working side by side with the man-robot.

Fig.8 shows the LBR iiwa, today it is integrated in a variety of industrial automation applications. With this machine, people and robots can work closely together to solve highly sensitive tasks without the need for safety fences. This creates new working areas in the field of manufacturing automation.

Fig. 8 Kuka LBR iiwa (Photo retrieved from https://www.kuka.com/)

3. CHALLENGES OF THE HRC

Having explained the meaning of collaboration between robots and humans and shown the multitude of benefits that can be obtained, this section will briefly describe the main problems or rather challenges that arise when introducing HRC. A compilation of the topics that have been considered most critical after reviewing the literature on robots will be made. These topics are human factors, situational awareness, safety and robots acceptance. Interesting arguments and developments made by expert authors on this topic will be quoted and shown to try to clarify why the design of these new workstations is so complex and why HRC has not yet been established everywhere.

To begin with, the two best known definitions for the term robot, written by the Robot Institute of America and the International Organization for Standardization (ISO), refer to robots primarily as "manipulators". Cencen et al. (2015) say that robots are often seen as tools, as devices through which tasks can be carried out. Robots should not be seen as tools, but as partners/pairs, so that true collaboration can take place.

This mentality of seeing robots as tools must be changed, this will require a change in the way society thinks. It is complicated because it requires society to adapt to new technologies, as was the case with the Industrial Revolution or the emergence of computers. A cultural change is needed, forgetting habits and adapting new techniques.

Because of this and many other reasons that will be described, different types of problems or issues arise when implementing HRC. Today, the scientific community is facing real challenges in achieving effective collaboration between humans and robots. Some of these challenges and their possible solutions are described below, all ideas have been taken from the literature indicated throughout this Master Thesis and are referenced. This section is intended to show and raise awareness of these difficulties.

3.1. HUMAN FACTORS

Many of the challenges that arise when implementing HRC have a common theme, referring to human factors. When human collaborations with machines or robots appear, these machines or robots must be equipped with a series of human factors for these collaborations to be effective.

Czaja and Nair (2012), define human factors as the scientific discipline that deals with the understanding of the interactions between humans and other elements. These include methods, theories and principles that contribute to the optimization of human well-being and overall system performance.

According to Badke-Schaun et al. (2012), the term Human Factors includes psychic, cognitive and social factors. One aspect of the Factore Humanos discipline focuses on the design of human-machine interfaces, especially on security issues and psychological aspects. Due to the increasing degree of automation, human skills within these interactions have a different function, for example in the form of control activities. One of the many questions that arises is what human characteristics can and should be taken into account when collaborating with robots.

Another human factor that poses a great challenge is communication, as already said, when there is a common plan and a common goal, communication is indispensable. The problem arises because of the multiple forms of communication that exist between humans. Apart from the most natural forms of communication such as speech, written communication or gestures, which are all carried out consciously and explicitly, there are also forms of communication that are carried out unconsciously and have an implicit meaning, such as the way we look, our facial expression or our tone of voice. Because of these unconscious forms of communication and their implicit meaning, the interaction between humans and robots becomes more complicated. It is very difficult to program a robot with all the information needed to perfectly understand each and every form of human communication.

Furthermore, during the performance of an action, the intention of the participants in the collaboration may change, so the action may no longer be useful. This is because the environment is not static, the robot must be able to realize this and act accordingly.

Artificial Intelligence (AI) is the science that studies how machines are able to perform human tasks. AI makes it possible for machines to learn from experience, adjust to new developments and perform human-like tasks. Computers and robots can be trained to perform specific tasks by processing large amounts of data and recognizing patterns in the data.

The term artificial intelligence dates from 1956, but AI has become more popular in recent years due to the development of technology, increased data volumes, the emergence of advanced algorithms, and improvements in computer power and storage.

Artificial intelligence can be the solution to the many challenges that arise in relation to human factors. With a great development of artificial intelligence of cobots many of these problems could be solved such as the limitation in the time to interact, a much more continuous communication and even capture implicit intentions of the participants could be developed. Also, through AI cobots may become capable of responding to new and unforeseen situations.

Following this path, Cencen et al. (2015) argue that Artificial Intelligence (AI) has helped to significantly improve all automated systems, however, it still cannot cope with unexpected events, so the most flexible production system is still considered to be that of the skilled and experienced human worker.

Further development of this science of AI is needed, and it is already being shown that this is the way forward to solve the challenges that arise between human factors and HRC.

3.2. Situation Awareness

Another of the great challenges faced by the scientific community when implementing HRC is that of situation awareness. When making decisions, human beings are able to make choices because they are aware of the situation they are in and have information about the environment around them.

Wenninger (1991) explains that we humans are able to process information from the environment around us thanks to perception. According to Wenninger, perception is a conscious sensory experience caused by a stimulus received through the senses of sight, hearing, taste, smell or touch. Receivers of sensory stimuli convert these stimuli into electrical signals, which are sent to the brain via the nerve pathways. The signals are analysed and processed on their way to the brain and in the brain itself, until finally a conscious perception experience occurs.

Wenninger argues that after a look at the process of human perception, ideally complete mental models emerge at the end of information processing, which allow for situational perceptions. Of the incoming stimuli from the outside world, only those that are relevant to action are collected, and attention is paid to them from the abundance of incoming stimuli based on the expectation of experience or attitudes. Here lies part of the challenge in developing collaboration between robots and humans, the robot must be able to select from all the stimuli that are continually present in the environment and only pay attention to those that are relevant to its objective.

Buxbaum et al. (2019) define situational awareness as the process by which individuals perceive and mentally represent a large amount of information in order to act effectively in a given situation. Many other definitions of Situation Awareness (SA) appear throughout the literature, but most of them coincide in referring to "knowing what is going on".

Endsley (1995), defined Situation Awareness as the perception of the elements of the environment within a volume of time and space, the understanding of their meaning and the projection of their state in the near future. Endsley distinguishes three levels or steps of SA:

- The first step is to perceive the status, attributes and dynamics of the elements of the environment. This is Level 1 SA, Perception of the Elements in the Environment. Inadequate presentation and cognitive abbreviations can lead to misperceptions and therefore to a misunderstanding of the situation.
- The second level is the Understanding of the Current Situation, it is based on synthesizing and schematizing the elements of Level 1. This second level goes beyond simply being aware of the elements that are present, one must understand the meaning of those elements and what function they have to fulfil the operator's objective. This level describes the understanding of the situation and is done through mental models and previous experiences. A lack of these mental models can lead to erroneous predictions and, therefore, to a wrong decision.
- Finally, Endsley explains that the highest level of SA is Level 3, the Future State Projection. It corresponds to the ability to project the future actions of the elements in the environment. This is achieved through knowledge of the state and dynamics of the elements and understanding of the situation. This provides the knowledge and time needed to decide the most favourable course of action to meet one's objectives.

Endsley (1995) concludes that the SA is based on much more than just the perception of environmental information. It includes understanding the meaning of that information in an integrated way, comparing it with the operator's objectives, and providing projected future states of the environment that are valuable for decision making. A diagram representing Endsley's SA model can be seen in Fig. 9.

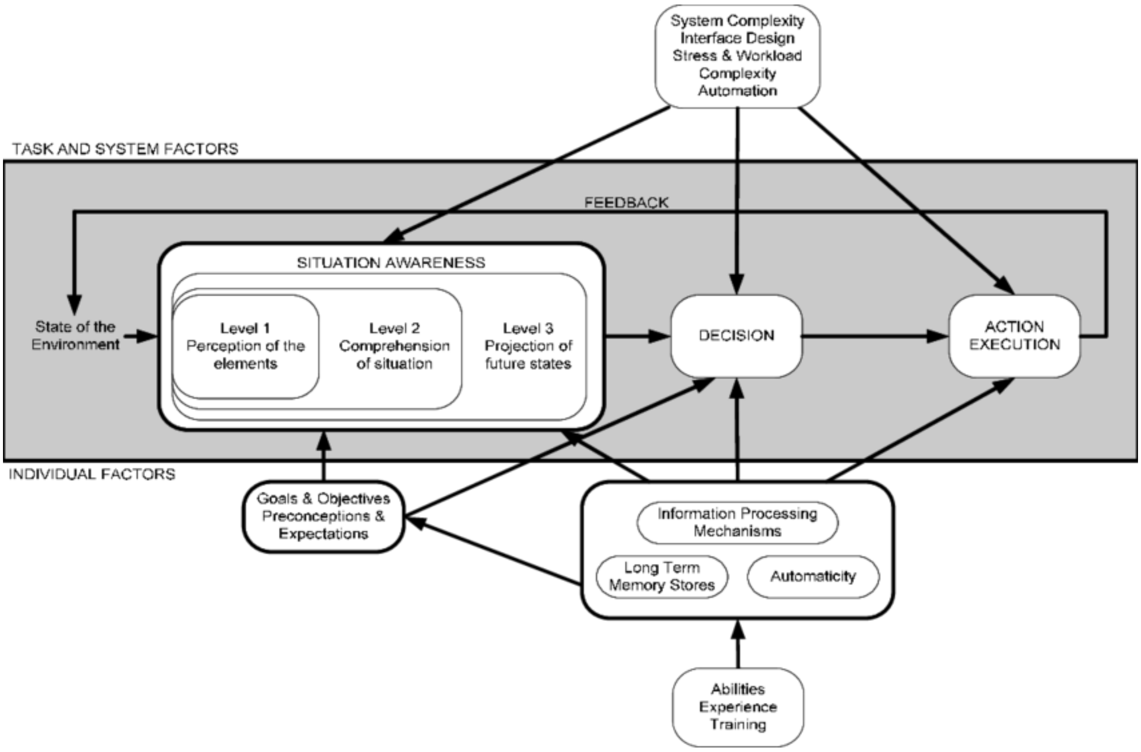


Fig. 9 Situation Awareness (Endsley, 1995)

Many characteristics of individuals and systems affect a person's ability to acquire and maintain a SA in the best possible way and at a higher level. Some of these factors and characteristics are as follows:

- The way in which attention is directed
- Limitations of attention and working memory
- Schemata and mental models available
- Expectations or preconceptions about future events
- Current goals
- The degree to which relevant feature of the environment are available
- The way in which information is presented via the operator interface
- Stress
- Workload
- Complexity
- Automation

Therefore, the SA is crucial when undertaking a task in a collaborative manner with a common goal, each team member must have a high level of knowledge about their SA and also about the SA of the other team members, in order to obtain the expected results efficiently. Thus, the better the SA of each member of a collaborative team, the better the results obtained, this means that a cobot, in an HRC, also has its own SA and that logically the better the SA of the cobot, the better the performance of the HRC.

This leads to the conclusion that it is important that the SA of the cobot is as good as possible, so a method is needed to measure the knowledge of the situation, in order to be able to compare and choose the best option.

3.2.1. SITUATION AWARENESS GLOBAL ASSESSMENT TECHNIQUE (SAGAT)

One of the best-known methods for measuring the situation awareness is the Situation Awareness Global Assessment Technique (SAGAT) that Endsley (1987) proposed. This technique is based on the world of aircraft, in this area the SA is the internal model that the pilot has about the world around him at any moment of time. This capacity of the pilot is crucial for the success of the mission. The maximization of the pilot's SA is essential to provide a great overall performance of the pilot/system. Therefore, these concepts have been developed in this area of aircraft. Endsley proposes SAGAT as a viable method to measure the SA in an objective manner. The technique is carried out as follows:

The pilot performs a flight in a certain scenario using a certain aircraft system in a simulation. At some random point, the simulation stops, and the cockpit and window screens are left blank. The pilot is asked a series of questions to determine his knowledge of the situation at that exact moment. These questions correspond to the pilot's SA requirements. The comparison of the real and perceived situation provides an objective measure of the pilot's SA.

Endsley (1988) indicates that SAGAT's main limitation is that the simulation must be stopped to collect the data. The advantages of SAGAT are that it provides a snapshot of the pilot's mental model of the situation, provides an overall measure of the SA, directly measures the pilot's knowledge of the situation and can be objectively collected and evaluated.

To apply this technique, a simulation environment that is as realistic as possible is required. An environment must be created that resembles reality as much as possible. Here is the next term that will be dealt with in this Master Thesis, the Full-Scope Simulation.

3.2.2. FULL-SCOPE SIMULATION

In order to perform experiments under real and repeatable conditions, Buxbaum et al. (2018) have developed a full-scope simulator for HRI applications that allows conclusions to be drawn about the situation awareness. It consists of an experimental platform that allows to investigate the collaboration between humans and robots. In this simulator, the desired environmental conditions for each experiment are achieved, as well as a very precise repeatability thanks to which results can be compared and statistical analyses carried out.

This full-scope simulation concept has been transferred from power plant technology to the HRC field. These simulators have been used in recent years, especially in nuclear power plants, to train the personnel, to gain knowledge of safety aspects, to study psychological and ergonomic issues, all of which are always around the awareness of the situation.

As mentioned above, these types of simulators are used to train power plant operators in the handling of regular and irregular operating conditions. Tavira-Mondragón and Cruz-Cruz (2011) explain in their article that the operation of power plants requires constant and effective training of operators, so the aim of this type of simulator is to achieve safe and efficient operation of power plants. These training programs are designed to increase the decision-making and analytical skills of the operators and to prepare them for problems that may arise when operating the real system.

The use of these full-scope simulators came to power plants thanks to the increase in computer power, their reliability and the wide variety of current graphic interfaces and seeking to reduce costs. In this way, power plants replaced their old control panels with a Human Machine Interface (HMI), in which all supervision and operation actions are carried out through interactive process diagrams, multi-window systems, graphics and displays. Naturally, the operators of these plants needed adequate training because they are facing a complete change in their mode of operation.

Tavira-Mondragón and Cruz-Cruz (2011) indicate that the main challenge for simulator users is the cultural change, since now operators must use a modern tool instead of a control panel, and therefore operators must forget their old operating habits and adopt new operating techniques for a smooth and safe navigation in a different HMI.

Therefore, in addition to serving as training for operators simulating critical or stressful situations, these power plant simulators have helped operators to adapt more quickly to the change in their way of working, since the simulators are handled in the same way as the new man-machine interfaces, thus making it easier to leave the operation of these power plants behind through control panels. Also, these simulators, thanks to their computer platform, have lower operating and maintenance costs, compared to the old control panels.

Tavira-Mondragón and Cruz-Cruz (2011) show that thanks to training programmes based on full-scope simulators, the benefits provided are related to having better trained personnel, which represents greater confidence on the operation of generation units, greater security of the facilities and personnel and the achievement of better efficiencies.

Returning to the reason why these simulators are being discussed in the present Master Thesis, that reason is to look for a way to be able to measure the situation awareness in an objective way and having conditions of repeatability, it is known thanks to authors such as Tavira-Mondragón and Cruz-Cruz (2011) or Buxbaum et al. (2018) that through these simulators special attention can also be paid to psychological aspects, such as attention and knowledge of the situation. Therefore, full-scope simulators could be a good way to realistically simulate collaboration between humans and robots in order to measure and compare different situations objectively.

The full-scope simulator for HRI applications developed by Buxbaum et al. (2018) simulates spatially close cooperation between humans and robots. This full-scope simulator is used to configure different HRCs to carry out different experiments under specific conditions chosen at will depending on the type of experiment, so the simulator is fully flexible in its configuration. The aim is to obtain results and conclusions that can be objectively analysed, to be able to record statistics thanks to repeatability, on situation awareness, perceived safety and focused attention. The authors argue that the situations of existing HRI applications are extremely diverse and therefore difficult to compare. The experiments are difficult to perform, because there is no suitable experimental research platform for the HRI. Buxbaum, Kleutges and Sen have developed a prototype experimental platform that allows experiments to be carried out under freely definable environmental conditions, can recreate real situations, and that allows follow-up experiments to be carried out. It is a full-scope simulator based on power plant technology.

Under the premise that comparable results can only be obtained if uniform conditions prevail in the environment and the procedures of each experiment are the same, the Full-Scope Simulator can be the platform through which to measure and compare situational awareness in collaborations between humans and robots.

3.3. SAFETY

It may be the first thought that comes to mind when it speaks of a collaboration between humans and robots, will it be safe for humans? Safety is one of the great challenges the HRC faces. Safety has unconditional priority since the beginning of robotics, the first law of the famous *Three Laws of Robotics*, written by Isaac Asimov in 1942, is:

- *A robot may not injure a human being or, through inaction, allow a human being to come to harm.*

Numerous authors have dealt with the subject of human safety when using robots, below are some interesting contributions on this subject.

Bauer et al. (2008) explain the world of industry has undergone a transformation in recent years, from an automatic manufacturing method to Industry 4.0. This transformation has been promoted predominantly from Germany and the USA. A new generation of systems has been introduced into the industry, great advances have been made in information and communication technologies, in data analysis and new devices have appeared such as collaborative robots. These transformations are making the tasks performed by industrial robots no longer limited to the transfer of objects, or other repetitive actions. Instead, there are a growing number of tasks in which humans and robots combine their skills in collaborative work.

When robots act together or in close proximity to humans, safety is a crucial aspect, thus Bauer et al. (2008) indicate that the first thought when designing a robot for HRC should be about safety. The robot's hardware should not be dangerous to humans. HRC robots must be safe and must not, under any circumstances, endanger humans.

Buxbaum (2020) explains that in HRC applications, humans and robots work in a common work system without being spatially separated by facilities such as safety fences. So, the main safety principle of industrial robotics, the separation of humans and robots, is abandoned here. Therefore, the safety of systems using HRC must be fundamentally re-evaluated. Safety fences, which were very common in classic industrial robotics applications, no longer make sense in this type of application. Instead, other types of safety systems need to be introduced, so that collisions can be prevented by detecting obstacles as well as their motion, applying appropriate avoidance strategies, and harm to the human can be minimized in case of an unexpected or unavoidable impact. Besides that, Buxbaum (2020) states that the omission of separating protective devices makes a spaces-saving possible, in this way it is possible to use in a more effective manner the productive space, and this leads to increase the general productivity. Buxbaum (2020) also indicates that by omission of fences, the collaborative robots are more flexible in terms of location, they can be used at different workplaces and for different tasks. This can be really useful for small and medium companies, Another great contribution collected from the literature on the safety of systems in which robots and humans coexist, is that made by Barho et al (2012), they differentiate four modes of operation for a safe HRI, depending on the space of collaboration. The following page shows an illustration (retrieved from Villani et al., (2018)) of these four modes of safe operation in Fig. 10, also briefly described below:

- Safety-rated monitored stop: In this mode the robot stops if a person enters the collaboration area, so humans and robots share the collaboration area, but do not work there at the same time. A safety fence is not required, but a sensor system capable of automatically detecting the approach of humans is required to stop the robot. The type of interaction within the classification made by Onnasch et al. (2016) is the co-existence.
- Hand guidance with reduced speed: The robot is guided by the operator manually. The movements and forces that humans make with their hand are transferred to the robot and are detected by a series of sensors equipped in the robot and converted into an immediate movement of the robot. To increase safety, the speed of the robot is limited. Hand guidance within the classification made by Onnasch et al. (2016) would be a cooperation type interaction.
- Speed and separation monitoring: In this mode the robot does not stop when a human enters the collaboration area. Safety is guaranteed by the distance between the human and the robot. The human and the robot work in the collaboration space at the same time. A sensor system monitors the distance between the human and the robot and the speed of the robot is reduced when approaching. No contact is allowed. If the minimum distance is less than the permitted one, a safety stop is activated. This prevents a collision. Speed and distance monitoring is a co-operation-type interaction within the classification by Onnasch et al. (2016)
- Power and force limiting: This mode also uses sensor-based monitoring, which slows down the robot if a human approach. However, contact between humans and robots is allowed. The risk of accident is reduced to an acceptable level by limiting the dynamic parameters of the robot. This is done by limiting the maximum force and speed of the robot to ensure that no human injury is caused even in the event of contact. The difficulty lies in defining the power and force limits, establishing limit values above which humans can no longer withstand the pain of a collision. This mode of power and force limitation is a collaborative type of interaction within the classification presented by Onnasch et al. (2016).

Therefore, the safe mode of operation when interacting with a robot, which is of interest for this Master Thesis, would be the only mode that involves a real collaboration between human and robot, that of level 4, power and force limiting.

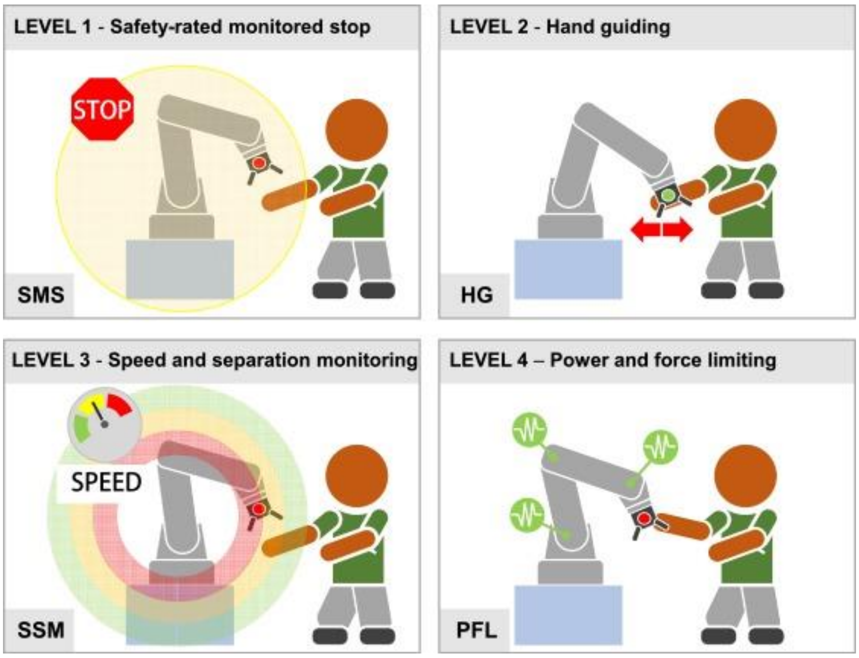


Fig. 10 Safety HRC (Villani et al., 2018)

Another trend that is being followed to increase the level of safety in HRC applications is damage reduction, minimizing the severity of the consequences in the event of a collision. Accidents can occur during a collaboration between robots and humans for various reasons, from direct contact, such as a collision, from cuts with the sharp edges of tools, there is also the possibility that parts of the body can be caught by a gripper. In all these possible cases of accident, it is important to keep the damage to a minimum. To minimize the risk of injury, measures must be taken when designing the robot, the robot must be designed with the safety of the humans who will be in contact with it in mind. An important line of research is focused on minimizing human injuries caused by collisions with robots. Solutions include limiting the force and power of robots, viscoelastic coverings, absorption elastic systems, safe actuators or lightweight structures, avoiding sharp edges or including cushioning at contact points. Robla-Gomez et al. discuss some of these measures in their article "Working Together: A Review on Safe Human-Robot Collaboration in Industrial Environments" published in 2017.

To minimize injuries in collisions between humans and robots, collision detection strategies can be followed. This is done by using surface tactile sensors to obtain information about the point of impact. Although it is very important to minimize injuries in human-robot collisions, prevention of robot-human impacts is highly desirable. Therefore, another objective of robot-human collaboration is to increase safety by applying systems to prevent collisions. For this purpose, collaborative robots use motion capture systems, simulated environments, sensors that capture local information, artificial vision systems, range systems or RGB-D devices, among other things.

The information about the possible consequences to the human body of having a collision with a robot is used to take the necessary measures to minimize injuries to humans and can be used to test new safety systems for robots, as discussed in their article Robla-Gómez et al. Everything concerning safety issues in HRC is covered in ISO-TS 105066:2016, “Robots and robotic devices - Collaborative robots”, which clarifies the limit values of force, speed and pressure that ensure action in case of collision below the threshold of sensitivity to human pain. Logically all collaborative robots must comply with the standard.

On the other hand, today safety is closely linked to security, to cyber security. The concept of security in HRC is also related to hackers, cyber-attacks, computer viruses, malware, etc. New technologies are susceptible to these types of attacks, so they must be considered and protected against them. Even more so if the robots are going to handle important and private data.

As can be seen, safety can be a constraint when implementing HRC, not only must total safety be ensured for the humans involved but also these humans must have full confidence that the robots will not harm them.

3.4. Robot Acceptance

The last but not the least challenge that will be discussed in this Master Thesis is the acceptance of robots by society. Many authors have addressed this issue, Beer et al. (2011) explain that understanding robot acceptance is a critical step in ensuring that collaborative robots reach their full potential. Beer et al. (2011) in their article discuss acceptance as a combination of attitudinal, intentional, and behavioural acceptance. Attitudinal acceptance is the positive evaluation of users or their beliefs about technology. Intentional acceptance is the users' plan to act in a certain way with technology. Finally, behavioural acceptance is defined as the actions of users in using the product or technology.

Beer et al. (2011) in their paper "Understanding Robot Acceptance" identify the following categories of variables as potentially impacting on robot acceptance: **robot function**, **robot social capacity** and **robot appearance**.

Firstly, on the **function of the robot**, Beer et al. explain that an important aspect is the level of autonomy of the robot. Autonomy can be defined in general as the capacity of a robot to adapt to the variations of the environment, the robot users expect that the level of autonomy of the robot meets or even exceeds their expectations. Another functional aspect that influences user acceptance and adoption is the type of human-robot interface and the ease of use.

Also, the task performed by the robot can influence the acceptance of it, the perceived usefulness of this task can mean a positive evaluation on the robot. Conversely, apparently useless robots are evaluated negatively. Therefore, the role of the robot plays an important part.

An additional factor that may influence acceptance is the nature in which the human controls and interacts with the robot. Beer et al. cite in their paper that Scholtz (2003) described five roles in which the human can participate while interacting with a robot, which could be as a supervisor, as an operator, as a teammate, as a mechanic/programmer or as a bystander. A supervisor supervises the behaviour of the robot, an operator can directly control the robot. A teammate collaborates with the robot to complete a task, works towards the same goal and finally, a bystander does not control the robot, but may be in the same environment as the robot. All of this is explained in Beer et al. (2011) in much more detail in their work.

The second variable that potentially influences the acceptance of robots according to Beer et al. is the **social capacity of the robot**. Variables such as social intelligence, emotional expression and non-verbal social cues can influence user expectations of the robot's social competence. Beer et al. (2011) argue that a mismatch between user expectations and the robot's actual social intelligence can negatively influence acceptance and use of the robot.

Finally, the third variable that affects the acceptance of robots identified by Beer et al. (2011) is the **appearance of the robots**. According to Beer et al. the similarity of robots to humans, their structure or shape, and the gender of the robot if it has one, are factors that can influence perceptions and attitudes towards robots. In addition, a proper match between a robot's appearance and the task it performs can improve people's acceptance of the robot. In addition, Beer et al. and many other authors agree that there are differences in evaluating robots among people depending on their culture, age, gender, profession, stereotypes about robots and familiarity with robots in general. People's personalities can also influence over the acceptance of robots.

Regarding the appearance of robots and their acceptance, there is a famous theory that tries to relate the human resemblance of a robot to the level of familiarity evoked in the person interacting with the robot, it is called the Uncanny Valley Theory and was described by Masahiro Mori in 1970.

Mori explains in his theory that, as robots become more and more like humans, people's "familiarity" with them increases to a point where this relationship suddenly ceases. Beyond this point, even though the robot's resemblance to humans is increasing, the familiarity with the robot stops growing. Instead, the robot begins to be perceived as strange in appearance. If the robot's resemblance to man continues to increase until it almost completely matches the appearance of a human, familiarity will again increase and be maximized when the robot cannot be distinguished from a healthy person. Beer et al. (2011) explain in their paper Mori's theory and indicate that the region of immersion in familiarity with increased familiarity is called the mystery valley.

In Fig. 11 this phenomenon can be seen graphically.

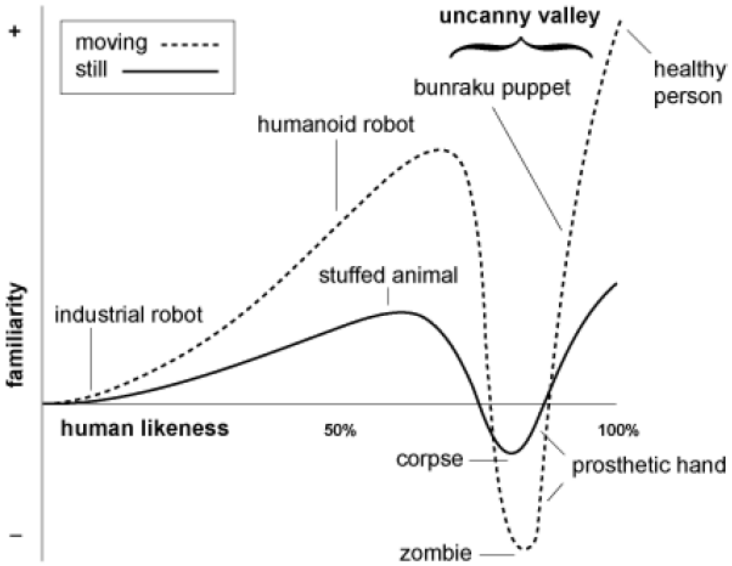


Fig. 11 Uncanny valley (Mori, 1970)

Mori explained these effects with an example: Imagine that a person you interact with has a hand prosthesis. As is well known, nowadays prosthetic hands are really well made and barely distinguishable from human hands, since they simulate skin, nails and even fingerprints, but they lack the common temperature at which the hand is usually found and the touch of human tissues. If you see a hand prosthesis from a distance you may not realize that it is a prosthesis. But when you shake this hand, what you will experience will not match your expectations and the result will be a strange and even unpleasant sensation.

One of the great controversies about the Uncanny Valley theory focuses on which term should be used as a dependent variable, since the term "familiarity" does not satisfy all authors. The original document, written in Japanese, used the term “shinwakam” for the dependent variable. Beer et al. (2011) indicate that there has been a lack of consistency in the translation of “shinwakam”. The word is a combination of two separate Japanese words: “shinwa”, which means to be mutually friendly or to have a similar mind and “kan”, which in Japanese means "the meaning of". Even with these definitions of the two components of “shinwakam”, it is not clear which English term best fits their meaning. "Familiarity" was the first translation made by MacDorman & Minato (2005), but familiarity changes with increasing interactions. The more often something new is seen or used, the more familiar it becomes. Other dependant variables used to assess people's opinions about the appearance of robots are probability, attractiveness versus repugnance, perception of anxiety, fear or dread but Beer et al. indicate that none of these terms can independently provide a holistic view of people's attitudes towards the appearance of the robot.

Many factors affect the human likeness of a robot. But one of the most important is the **movement**, and many of the authors who are experts on this subject agree on this. Thus, a rich motion behaviour, a high smoothness of movement and an adequate speed are evaluated as positive and will lead to a higher acceptance. In contrast, limited movement often leads to feelings of disappointment when evaluating robots. On the other hand, the way a robot moves can serve as a signal to categorize the robot as such and thus have a positive effect. Since sometimes the problem is that it is not easy to categorize a robot as such and this causes negative feelings in people, the limits of the categories are sometimes diffuse.

Looking for a way to explain the Uncanny Valley phenomenon, which factors produce it or why it happens, Rosenthal-von der Pütten, A. proposed in his doctoral dissertation "Uncanny Human" a classification of three different explanations of the uncanny valley effect after having carried out a review of the literature about this topic**: perception-oriented**, **evolutionary-biological**, and **cognitive-oriented** approaches.

The first reason Rosenthal-von der Pütten (2014) gives for the Uncanny Valley phenomenon is due to **perception-oriented** explanations that include conflicting perceptions, the violation of previously held expectations, errors in predicting movement, or uncertainty at category boundaries. Mismatches in expectations about perceptions and real perceptions in any of their forms lead to further processing about how to interpret, categorize or react to stimuli that cause uncertainty and thus produce a negative reaction towards the robots.

Rosenthal-von der Pütten (2014) points out that the second reason why this phenomenon occurs is due to **evolutionary-biological** explanations, in which it is considered that these strange reactions are due to a hypersensitivity bias of the behavioural immune system. These reactions may occur for fear of increased mortality.

Finally, the third reason given by Rosenthal-von der Pütten (2014) for the Uncanny Valley phenomenon is **cognition-oriented** explanations involving personal and human identity, categorical perception and subconscious fears of reduction, replacement and annihilation.

To finish with the Challenges of the HRC section, a brief summary will be made. The intention of this section was to present the main problems or rather challenges currently facing the HRC. They have been divided into four sections, human factors, situational awareness, safety and acceptance of robots. The contents of the sections have been gathered from the literature referenced in this paper. In the first section it was concluded that through artificial intelligence a much more satisfactory interaction between robots and humans can be achieved. The second section has explained the importance of situational awareness in the collaborations between robots and humans and the need to be able to measure it in order to perform experiments and comparisons. This is possible thanks to techniques such as SAGAT and platforms such as the Full-Scope Simulator. Thirdly, the importance of safety when interacting with robots has been discussed. Several ideas have been presented such as the four modes of operation of Barho et al. (2012), strategies to minimize injuries or strategies to avoid collisions. And it has become clear that all cobots must meet a series of safety requirements in standards such as ISO-TS 105066, in order to obtain a certificate and to be launched onto the market. Finally, the fourth part of this section deals with the acceptance of robots by society, which is also a major challenge facing HRC. The three variables affecting the acceptance of robots proposed by Beer et al. (2011) have been presented, which are the function of the robot, the social capacity of the robot and the appearance of the robot. Regarding the appearance of the robot, the phenomenon of Uncanny Valley proposed by Mori has been briefly explained. The importance of movement when evaluating a robot has been indicated. Finally, the reasons for the Uncanny Valley according to Rosenthal-von der Pütten have been presented, according to this author there are three explanations: perception oriented, evolutionary-biological and cognitive-oriented approaches.

Then, in the next section, HRC will be discussed in the health sector. In this sector, this technology is not as well established and developed as it is in the industry, but the challenges that will arise as it is implemented more and more will be the same as in the industry. That is why it will be helpful to have presented the challenges that HRC currently faces earlier, in order to be able to address them and find solutions more easily.

4. HUMAN ROBOT COLLABORATION IN THE HEALTH CARE SECTOR

Once the theoretical framework under which this Master Thesis is developed is presented, in this fourth section the central part of the work will be shown, which is none other than to look for possible solutions through the Human Robot Collaboration for the health sector and more specifically for the current crisis situation due to the coronavirus pandemic. The aim is to try to alleviate the great workload of health personnel, who due to the large number of people infected by Covid-19, are being overwhelmed and sometimes do not manage to offer the service they would like due to lack of time. It is also a matter of protecting the health workers, as we will discuss later, a large number of professionals are becoming infected, further aggravating the situation.

Before this crisis of coronavirus began, Buxbaum et al. (2019) already commented in their article that the healthcare sector has several problems that have now been much more aggravated. Society is undergoing a demographic change, there are more and more elderly people, life expectancy is increasing, so they are needing more and more care so the demand for health services is increasing exponentially. In addition, there is a growing shortage of healthcare staff, which makes the situation even worse. That is why new concepts to combat this problem must be tested and put into practice. The idea of transferring the knowledge of human-machine collaboration to the health sector could be interesting.

If a look is taken at the industry, something similar happened a long time ago. Due to the high labour demand and the lack of personnel, new and innovative machines were introduced in the industry, which not only relieved human work, but also created a new way of thinking. Buxbaum et al. (2019) indicate that collaboration between humans and robots enables a new way of designing workplaces and relieving people's workload. This type of collaborative machinery can also help to reduce the workload on healthcare workers. Their assistive functions make it possible to take on simple tasks and give staff space for other, more important activities.

The aim is not to replace inpatient care with robots, but rather to relieve staff by taking over support activities, such as distributing medicines, bringing food and drink to rooms or doing cleaning work.

Throughout this section, firstly, it is going to be described the current trend that the health sector is following in terms of the introduction of new technologies and the use of robots. To do so, the term Healthcare 4.0 is going to be introduced. It has already used by other authors, making a similarity with the term Industry 4.0. Their characteristics will be described and focusing again on the objective of the present Master Thesis, some of the most famous robots introduced in the Healthcare 4.0 era will be presented. Characteristics that can be used when introducing a collaborative robot to help face the Covid-19 will be searched.

Secondly, a brief description will be given of what the coronavirus crisis is entailing, the number of global infections and deaths is dismaying the whole world. The health sector has needed help during this pandemic, and through collaboration between robots and humans it could have been given some of this help. As has been seen throughout history in the wake of pandemics, great changes have taken place in society, so why not give the Human Robot Collaboration a chance after the coronavirus in a definitive way in the health sector. This could be a turning point after which to introduce collaborative robots in the health sector and to normalize the interactions between robots, health personnel and patients, because despite the fact that there are many developments in health technology, collaborative robots are not convincing and do not have a place in the health sector. Therefore, if the great help they could have offered during this pandemic is demonstrated, this could be their great opportunity.

Finally, in the third section, possible applications will be presented that HRC could offer in the health sector by treating highly contagious diseases and more specifically in support tasks for nurses. Two possible applications will be described to demonstrate the great use of collaboration between robots and humans in this type of situation.

4.1. HEALTHCARE 4.0

In recent years, great advances have been made in health engineering. These interdisciplinary advances are achieving predictive, preventive, precise and increasingly personalized medicine. Powerful tools used in process or factory automation, such as distributed control systems and robotics, are penetrating biomedical and health applications. Pang et al. (2018) by analogy with Industry 4.0, use the term "Healthcare 4.0" to denote the trend that the healthcare sector is following in terms of the use of technologies coming from or already used in Industry 4.0.

The paper by Pang et al. (2018) uses Fig. 12 to illustrate the concept of Healthcare 4.0. This is a revolution in healthcare services driven by technologies originating in Industry 4.0. Healthcare 4.0 is a revolution in healthcare, including major advances in medicine and the production of medical equipment, a transformation in hospital and non-hospital care and also in healthcare logistics. A large number of cybernetic and physical systems are being introduced into healthcare, which are closely combined through IoT, complete sensing of people's vital signs, intelligent detection, big data analytics, AI, cloud computing, automatic control and autonomous execution, and robotics. Fig. 12 shows which technologies are included in Healthcare 4.0. Thus, Pang et al. (2018) indicate that Healthcare 4.0. is not only about the introduction of new products and new healthcare technologies but also about providing a transformed and fully digitized healthcare service.

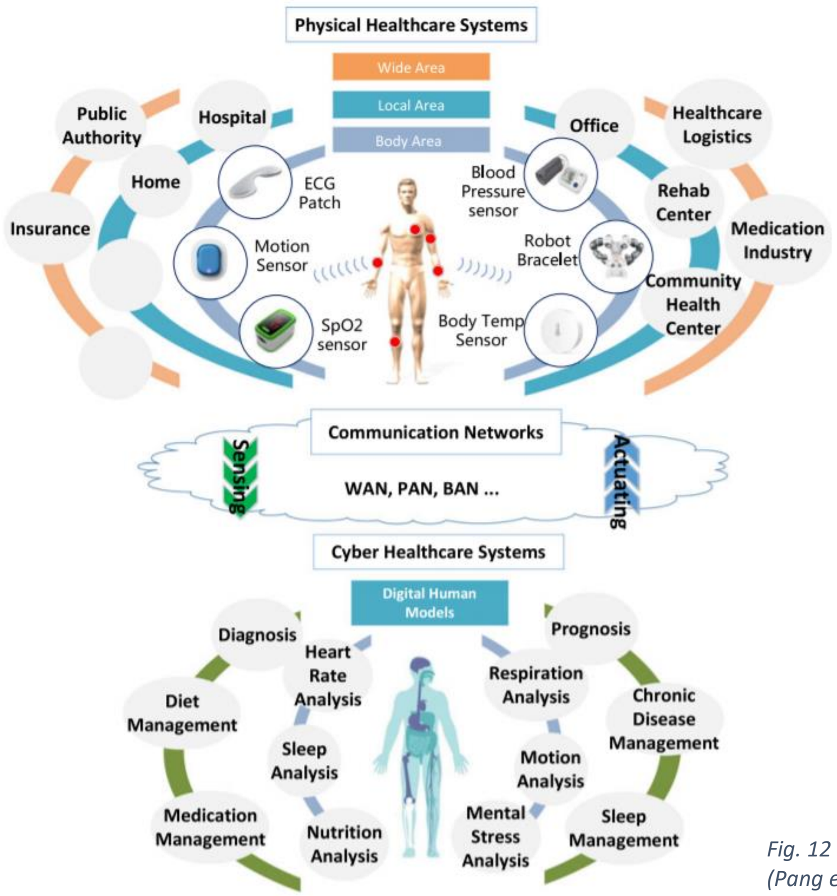


Fig. 12 Healthcare 4.0 (Pang et al., 2018)

Fig. 13 shows the fundamental advances in medical and biological engineering of the last 100 years, it is a picture taken from the Hall of Fame, American Institute of Medical and Biological Engineering. Pang et al. (2018) argue that by placing these milestones next to the history of industrial revolutions, an interesting temporal correlation between them is observed, as shown in Fig. 14. taken from their article: "Introduction to the Special Section: Convergence of Automation Technology, Biomedical Engineering, and Health Informatics Toward the Healthcare 4.0"

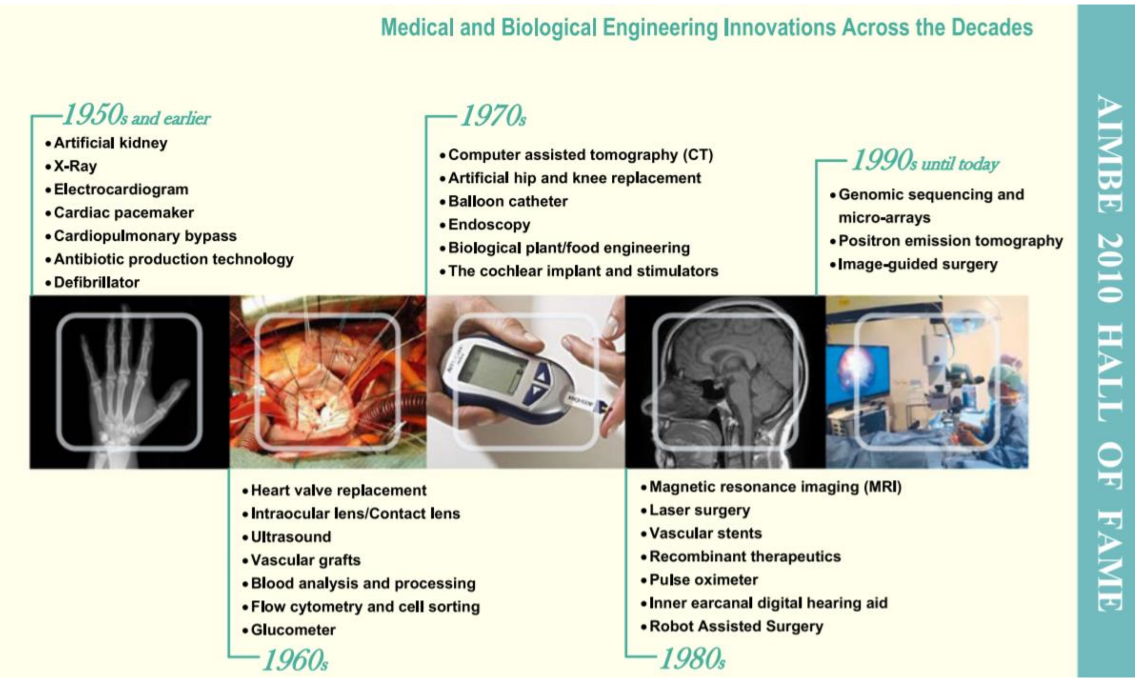


Fig. 14 Medical Innovations (Pang et al., 2018)

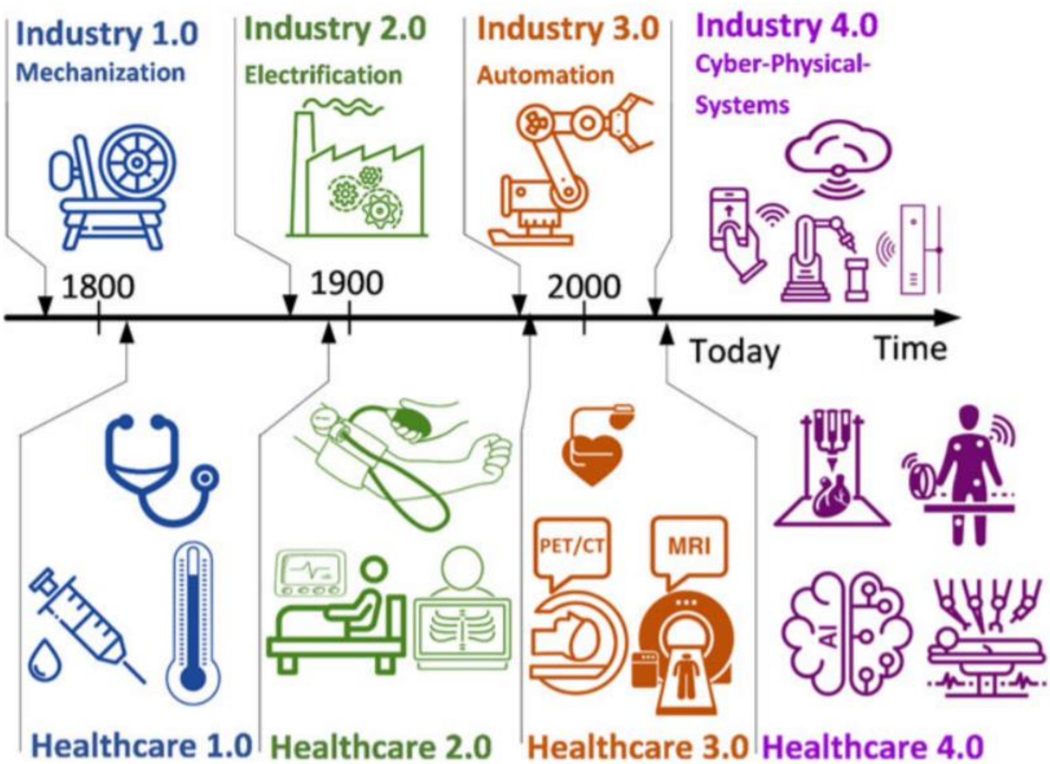


Fig. 13 Temporal correlation between Industry and Healthcare (Pang et al., 2018)

Within Healthcare 4.0, medical robots appear. Unlike human beings, robots are tireless, and their "hands" never tremble. They can make precise movements even beyond the human range of motion and be present with patients as long as necessary. In addition, they can automate low-level or repetitive tasks and leave high-level work to humans. Below are some of the most famous medical robots of the last years, not all of them are collaborative nor all of them would be helpful when dealing with the coronavirus, which is the central theme of the present Master Thesis, but they serve to visualize the trend that is being followed in Healthcare 4.0 robotics and also maybe some features of them will serve to get closer to the objective of the Master Thesis. Each robot will be put in context and it will be indicated if it can be useful or not for the objective of the present paper. These robots have in common that they are of recent development and serve to improve the quality of care and the results obtained when treating a patient:

- The da Vinci Surgical Robot: It is a multi-arm robot whose aim is to reduce surgical errors and achieve less invasive surgery for patients. The da Vinci Surgical System gives surgeons more precise control, achieving less blood loss, minimal incisions and much faster recovery. Through high-definition 3D magnified vision and handheld controls, surgeons control the robot and perform operations through it. The da Vinci System makes tiny, precise incisions that human hands are unable to make. Therefore, this is not a collaborative robot, since the Da Vinci lacks autonomy and is used as a tool. The surgeon handles the robot at will, the function of the robot is to increase the precision of the surgeon's hands. The interesting thing about this system is that it is a robotic arm, it uses a technology that looks similar to that of collaborative robotic arms, but the way it is used does not coincide with a collaboration between robots and humans. But it is positive to see that robotic arms can be very useful in the health sector. Fig 15. Shows The da Vinci Surgical Robot.

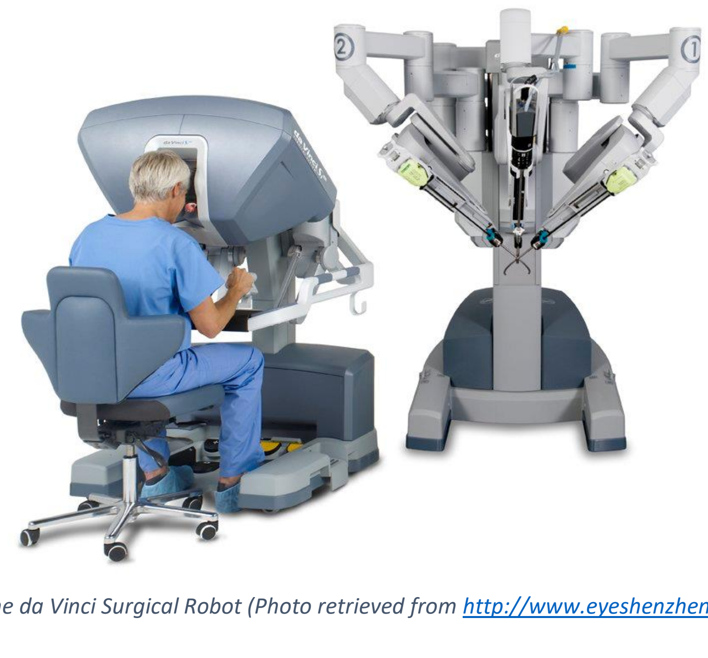


Fig. 15 The da Vinci Surgical Robot (Photo retrieved from http://www.eyeshenzhen.com/)

- The Xenex Germ-Zapping Robot: Hospital Acquired Infections (HAIs) are another widespread health care problem that could be improved by robots, and these types of infections are the order of the day because of the coronavirus, much of the health care staff has been infected while working. HAIs often occur because hospitals are not always able to clean rooms to ensure total sterility, either because of lack of time or because of the difficulty to eliminate all the germs. It is of great importance to have clean hospitals in order to prevent health personnel or patients in a weaker state who lack the necessary immune defences from becoming ill. To combat this serious problem, the Xenex, is an automated and portable robot, which is used to disinfect hospital rooms in a few minutes using full spectrum UV rays that completely eliminate bacteria and viruses. The robot works as follows: a health worker must take the robot to the room to disinfect and leave it in the room alone. When no one is in the room, the robot starts disinfecting through UV rays. There is also a newly developed model of the robot that moves by itself and does not need to be carried around. The function of this robot would fit in part with the objective of the present Master Thesis, since it helps to reduce the risk of infection of health care personnel, but as in the previous case of the da Vinci robot, it is not a human-robot interaction that can be considered as collaboration, but rather an interaction of the coexistence type according to the classification proposed by Onnasch et al. (2016). But it is comforting to see that robots can be useful in treating highly contagious diseases. Fig. 16 shows the Xenex Germ-Zapping Robot.

Fig. 16 The Xenex Germ-Zapping Robot (Photo retrieved form https://www.xenex.com)

- The PARO Therapeutic Robot: This robot is designed to improve the quality of life during recovery from surgery or treatment of depression or other mental illness. It is an interactive device with the appearance of a baby seal and is designed to provide the benefits of animal therapy without relying on live animals. Animal therapy is a common tool for relieving stress in patients, but trained animals are not always available to meet current needs. The PARO robot is used with elderly patients with dementia and has been shown to reduce stress and provide comfort to anxious patients. The PARO robot can respond to your name, enjoys being petted and, over time, develops a personalized and pleasant personality, adapted by its memory of past interactions. This type of robot is far from the objective of the present Master Thesis, so it should be classified as great but unsuitable, since it would not be useful to relieve the workload of health personnel nor would it reduce the risk of contagion when dealing with the coronavirus. The reason why this robot has been included in this work is because it can serve as an example that a deeper interaction, in this case between robot and patient, can be useful and helpful also in the health sector. In this case, it is only a companion robot, but it is good that more developed human-machine interactions are beginning to appear in this sector, since the objective of this work is none other than to demonstrate the great benefit that could be obtained by introducing collaborative interactions between humans and robots in the health sector. Fig. 17 shows the PARO Therapeutic Robot.

Fig. 17 The PARO Therapeutic Robot (Photo retrieved from https://robots.ieee.org/robots/paro/)

- The TUG: Transporting medicines, supplies, meals and other materials around the hospital is one of the most time-consuming tasks for health workers. For example, in a hospital of about 200 beds, transporting meals, bedding, laboratory samples, waste and other items is estimated to be the equivalent of travelling more than 80 kilometres per day. The TUG is an autonomous mobile robot developed by Aethon Inc. to transport supplies to where they are needed, freeing health care personnel from heavy physical loads and long journeys, allowing them to focus on patient care. They are programmed with the hospital's floor plan and are also equipped with a multitude of sensors to prevent collisions so that they do not encounter anything on their way through the hospital. They also have built-in speakers that gently ask people to step aside as they move through the congested hallways. This type of robot fits perfectly with the objective of the present Master Thesis in terms of features and mode of interaction. It is a collaborative robot since it works as a team with the health staff to achieve a common goal, efficient and effective hospital care. Its characteristics make it an ideal robot to face the coronavirus, and at the same time it relieves the workload of the health personnel and protects them, since thanks to a robot of this type the access to rooms of infected patients would be minimized and so would decrease the risk of infection for the health personnel. For all this, the characteristics and the way of working of the TUG robot will be taken into account when thinking about possible applications of collaborative robots to help the health sector with the coronavirus crisis. Fig. 19 shows a nurse working with the TUG Robot.

Fig. 18 The TUG (Photo retrieved from https://www.businesswire.com)

As already mentioned, some of these robots are rather tools for doctors or surgeons like the da Vinci, which does not perform any tasks on its own and must be handled by humans. The Xenex Germ-Zapping robot is also like a tool because when using it, a person must take it to the area to be cleaned, activate it and leave it alone in the room. It does not move by itself and does not interact with humans in any way. These examples are not collaborative robots, these technologies are not the focus of this work, but it is worth pointing out how useful they can be in certain situations. Due to the great social inequalities that exist in the world, not all countries enjoy the same level of health care. For example, in Africa it is true that the number of highly qualified doctors and nurses is much lower than in first world countries due to lack of resources. This is where the great opportunity of telematic assistance comes in, which could improve health care in countries with fewer resources.

Many health services can be provided by telematics, such as remote operation of robots like the da Vinci, providing image diagnosis, diagnosis by robotic microscopes, tele-endoscopies, consultations, definition of treatments, clinical advice and also academic training.

This is what the NAMA Foundation is working on. The purpose of the Navarra Foundation for Medical Assistance in Africa (NAMA) is to promote quality medicine and health sciences training in sub-Saharan African countries. To this end the NAMA Foundation has initiated a programme called CHAT Africa. The CHAT Africa program aims at improving health care and medical education in sub-Saharan Africa. It intends to reinforce the African sanitary system acting both locally and remotely.

For this purpose, a modern and well-equipped Teaching Hospital will be installed in the capital of an African country. This Centre will simultaneously be a School of Medicine, Nursing School and a Training Centre for Specialists in the different branches of medicine and surgery. The Teaching Hospital staff will initially consist of expatriates who will be progressively replaced by personnel trained in the Centre itself. It will be managed by the promoters of the CHAT Africa project as a nonprofit institution.

The African Teaching Hospital will operate in telematic connection with a consortium of European and American University Hospitals which will support the African Hospital both in medical assistance and teaching activities using the recent advances in telematics and robotics. Each Hospital of the Consortium will dedicate a space to install the necessary equipment for the connection with the African centre. Doctors will work remotely for Africa acting from their own hospital and will provide assistance in multiple fields including image diagnosis (CT, MRI, microscopy), robotic ultrasonography, medical consultations, videoconferences for clinical sessions and lessons for students, etc. Thus, the African Teaching Hospital will have “on-site” staff which will be complemented by “on-line “staff.

CHAT Africa is an initiative of the European Chat Africa Federation (ECAF) which embraces the Spanish Fundación NAMA (Fundación Navarra para la Asistencia Medica en África), the French association AFTAMA (Association Française de Télé Assistance Medicale en l´Afrique) and the German association MDAV (Medizin und Digitalisierung in Afrika e.Verein). The aim is to enlarge the scope and to convert CHAT Africa into a Euro-American project implicating in this initiative the US government and several US University Hospitals. Fig. 20 shows the logo of NAMA Foundation.

Fig. 19 NAMA Foundation (Photo retrieved from http://www.namafundacion.com/)

Leaving behind the issue of telematic medicine and refocusing the work on collaboration between robots and humans which is the main theme, it has already been commented that the above-described PARO Therapeutic Robot is an example of a more complex human-robot interaction, it is a collaborative robot but its function does not fit the objective of the present work since it would not achieve either a relief of the workload of the health personnel or a reduction of the risk of contagion. Therefore, it should be classified as an interesting development, but it does not fit in the present Master Thesis.

On the other hand, from the mentioned robots, the TUG is the best example of HRC, it works in team with the medical staff, it has its own objective that helps the health staff by reducing their workload, achieving an improvement in the general performance of the hospital.

But even though the PARO and the TUG are collaborative robots, neither of them has the typical shape of an industrial collaborative robot, nor the shape of a robotic arm. Here the question arises as to whether a standard collaborative robot already marketed could fit in the healthcare sector and be useful? Could a robotic arm such as the Kuka LBR iiwa mentioned above perform any tasks that would it be helpful to health care personnel? Thus, the following example of a collaborative robot application in the health sector shows that this is also possible.

- The ROBERT rehabilitation robot: Life Science Robotics has developed a medical product to perform patient mobilization tasks. The ROBERT robot has been developed using the mechanics of the LBR iiwa, this is the mechanical arm developed by Kuka discussed in section 2.3. and shown in Fig. 8. It is an innovative and pioneering robot that focuses on efficient rehabilitation and early mobilization of patients. The robot offers both active resistive and assistive mobilization and provides patients and health professionals with better conditions for rehabilitation. It reduces heavy and repetitive lifting for staff and is very easy to set up and use. The robot works in the following way: the nurse holds the robot's arm to the patient's leg, for example, and performs the therapeutic movements manually, moving both the robot and the patient's leg at the same time. In this way, the ROBERT robot memorizes the movements and can then perform them independently, just as the nurse has done and as often as required. Fig. 21 show a nurse using the ROBERT robot.

Fig. 20 ROBERT Robot (Photo retrieved from https://www.kuka.com)

This is a good example that the technology developed in the field of HRC, typically in the industry sector, can also work very well in the health sector. A commercial robotic arm has been successfully harnessed to help health workers.

As it has been shown that collaboration between humans and robots is also possible in the health sector, it has been demonstrated through these previous robots that they can be of great help. So why are robots like the TUG not yet implemented in all hospitals? Why is it that no more applications for collaborative robots like the KUKA LBR iiwa are being sought in the health sector if it has been demonstrated with the ROBERT robot that they can be of great help?

Whether it is due to a lack of budget from governments for the health sector, a lack of confidence in these new technological developments, or because their great usefulness has not yet been proven, collaboration between robots and humans is still rare, if not non-existent, in hospitals today. This may also be due to a lack of acceptance of robots by society or a fear of being replaced by them. But for one reason or another the task of robots in the health sector today is to be used as tools, to increase the precision of surgeons, to perform MRIs or X-rays or to perform very specific tasks, but robots are almost never used as teammates who have a certain autonomy, and can help achieve objectives more easily.

In the following section, the coronavirus crisis will be presented as a turning point from which HRC is more commonly introduced in the healthcare sector. If collaboration between humans and robots was already useful before the coronavirus pandemic occurred, this virus, as well as any other highly contagious disease, may prove to be very useful in this type of situation. Robots cannot become infected and sick as is happening with a large number of doctors and nurses. If there were more applications of HRC in the healthcare sector the number of infections of healthcare workers could have decreased significantly.

4.2. COVID-19

Disease is intrinsically part of human history. At present, the world is suffering the coronavirus pandemic, but ever since human beings began to organize themselves in society and to create nuclei of people who lived together in the same territorial space, contagious diseases took on a special role. In many of these pandemics, after having overcome them, there is a radical change in society and in the economy, they are a turning point.

Just look at what has happened throughout history, after the Black Death the Modern State was created, after smallpox there was a great development in the economic system that gave rise to today's capitalism and after the cholera, public health began to be provided. So, it is very likely that there will be changes in society and economy, once we get past the current pandemic.

For the past few months, everyone has been on the lookout for the much-named COVID-19 (Corona Virus Disease 2019). It is an infectious disease caused by the SARS-CoV-2 virus. It was first detected in the Chinese city of Wuhan in December 2019, having reached more than 185 countries on 5 continents. On March 11, 2020 the World Health Organization declared it a pandemic. The COVID-19 keeps the whole world on edge. So far, more than 555.000 people have died and there are more than 12,2 million confirmed cases worldwide

People can catch COVID-19 from others who have the virus. The disease can spread from person to person through small droplets from the nose or mouth which are spread when a person with COVID-19 coughs or exhales. The WHO estimates that the rate of infection (R0) of the virus is 1.4 to 2.5, although other estimates speak of rates as high as 3. To control an epidemic, the R0 needs to drop below 1. Fig. 22 shows the accumulative number of reported COVID-19 cases per 100.000 habitants in every country in the world.

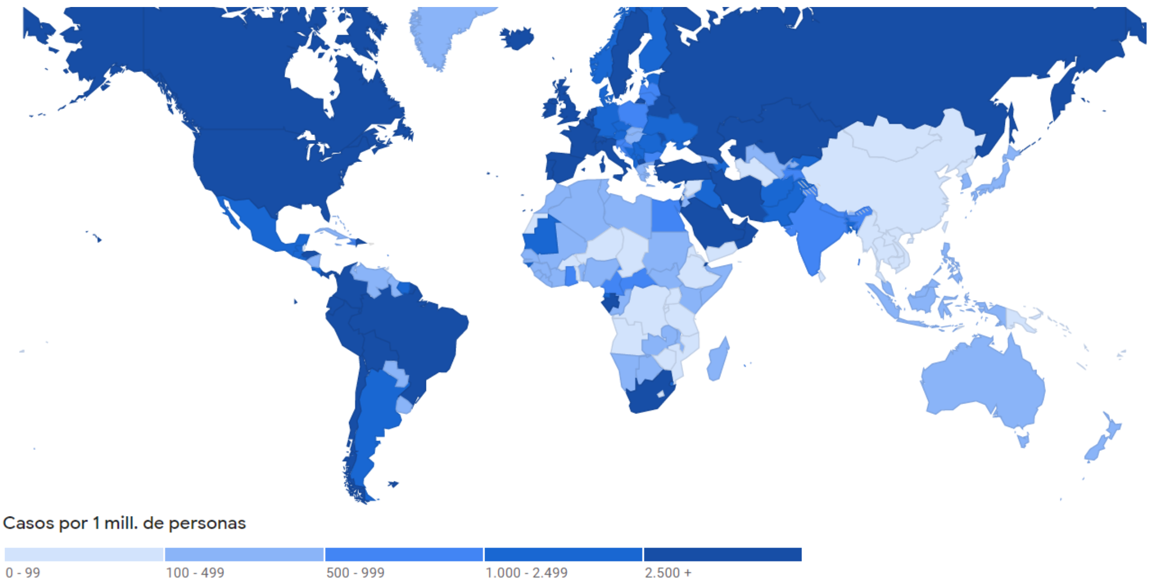


Fig. 21 COVID-19 cases per 1.000.000 habitants (Photo retrieved from https://www.google.com/covid19-map/?hl=es accessed July 10th, 2020)

One of the big problems that has been faced during this pandemic has been the lack of medical personnel. Every day there were many new infections and the number of doctors and nurses was not enough to cope with the amount of work to be done. In addition, because it was a highly contagious disease, many medical personnel also became ill, either because of a lack of protective material or simply because they were more exposed than the rest of society.

In Spain, a large number of nurses have had to leave the hospitals due to symptoms of COVID-19. A survey was conducted by the Spanish Nursing Association on the impact of Covid-19 on the nursing profession. The organization estimates that about 70,000 nurses in Spain may have been potentially infected with coronavirus. 31% of nurses believe that they were infected due to lack of protective equipment. 76.2% of the professionals with positive tests believe they have been infected while providing health care, of these, the 35.1% due to lack of adequate equipment or material and the 41.1% due to care of undiagnosed patients.

The following conclusion can be drawn from this survey: nursing has been one of the professions most affected by the coronavirus and probably the one with the highest number of infections in the health sector. The main problems that have arisen are the following:

- Lack of personnel due to the large number of patients to be treated
- High degree of exposure to be infected
- Lack of sanitary protection equipment, such as masks, gloves, gowns, protective screens, etc.
- Too much workload and consequent fatigue
- Scarcity of tests carried out

Looking at what happened, this is a great opportunity for HRC in the health sector. This could be the turning point behind this pandemic, to get the HRC introduced in a definitive way in the health sector, to get the already existing cobots introduced in all hospitals, to keep developing these technologies based on the HRC, to look for new applications and develop the existing ones and to get governments to invest money and time in it. It is clear that HRC in the health sector can be of great help in this type of situation, both for patients and professionals, as it would reduce the workload and the risk of infection significantly.

The main advantage that HRC have in this type of situation is obvious, robots cannot contract diseases no matter how contagious they are. In this way, cobots could prevent nurses and doctors from spending unnecessary time exposed to infection, thus reducing the number of infected professionals.

In the next section of this paper, two possible applications of HRC with a nurse when dealing with a highly contagious disease like Covid-19 will be described. The solutions will focus on assistance to nursing tasks, since, as explained above, this has been one of the professions that has suffered most, if not the most, from this coronavirus crisis. But HRC could achieve benefits in any area of the health sector.

4.3. Possible Applications of HRC in Nursing to Cope with the COVID-19

First, it is important to understand the meaning of nursing in order to develop technology that will help the profession. Society is increasingly surrounded by technology and tools that help to perform the respective jobs in a more efficient and productive manner. In the nursing profession, the humanization of care must not be forgotten. Florence Nightingale, a famous nurse pioneer of modern nursing said, "*Wise and humane management of the patient is the best safeguard against infection*". Another famous quote, related to palliative care, says "*If you can heal, heal; if you cannot heal, relieve; if you cannot relieve, comfort; and if you cannot comfort, accompany*". As can be seen, it is clear that nursing without the human factor is meaningless, a robot lacks the necessary feelings that characterize good nurses.

Therefore, it will be assumed that these possible applications of human-robot collaboration will always be complementary and never a replacement for a human nurse. Therefore, the following are some of the tasks that nurses perform on a daily basis that could be performed in collaboration with a robot. Always seeking to ease the workload on repetitive tasks and never forgetting the humanization of care. This list of tasks is made with the intention of identifying those that fit more easily in a collaboration between a nurse and a robot when dealing with the coronavirus, which is the objective of this Master Thesis. The tasks identified are the following:

- **Preparation of medication**: The medication to be administered to the patient must be selected, prepared and checked. Making sure it is the right patient, the right medication, the right dose, the right dilution, the correct route of administration is used, and the time of administration is indicated. These tasks are very similar to those already automated in the industry, such as checking references, quantities, picking and delivery. It is therefore very feasible to apply HRC to these types of tasks.
- **Taking vital signs**: Measurement of blood pressure, heart rate, oxygen saturation, temperature, respiratory rate. A commercially available robotic arm equipped with the necessary sensors could perform these tasks, thus saving nurses a lot of time. In addition, the data could be passed instantly via Wi-Fi to the computer system and thus have it in the patient's medical history.
- **Oral medication administration**: This is the least risky form of medication administration. The medication should only be taken close to the patient's mouth, normally in tablet form. In this way, it is a task very similar to those carried out in industry, when a robotic arm supplies parts to be assembled to an operator. But in this case, it must be also checked the patient's first and last name, the history number (it can be by reading the barcode on the patient's identification bracelet through a sensor) and check that the oral medication it is been administered is the correct one.

- **Weighing the patient**: In some cases, it is often necessary, such as children, since the doses of medication are a function of weight, also in patients who retain fluids is necessary to control the weight regularly or for liver and kidney diseases. In patients with chemotherapy it is also necessary to control the weight or in patients who have eating disorders. For this type of tasks the use of a collaborative robot can be useful. As in the industry the collaborative robot helps the operator to lift a heavy load, this type of robots could be transferred to the sanitary sector including load cells to measure the weight of the patients.
- **Assist in personal cleanliness for patients with reduced mobility**: As in the previous case, the task is to reduce the effort made by the healthcare professional when moving the patient in this case to clean him/her.
- **Cleaning tasks**: This type of task is not related to nursing, but it is a daily task in hospitals and nursing homes that can be easily automated. Among them would be, cleaning the rooms and furniture, collecting dirty clothes, depositing them in the laundry, delivering clean clothes, etc. Most of these tasks are already carried out and automated in other areas separately. Collecting and delivering clothes is a pick and drop task, very common in the industry, and on the other hand, there are currently robots in charge of cleaning such as the world-famous Roomba. There are also robots in charge of disinfecting and eliminating all kinds of germs and viruses like the aforementioned The Xenex Germ Zapping showed in Fig. 16.
- **Bringing food to hospital patients**: Every day, between 3 and 5 times a day, health personnel bring food to each hospital room. This task could be performed by a robot. Something similar happens in factories and could serve as an example for hospitals. Every day, pieces must be continuously brought from the warehouse to the workstations. In many factories, this flow of pieces is done by robots, as is the case of the AGVs (Automatic Guided Vehicles), they are vehicles that move without a driver throughout the factory, have guidance, control and management systems, allowing them to collect, move and deliver goods. In addition, they can detect obstacles in their way and avoid collisions. This type of technology could be implemented in hospitals to carry out the tasks of supplying food to the rooms from the hospital kitchen. There are already robots of this type like the previously mentioned TUG showed in Fig. 19.
- **To serve as a communication system with the family**: There are many times when a patient is admitted and cannot receive visitors, because they must remain isolated. In these situations, communication with the family is done either through intermediaries, such as a doctor or nurse, or through smart phones or tablets, and believe it or not, not everyone has this type of device or knows how to use it, as is often the case with older people. In this type of situation, a robot equipped with a camera, microphone, speakers and screen, that allows a certain degree of interaction with the patient, could make this experience much closer. The family might even be able to move the robot around the room as they wish to look where they want. Enabling each room where there are isolated patients with this type of equipment, would save a lot of time for healthcare personnel and increase the closeness between patients and family.

These types of robots could also have the patient's data updated in real time to keep the family informed, but this would already be an entry point for data protection issues and the ethical dilemmas they pose.

Eight possible tasks within hospitals have been presented that could be performed by cobots. In addition, many of them could use technologies currently available on the market such as Kuka robotic arms or TUG robots, which would save research and money.

Many of these tasks are very common applications in industry such as search, supply, application and delivery, functions such as move, grab, retrieve and bring are solved in industrial handling technology in various ways and can be easily transferred to the health care sector. These technologies with their respective experiences, methods, regulations and safety standards can serve as the basis for the development of HRC in the health sector and transfer all the necessary knowledge from them.

Following the list of possible applications, which could be much longer, the two applications that come closest to the objective of this Master Thesis will be selected. It is reminded that they should try to help healthcare personnel, especially nurses, to cope with the coronavirus. In this way, they should be applications that try to relieve the workload of nurses, and at the same time reduce their risk of infection. The following two sections will describe in more detail the two situations in which a collaborative robot can help achieve this goal.

4.3.1. COBOT FOR VITAL SIGNS MEASUREMENT IN EMERGENCIES

The first application that has been thought to be of great help when dealing with the coronavirus is the above-mentioned vital signs monitoring. This task is performed whenever an emergency arises and during the coronavirus crisis one of the major problems has been the overwhelmed of hospital emergency departments as explained below.

During the coronavirus crisis, one of the most serious problems that has occurred in hospitals, in countries such as Italy or Spain, has been the crowding of the emergency departments. The health personnel could not cope with so many patients arriving at the hospital and large crowds of people and long waiting times were formed. Some hospitals in Madrid have recorded up to almost 2000 emergencies per day when normally less than 300 emergencies are received daily in a normal hospital. This means receiving almost 7 times more emergencies than normal. Thus, finding a way to alleviate the work to be done in the emergency department would be of great help.

In all hospitals, when entering the emergency department, a very similar protocol is followed. They ask for the patient's personal data, reason of the consultation, date of onset of symptoms and vital signs are taken.

Healthcare workers have been advised since the beginning of the pandemic to reduce contact with infected patients as much as possible. The only step in the emergency protocol that requires physical contact between patient and nurse is when measuring vital signs. In this way, to reduce the danger of contagion, a collaborative robot could be designed to take the patient's vital signs. In addition, the workload would be reduced because while the robot takes the vital signs, the nurse could ask the patient for data and thus speed up the process, always maintaining a safe distance.

The robot could perfectly be one of the many collaborative robotic arms already on the market, like the Kuka LBR iiwa showed in Fig. 8, which equipped with the corresponding sensors should be able to measure:

- **Body temperature**: The robot must be equipped with a thermometer or a thermographic camera. There are many digital thermometers that are easily attached to a robotic arm like the one in the Fig. 24.

Fig. 22 Digital Thermometer (Photo retrieved from https://www.quirumed.com)

- **Pulse rate**: Many of today's sports watches are equipped with highly reliable pulsometers, this developed technology could be used and equip it in the robotic arm. But it will not be necessary, since by equipping the arm with the necessary devices to measure other constants such as blood pressure or oxygen saturation, the heart rate is also measured.
- **Blood pressure**: A blood pressure cuff, like the one of the tensiometer showed in Fig. 25, should be incorporated where the patient can insert his arm to have his blood pressure measured. This system could be used to measure also the heart rate and thus save the pulsometer. It could be placed on the forearm of the robotic arm.

Fig. 23 Tensiometer by Omron (Photo retrieved from https://www.quirumed.com)

- **Blood oxygen saturation**: It is measured with the pulse oximeter, which consists of a transducer with two parts, a light emitter and a photodetector, and is usually shaped like a clamp like it is showed in Fig. 26. The clamp is placed on the finger to take the measurement and receives the oxygen saturation and heart rate information. Since the robotic arm must be equipped with a pulse oximeter and a blood pressure monitor, the data collected by these two devices on the heart rate can be contrasted. In this way, the pulsometer can be dispensed with definitively.

Fig. 24 Pulse Oximeter (Photo retrieved from https://www.quirumed.com)

- **Respiration rate (rate of breathing)**: The breathing rate is measured by simply counting the breaths in one minute, the nurse could perform this measurement from a safe distance. But since the coronavirus affects the respiratory system, it would be useful to incorporate a stethoscope with a microphone that captures the sound of breathing. There is a digital stethoscope developed by eKuore Pro showed in Fig. 27, that presents advantages of adaptability, incorporates cardiac/lung filters, allows recordings and visualizations of phonograms that would be perfect for this type of use. This would help to measure the breathing rate and also be able to detect possible breathing abnormalities. The sound received by the microphone would be heard by the nurse in the distance.

Fig. 25 Classic Stethoscope and Digital Stethoscope by Ekuore (Photo retrieved from https://www.ekuore.com/)

In short, the robotic arm should ideally be equipped with a digital thermometer, a blood pressure cuff, a pulse oximeter and a digital stethoscope. The robotic arm would be equipped on its hand or wrist with a coupling that would include the thermometer, the pulse oximeter and the stethoscope. The blood pressure cuff could be placed on the forearm of the robotic arm, in order to make room for the other tools. The coupling should allow the robot to alternate between the 3 tools, and the robotic arm is a good solution as it would allow you to move the right tool to the right position to make the measurements. A possible solution would be for the patient to manually guide the robot to the position where the measurement is to be made, with the help of the nurse's instructions from a distance. This would be a haptic interaction between the robot and the patient, many problems in programming the robot's movements would be avoided, as well as possible risks of collision and damage to the patient. Other collaborative robots use this type of interaction in the health sector, such as the example of the therapeutic robot Robert showed in Fig. 21.

The use of such a robot would prevent a nurse from taking the vital signs of a potential coronavirus-infected patient, which usually takes about 5 minutes per patient. This also avoids the risk of contagion that comes with being so close to the patient. Receiving more than 1500 emergencies per day, such as those received during the pandemic, would save a total of 125 hours of work and decrease the risk of transmission to nurses.

This type of cobot would meet the objectives of this Master Thesis, using technologies already existing in the industry, such as the cobot Kuka LBR iiwa showed in Fig. 8, and adapting it with the necessary instruments, also existing in the health sector, it would be possible to relieve the workload of nurses when treating the coronavirus, reduce the exposure time of nurses to be infected and all this through a collaboration between robots and humans in the health sector.

4.3.2. COBOT FOR CORONAVIRUS TESTING

The second task in which it has been thought that a collaborative robot could be helpful, has been to help to carry out the coronavirus tests in hospitals. This is a task that is being done every day on numerous occasions as will be explained below. As in the application of taking vital signs, this can also easily take advantage of existing technologies, as will be described below, to benefit from collaboration between humans and robots when dealing with the Covid-19. But first, to explain how a collaborative robot could help in this task, how this kind of tests are carried out will be explained.

One of the firsts tasks that must be performed in hospitals whenever a patient with possible symptoms of COVID-19 arrives, is to take a coronavirus test on the patient as soon as possible to determine whether the patient is infected or not, and so, to be able to act correctly as soon as possible. The main laboratory test for detecting coronavirus is called Polymerase Chain Reaction (PCR), a laboratory technique that allows small fragments of DNA to be amplified to identify microscopic germs that cause the disease.

To perform the analysis, a sample is taken with a swab. This procedure is also called a smear and is performed in the nostrils and throat. The procedure for taking the sample of cells with the swab is as follows:

Two nurses are required to be present in the patient's room, the two nurses enter the patient's room equipped with all the necessary protection equipment, mask, goggles, gloves, gown, protective screen, etc.

A nurse uses swabs to obtain samples from both the patient's nose and throat. For the throat smear, the swab is inserted up to the height of the bell and swabbed, like it is shown in the Fig. 28. For the nasal smear, the swab is inserted through the nostrils while the patient's head is held, as it instinctively moves backwards, and swabbed again.

Fig. 26 Throat smear (Photo retrieved from https://www.niusdiario.es/)

The sample is isolated in a sterile container, which is held by the second nurse who waits for the other nurse to take the swabs, opens the container and closes it once the samples have been inserted, as shown in Fig. 29.

Fig. 27 Nurse holding steril container (Photo retrieved from https://www.niusdiario.es/)

This is done in this way so that the nurse who has come into contact with the patient does not touch anything else and so that no transmission of the virus occurs. The sample is sent immediately to the laboratory, which takes an average of 4 to 5 hours to get the test result.

There are other tests for the detection of COVID-19 such as nasal aspiration, tracheal aspiration, sputum test or blood test but the most widespread is the swab sample which allows a quick and accurate diagnosis of the virus.

Now it is time to find a task for a collaborative robot to facilitate the coronavirus testing process for nurses. As can be seen in the brief description of the test, two nurses are needed to perform the test. The nurse in charge of taking the samples performs functions that require special care of the patient, as these are sensitive areas, in which tact and empathy are important, so this task is difficult to perform by a robot. And if, in any case, this task was performed by a robot, it could make the patient feel uncomfortable, scared or distrustful. But the other nurse only holds, opens and closes one sterile container, and follows the other nurse to the patient's room. This task could be perfectly carried out by a collaborative robot and thus the staff needed to perform the test would be reduced by half. This would reduce the number of medical personnel entering the rooms of possibly infected patients, thus reducing exposure and the risk of contagion of personnel.

Only in Spain, more than one million PCR tests have been performed for the diagnosis of coronavirus, at an average rate of about 40,000 tests per day. The use of collaborative robots in this test will mean a great relief of workload for health personnel, since, as mentioned above, the personnel required would be reduced by half. The characteristics required for a robot to perform a function of this type will be described below.

The main requirement logically is that the robot must be able to open and close a sterile container when the nurse wishes to deposit the sample in it. This task does not seem to be a great difficulty, many collaborative robots are engaged in similar tasks in the industry. The knowledge from such workstations could be transferred for this function.

The collaborative robot must also have some kind of interface that allows the nurse performing the test to communicate with it. Since the nurse must not touch anything other than the sample, buttons, touch screens, and any type of interface that requires direct contact are discarded to prevent the transfer of the virus. Robot-nurse interfaces through gestures or speech would be valid. The robot, through the interface, would receive the necessary information to know when to act. It should open the box when the nurse approaches with the samples and close it once the nurse has inserted the sample in it.

On the other hand, the robot will also have to move on its own, as there cannot be any contact with the nurse performing the test. In this way, the robot must be able to follow the nurse through the hospital corridors to the patient's room, remain still while the samples are being taken, and once this has been done, collect the samples and then follow the nurse to another room if necessary or take the samples to the laboratory.

After reviewing the literature, it has been concluded that the most useful and currently accepted for this type of work, are the robots that move by means of wheels, so the option of a bipedal robot would be discarded. Wheels would not be an impediment to move around a hospital since all of them are completely enabled for wheelchairs and stretchers to move without any problem along each floor and from one to another by means of lifts.

In this way the robot must know the location of each room, it must know the layout of the hospital. It must also be able to detect obstacles in its path and avoid collisions. This type of technology is developed in the industry sector, as previously mentioned, the AGVs (Automatic Guided Vehicles), also move along the factories from the warehouses to the workstations without a driver, they know the layout of the plant and detect and avoid obstacles with total safety. This kind of technology if transferred to hospitals would be of great help.

In the Healthcare 4.0 section, the TUG robot, developed by Aethon Inc. has appeared and showed in Fig. 19. It is a robot that carries medicines, meals and other needs to the patient rooms. It moves on its own, knows the layout of the hospital and is equipped with sensors to avoid collisions. The technology developed for the implementation of this robot would be really useful at the time of developing the collaborative robot for the coronavirus test, it fulfils all the functions, only a communication interface should be enabled between the nurse and the robot that does not require physical contact.

Just add to the TUG robot the ability to open and close its drawers without the need for a nurse to do so. The drawers should also be completely sterilized and isolated from the rest of the drawers to keep the samples in perfect condition. But a robot with the features of the TUG robot would serve perfectly to help perform the coronavirus PCR test by taking samples.

Summarizing the content of this section 4.3 of the present Master Thesis, two possible applications are proposed in which through a collaboration between robots and nurses tasks are performed when treating the coronavirus. After listing possible tasks in which a collaborative robot would fit in this type of situation, the measurement of vital signs and the taking of samples for the coronavirus PCR test have been chosen. In both situations, it has been explained that using HRC in these applications, a reduction of the workload of health personnel could be achieved, as well as a reduction in their exposure to infection, which is the aim of this study.

Furthermore, in both applications it is proposed to use already existing technologies when developing these two HRC applications. Using robots such as the Kuka LBR iiwa equipped with the corresponding sensors and the TUG robot with the addition of a human-machine interface that avoids direct contact, the proposed objectives could be achieved.

These two applications are only two hypothetical situations in which a cobot could be of help in the health sector among the thousands that could be developed. This section has also tried to demonstrate the usefulness that collaboration between robots and humans can have in the health sector, as well as the opportunity to take advantage of the development of HRC technology used in the industry sector.

Once the usefulness of HRC has been demonstrated when dealing with the coronavirus, the following section will discuss the restrictions that will appear when using robots in the health sector.

The restrictions that appear when introducing cobots in the health sector will be discussed, leaving aside the safety restrictions, which will be quite similar to the restrictions that cobots have in areas such as industry, the discussion will focus on restrictions of an ethical and moral nature. Since the beginning of the use of the term robot in Karel Kapek's play in 1921, there has always been a fear on the part of humans of being replaced by robots. In especially humane professions and services such as caring for people in the health care sector. This kind of thinking is aggravated and does not help to achieve the introduction of collaborative robots even though they may ease the workload and protect the staff.

Finally, these kinds of ethical dilemmas that appear as restrictions will give way to the survey carried out in the next section of this Master Thesis.

5. RESTRICTIONS ON THE IMPLEMENTATION OF HRC IN THE HEALTHCARE SECTOR

5.1. IMPLICATIONS FOR SOCIETY AND HEALTHCARE STAFF OF INTRODUCING COBOTS IN THE HEALTHCARE SECTOR

Throughout this Master Thesis it has been commented and demonstrated the great possibilities that exist when implementing collaboration between humans and robots in the health sector. The great benefits that can be obtained from HRC in sectors such as industry have been more than demonstrated. Therefore, if this technology has not yet been transferred to the health sector, it is because some restrictions appear when it comes to doing so. These restrictions will be discussed in this section.

The main restrictions that appear when using cobots in the health sector are similar to those in any other sector. Limitations appear due to safety issues, there are also limitations or difficulties due to the lack of experience in the use of these new technologies, but that could be overcome with staff training. As in the industry, a change of mentality is needed here too to accept and adapt to these new technologies. As seen in previous examples, the collaboration between humans and robots in the health sector can offer great advances and improvements in this service but the staff will need some time to adapt to the new technologies.

If safety was already important in the industry, in the health sector it is much more. The endangerment of humans must be ruled out, the safety has unconditional priority, people in hospitals are often much more vulnerable and can be very weak so any accident with a cobot could be catastrophic. That is why all safety issues are rigorously controlled through regulations, in order to launch a new medical device on the market and to be able to start using it, it must first obtain a quality and safety certificate. It must meet several stringent requirements for this, which are set out in standards such as IEC 60601-1, IEC 62304 or ISO 13485. So, all the regulations related to safety are included in these standards and must be fulfilled.

To obtain this type of certificate, the progress made by Buxbaum et al. (2018) is very useful. The HRC Full-Scope Simulator developed by them, can be very helpful, as explained above, consists of a combination of real test environment and simulator where measurements can be made under constant conditions in an experiment. It is necessary to test to what extent it is accepted the cobot and how dangerous it is. Therefore, simulations that include people and their perceptions and actions are suitable for this purpose. In this kind of proband experiments, it is possible to capture, human expectations, information processing and more characteristics related to the SA.

But, from my point of view, there are other reasons, apart from safety issues, of equal or greater weight that are restricting the implantation of HRC in the healthcare sector. Most of these reasons are based on ethical dilemmas produced by the evolution of new technologies. Ethical issues must be considered particularly in the field of healthcare and medicine.

The literature gives a good overview of potential ethical issues in healthcare robotics and shows that philosophical reflection delivers valuable insights into what exactly might be problematic in this area and why. Here are some ethical and social issues and philosophical discussions that Stahl and Coeckelbergh (2016) identify as central and correspond to the above constraints

Firstly, Stahl and Coeckelbergh (2016) raise the implications for society and healthcare of introducing robots in the healthcare sector. The authors distinguish the following two topics:

- **Replacement and its implications for labour**: This topic raises questions about the purpose of introducing robots into the health care sector. The authors ask whether robots are introduced to solve the problems of the health care sector or to save money by replacing personnel with robots or to further develop research and the robotics industry. This point also raises questions about the fear of being replaced by robots, whether robotics is really a threat to employment and more specifically what consequences the introduction of robots would have for health care workers.
- **Replacement and its implications for the quality of care**: This second point identified by the authors Stahl and Coeckelbergh (2016), focuses on the human factor characteristic of health care. Throughout this Master Thesis, this irreplaceable factor has already been discussed, care and healthcare intrinsically carry certain human factors. Thus, not only is there a fear of being replaced by robots and losing jobs in the health sector, there is also a fear of the dehumanization of healthcare, the "hot" and "human" capacity of healthcare would be eliminated and replaced by a robotic care that sounds "cold" and mechanical. Robots can hardly present empathy or real emotions, and humans have social and emotional needs that a robot could not meet.

Secondly, Stahl and Coeckelbergh (2016), identify issues throughout the literature that have less to do with the idea of being replaced by robots, but that depend on the interaction between man and robot in the healthcare sector, depend on the ability of the robot to take on tasks, and the consequences that arise because of this. The following points are thus identified:

- **Autonomy**: As has already been mentioned throughout this Master Thesis, not all robots used in the health sector have the same autonomy. Some robots like the Da Vinci shown in Fig. 15 lack autonomy and are totally controlled by the surgeons, but others like for example the TUG robot shown in Fig. 19 are able to move by themselves all over the hospital. The more autonomy a robot has, the more capable it is of carrying out tasks without being supervised by humans, and because of this, another ethical dilemma arises: up to what level a robot should be given autonomy? The more autonomy they have, the greater the fear of being replaced by robots. To what extent should a robot be autonomous enough to perform tasks in the health sector without being supervised by humans? These are some of the ethical dilemmas that arise regarding the autonomy of health robots.
- **Role and tasks:** The next ethical conflict identified in the literature by Stahl and Coeckelbergh (2016) is about the role that the robot should play in the health sector and is closely related to the previous point about the autonomy of the robot. In this case, when thinking about the tasks that robots can perform in health care, many questions also appear that cause ethical conflicts, such as, for example, if collaborative robots are introduced in a definitive way in the health sector which tasks should be performed by them and which tasks should be performed by humans. To what extent can tasks be delegated to robots or should robots only help humans, or could they also take over certain types of tasks entirely?
- **Moral agency**: Another discussion provoked by the introduction of robots in the health sector focuses on the fact that robots lack the capacity to reason morally or to solve ethical dilemmas, a robot cannot reflect on the ethical quality of what it does. No matter how much autonomy is given to robots, it seems that they will not be able to solve these kinds of dilemmas from an ethical and moral point of view.
- **Responsibility**: On this subject, Stahl and Coeckelbergh (2016), explain their close relationship with the autonomy and role of the robot in the health sector. As the robot becomes more autonomous and does more and more tasks that were previously performed by humans, the need for the robot to be supervised becomes less and less. But then dilemmas of responsibility arise, such as who is responsible for the tasks the robot does if something goes wrong, humans should be held accountable if they no longer have control over the robot and do not supervise it either.
- **Trust**: The last topic collected from the literature by Stahl and Coeckelbergh (2016) in terms of the tasks that can be performed by a robot in the health care sector is about trust. If a robot is autonomous enough to perform a health care task without the need to be supervised by a person, can the robot be trusted or

does the term trust not apply to robots, would it be more convenient to use the term trust?

Thirdly and finally, Stahl and Coeckelbergh (2016) distinguish a third group of ethical dilemmas that focus on human users when using robots, in this case patients and healthcare personnel, there are two possible issues that give rise to ethical dilemmas:

- **Privacy and data protection**: The development of robotics in the health sector and the introduction of robots that collaborate with healthcare personnel means that robots must be aware of patient data. This raises questions about what data should be collected, who can have access to it, only health professionals or also patients' relatives to be aware of the patient's situation, on the other hand how and where this data should be stored and also what happens to it once health care has been completed.
- **Safety and avoidance of harm**: Finally, Stahl and Coeckelbergh (2016) identify the issue of safety, a topic that has been discussed throughout this Master Thesis and is of paramount importance in HRC. Robots must not harm people and must be safe to work with. If this was already very important in industry and other sectors where robots are used, in the health sector it is even more so, since as mentioned above, in this sector it is very common to deal with people who are especially vulnerable, such as the sick, the elderly and children.

These are some of the ethical dilemmas collected throughout the literature by Stahl and Coeckelbergh (2016), the ethics of robotics and the philosophy of robotics are areas that are attracting more and more experts, as some of these dilemmas and issues raised, make it difficult for society to accept robots and therefore the development of this technology with as much potential as the collaboration between robots and humans in the health sector.

Next, in order to give my two cents on the development of HRC technology, in the following section a questionnaire will be conducted on the issues that cause the above-mentioned ethical dilemmas. If this questionnaire serves in any way to resolve or clarify the way society thinks about these ethical conflicts, it could be of great help in further developing and researching human-robot collaboration in the health sector.

5.2. SURVEY ON THE RESTRICTIONS CAUSED BY ETHICAL DILEMMAS

A survey has been carried out with the intention of showing how people think about collaborative robots and their application in the health sector. The survey has been carried out through the Google Forms application, as it allows to create surveys easily and quickly. It allows to include different types of questions such as short answers, multiple choice or checkboxes and also to include images. It is also a free tool. This application saves the feedback received and allows it to be transferred to spreadsheets for analysis.

The survey was shared through social networks such as WhatsApp, Facebook or Twitter and also by email. The objective was to reach a sample size of 100 people so that the survey would be sufficiently representative.

The survey on the first page, as showed in Fig. 28, contains a brief description of its content in case any of the respondents are unaware of how collaborative robots work.

Survey on the Implementation of HRC in the Healthcare Sector

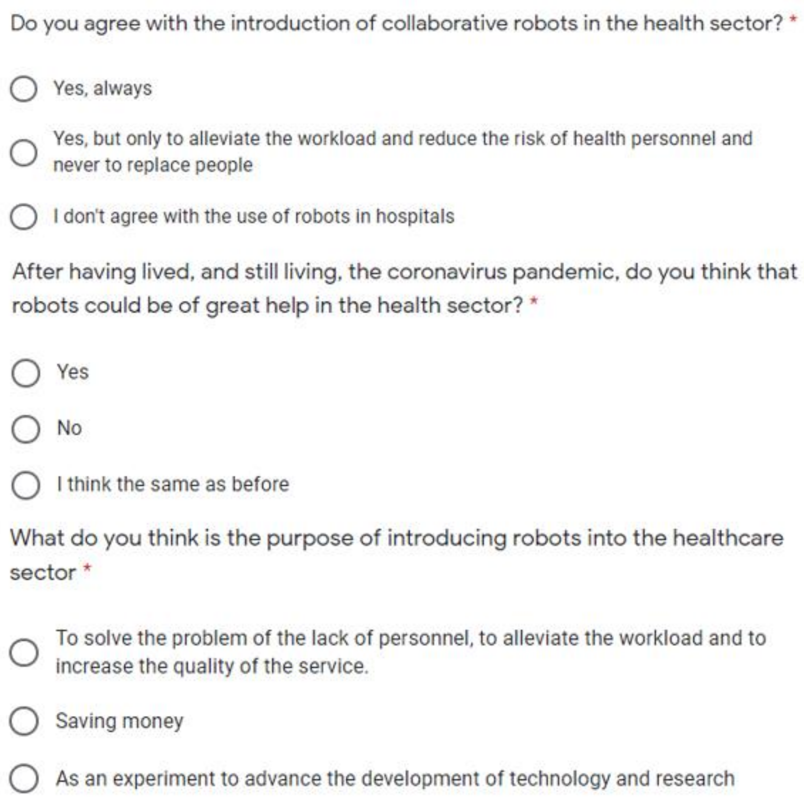
Recently a new type of robots has been developed, the so-called cobots (short for collaborative robots). Cobots are designed to work together with humans, in the same working environment and sharing a common goal.
Thanks to HRC (Human Robot Collaboration) complex tasks that cannot be fully automated can be divided to be performed partly by humans and partly by robots.
For example, a cobot in an industrial application can deliver a component to the worker for assembly, or the cobot can quickly and accurately insert a component selected by the worker.
It has been proven in the industry the great utility of this type of technologies, taking advantage of its great flexibility and versatility have been achieved great benefits in many applications.
Therefore, if so many advances have been made thanks to HRC in industry, why is this technology not being used in other sectors?
The healthcare sector has needed help lately, healthcare personnel have been overwhelmed by the heavy workload due to the coronavirus crisis and a large number of workers have ended up infected. Thus, the use of cobots could be of great help in this sector.
Could the knowledge on HRC developed in the industry be used and transferred to the health sector?
This survey aims to find out what people think about the possible use of this type of technology in the health sector.

Fig. 28 Introduction to the Survey

After this brief introduction, the next page of the survey asks for the sex, age and profession of the participants with the intention of observing whether any of this data influences the decisions made, as has been seen in other surveys conducted throughout the literature reviewed on similar topics, such as Rosenthal-von der Pütten's doctoral thesis Uncannily Human, in which she observes how nationality or age affects the assessment of a robot's appearance.

Once the subject of the survey has been introduced and the necessary data has been collected from the participants, the survey questions are asked. In order to reach the target sample of 100 people it has been decided to prepare a short survey that invites to be filled in in an easy and simple way. The participants invest between 5 and 10 minutes of their time to do it. This way, the proposed objective will be reached more quickly. The survey contains 16 questions in total with the first three questions about personal data of the participants, it could have been longer, but if so, it would have been more complicated to reach the sample of 100 people.

The first three questions are about the introduction of collaborative robots in the health sector, they are intended to find out what people think about it, whether they agree or disagree with the use of collaborative robots in the health sector. They are shown in Fig. 29.


Do you agree with the introduction of collaborative robots in the health sector? *

- Yes, always
- Yes, but only to alleviate the workload and reduce the risk of health personnel and never to replace people
- I don't agree with the use of robots in hospitals

After having lived, and still living, the coronavirus pandemic, do you think that robots could be of great help in the health sector? *

- Yes
- No
- I think the same as before

What do you think is the purpose of introducing robots into the healthcare sector *

- To solve the problem of the lack of personnel, to alleviate the workload and to increase the quality of the service.
- Saving money
- As an experiment to advance the development of technology and research

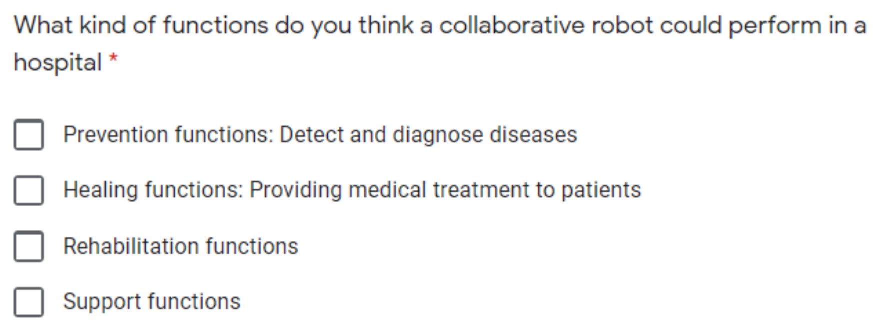
Fig. 29 Questions about the introduction of cobots in the Healthcare Sector

Another topic discussed in this Master Thesis was the coronavirus crisis, which was presented as a great opportunity, even as a turning point, after which collaborative robots could acquire an important role in the health sector. During this crisis, healthcare personnel have been overwhelmed by the workload and many have ended up infected. Therefore, the survey decided to ask about this issue in the second question of Fig. 29.

Finally, the third question deals with the final purpose of collaboration between robots and humans in the health sector. Some authors attribute the lack of acceptance by society of collaborative robots to the possible purposes they could have, such as saving money, saving people's wages, so the answers to this question could be interesting.

The next section of the survey deals with the possible roles that collaborative robots could have in the health sector. As has been seen throughout the literature, the type of tasks performed by a robot and the environment surrounding it have a significant influence on its acceptance by society. Thus, the results of these questions can give clues about which tasks can be accepted more easily.

In the first question of this section, shown in Fig. 30, an attempt has been made to divide the possible tasks or functions that exist in a hospital into four. The classification made is as follows: firstly, there are preventive functions such as detecting and diagnosing illnesses; secondly, there are the curative functions, which try to provide medical treatment to patients with any type of diagnosed illness; and lastly, there are the rehabilitation functions, which aim to ensure that the patient recovers completely after being treated or operated on. In addition, a fourth type of function has been established which would consist of carrying out support tasks in order to be able to perform the above functions.


What kind of functions do you think a collaborative robot could perform in a hospital *

- ☐ Prevention functions: Detect and diagnose diseases
- ☐ Healing functions: Providing medical treatment to patients
- ☐ Rehabilitation functions
- ☐ Support functions

Fig. 30 Question about functions in a hospital

Based on the idea that collaborative robots in the health care sector are introduced with the intention of relieving the workload, the next question shown in Fig. 31 shows four possible types of applications for collaborative robots. Respondents should choose one of the following applications, these are typical applications that could be found in the industry for collaborative robots, so the technology developed in the industry sector could be transferred to the healthcare sector and thus facilitate the introduction of collaborative robots in it.

If the function of the collaborative robot in the hospital was to relieve the workload of the staff, what kind of tasks do you think would be most suitable for the robot *

- ◯ Performing repetitive medical tasks, such as preparing medication, taking patient data, taking vital signs, etc.
- ◯ Performing tasks involving the lifting of heavy loads, such as helping to move heavy patients
- ◯ Carrying out transport tasks such as bringing medication, food and drink into patient rooms
- ◯ Carry out cleaning and disinfection tasks

Fig. 31 Question about functions of cobots

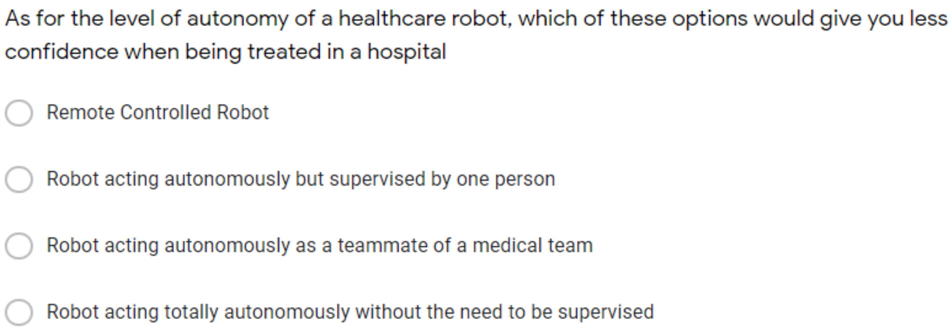
Section 4.3 of this Master Thesis cites eight possible robot applications in the health sector, from which the two possible applications for collaborative robots in the health sector proposed in this paper are developed and described in more detail to help deal with the COVID-19 pandemic. Thus, the third question in this section, shown in Fig. 32, invites respondents to select two of the eight possible applications proposed, with the aim of showing in which tasks in the health sector society sees the use of collaborative robots as most feasible.

What kinds of tasks do you think could be performed by robots in the healthcare sector (choose two options)

- ☐ Preparation of medication
- ☐ Taking vital sings
- ☐ Oral medication administration
- ☐ Weighing the patient
- ☐ Assist in personal cleanliness for patients with reduced mobility
- ☐ Cleaning tasks
- ☐ Bringing food to hospital patients
- ☐ To serve as a communication system with the family

Fig. 32 Question about kinds of tasks

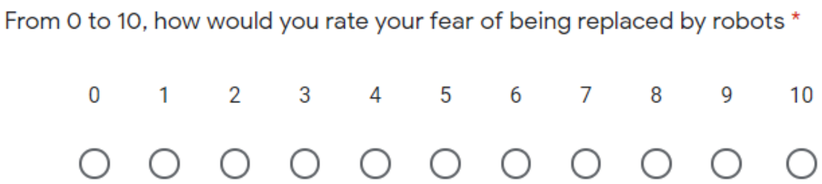
Another of the issues discussed, and which also causes great dilemmas when introducing robots into the health sector, is the level of autonomy that the robot must have. The following question, shown in Fig. 33, deals with this issue and intends to show which of the following four options is the least suitable for the tasks performed by collaborative robots in the healthcare sector.


As for the level of autonomy of a healthcare robot, which of these options would give you less confidence when being treated in a hospital

- Remote Controlled Robot
- Robot acting autonomously but supervised by one person
- Robot acting autonomously as a teammate of a medical team
- Robot acting totally autonomously without the need to be supervised

Fig. 33 Question about the autonomy of the robot

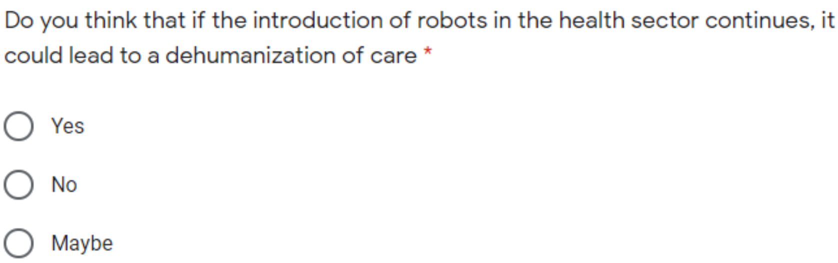
The following survey questions address the negative aspects, or those that may cause negative thoughts towards collaborative robots. The first one can be seen in Fig. 34 and it is about the fear of being replaced by robots. Participants are asked to rate it in a scale from 0 to 10. Many are the authors who have dealt with the fear of being replaced by robots as it has been seen along the literature referred to in this Master Thesis, and this may be one of the reasons why robots are not fully accepted in applications until now made entirely by humans as they can be in the health sector.


From 0 to 10, how would you rate your fear of being replaced by robots *

0 1 2 3 4 5 6 7 8 9 10

Fig. 34 Question about the fear of being replaced

The introduction of robots in the health sector is causing part of society to start thinking that it can lead to the dehumanization of patient care. The introduction of collaborative robots could aggravate the situation and lead to an increase in this type of thinking. The practice of health care is based on ethical components and is founded on humanist principles such as understanding, involvement and compassion. Empathy makes it possible to develop these kinds of attributes; it is about the ability to feel the "other". In this way, through the question shown in Fig. 35, it is tried to show if this way of thinking has an important weight in society.


Do you think that if the introduction of robots in the health sector continues, it could lead to a dehumanization of care *

- Yes
- No
- Maybe

Fig. 35 Question about the dehumanization of care

The last question in this section, shown in Fig. 36, deals with some of the disadvantages of medical robots. It is intended to find out which of the following disadvantages is most important when evaluating a collaborative robot for a healthcare application. These disadvantages have been cited throughout this Master Thesis.

Which of the following do you think is the main disadvantage in using robots in the healthcare sector *

- ◯ Robots create a sense of fear and insecurity in some people
- ◯ Robots lack feelings, reasoning and awareness
- ◯ The robots have a cold and rocky appearance
- ◯ It is impossible for communication with a robot to be as complete as with a human

Fig. 36 Question about the disadvantages of cobots

In section 2.3 of this paper, an introduction to HRC is given. It discusses the different possible forms of communication that can take place through a human-machine interface. Bauer et al. (2008) make a classification shown in Fig. 7. The following question, shown in Fig. 37, deals with this topic and takes the five forms of communication described by Bauer et al., asking respondents to choose which one they feel is most suitable for an application in the health sector.

Which of the following forms of communication do you think is most appropriate between a robot and a patient *

- ◯ Speech
- ◯ Gesture
- ◯ Action, the robot will be able to identify certain actions and act accordingly
- ◯ Haptic Signal, through physical contact with the robot
- ◯ Physiological signal, through signals such as pulse, brain activity, or muscle activity

Fig. 37 Question about the ways of communication

To finish the survey, the last two questions focus on what the collaborative robot for the health application might look like. For this purpose, images of robots that have been appearing mostly throughout the Master Thesis have been taken. A total of 6 robots have been chosen, as shown in Fig. 38. The robots chosen are: TUG, Robert Therapeutic Robot, Assistant Robot AR, Asimo, CB2 and Geminoid HI-4. The only two of these six robots that have not appeared throughout the work are the Assistant Robot AR and the CB2 robot, but they do appear in works such as Uncannily Human, which has already been mentioned throughout the Master Thesis. The function of these robots is not important since only their appearance will be evaluated in these questions.

It has been tried to make the appearance of the chosen robots more and more similar to the human one, starting from robots with a clearly mechanical appearance to humanoid robots, trying to follow a more or less linear trend. This has been done in this way to see if there is, in some way, some phenomenon similar to the "Uncanny Valley" commented in section 3.4 of the present Master Thesis.

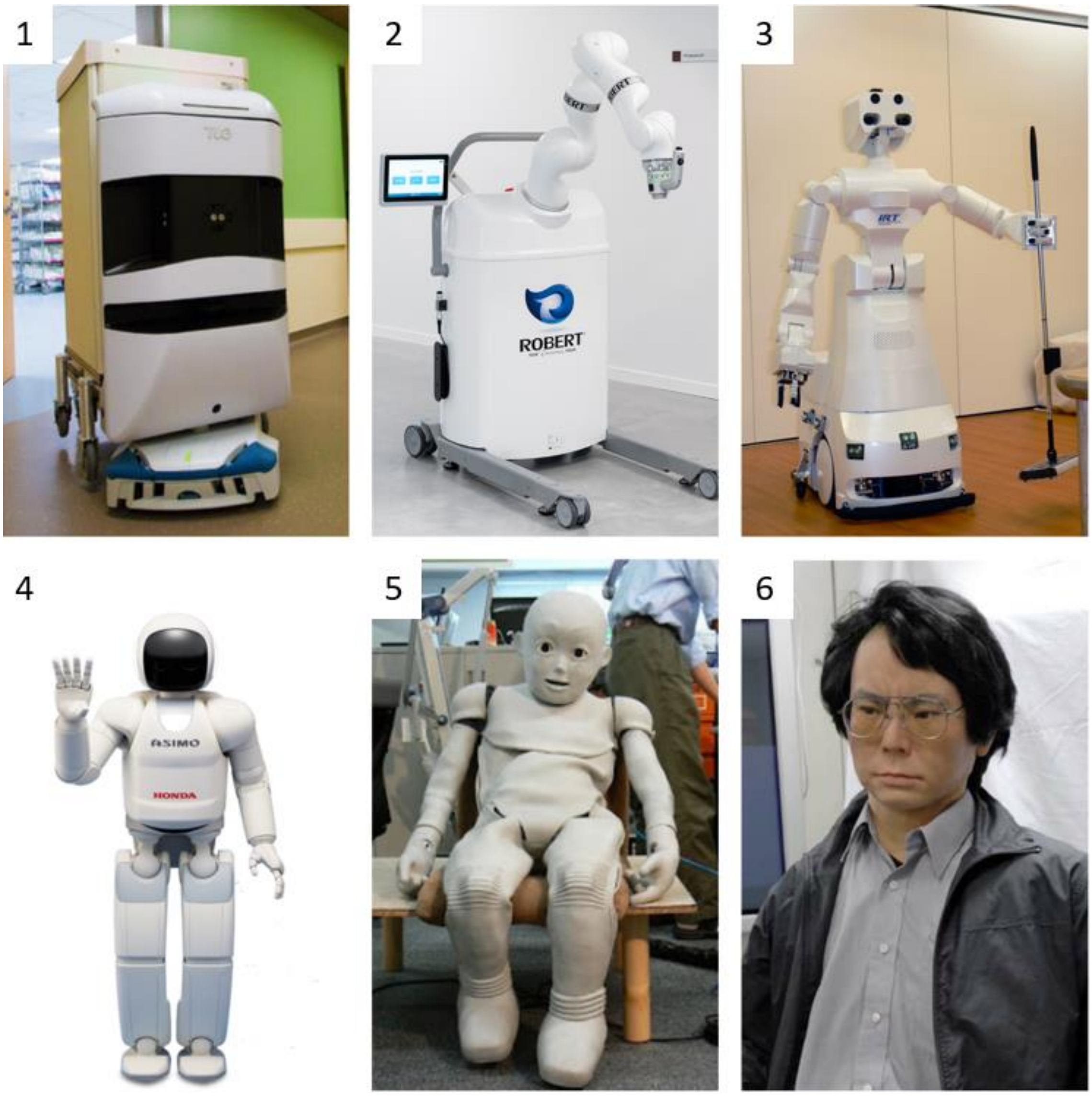


Fig. 38 Robots chosen for the questions about appearance

Two questions are asked about these robots, and each question only allows to choose one of the six robots. The questions are as follows:

If you saw such a robot in a hospital, what would you find most pleasing? *

And which do you think will be the most useful? *

The first question focuses only on the appearance of the robot, asking which one is more pleasant and the second question on the usefulness of the robots. These issues have been addressed by different authors throughout the literature reviewed on robots. Appearance and utility are of great importance when evaluating a robot and also influence the acceptance of the robot by society. If the appearance is pleasing to the patients the robot will have a higher acceptance, as well as if the robot seems to be useful. But care must be taken because if the robot's capabilities do not correspond to those it appears to have, it can cause a negative reaction towards the robot. These two questions are intended to find out what people think about the appearance of robots in the health sector.

5.3. Analysis and Interpretation of the Survey

The survey was active and waiting for responses for one weekend, after which the number of participants was 106, so the goal of reaching a sample size of 100 participants was met and no more responses were accepted. This section will then proceed to the analysis and interpretation of the data collected in the survey.

As mentioned above, the survey was completed by a total of 106 participants, 67 of whom were men and 39 women. The age range of participants varies from 18 to 72 years, but the vast majority of participants are under 30 years old. Finally, the professions of the most repeated participants were engineers, health sector personnel, lawyers and students. All these data are included in the following tables and will be used to check if any of them influences the decisions of the participants.

What is your gender?		
	Recount	**Percentage**
Female	39	36,79%
Male	67	63,21%
Total	**106**	**100,00%**

Fig. 39 Table results gender

What is your age?		
	Recount	**Percentage**
Less than 30	73	68,87%
30-55	14	13,21%
More than 55	19	17,92%
Total	**106**	**100,00%**

Fig. 40 Table results age

What is your profession?		
	Recount	**Percentage**
Administrative	4	3,77%
Engineer	17	16,04%
Architect	9	8,49%
Entrepreneur	3	2,83%
Healthcare Sector	17	16,04%
Commercial	4	3,77%
Consultant	2	1,89%
Deliverer	1	0,94%
Designer	1	0,94%
Economist	4	3,77%
Journalist	4	3,77%
Lawyer	14	13,21%
Musician	2	1,89%
Retired	3	2,83%
Student	11	10,38%
Teacher	8	7,55%
-	2	1,89%
Total general	**106**	**100,00%**

Fig. 41 Table results profession

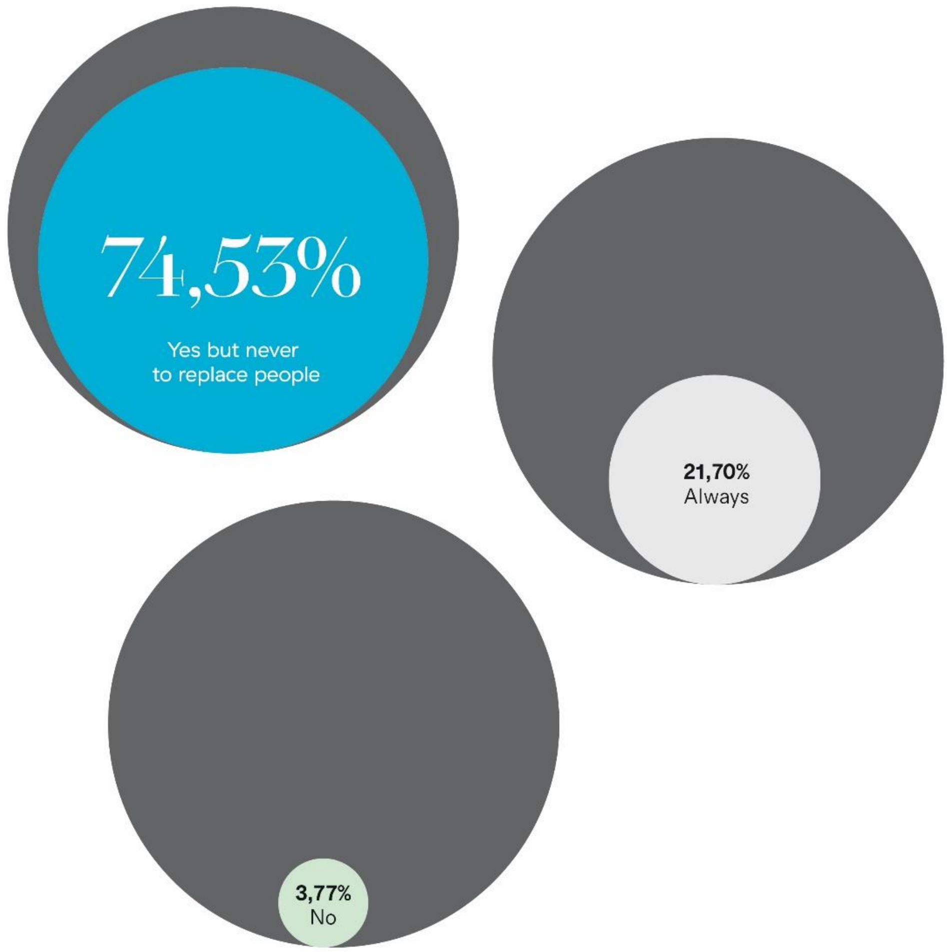
Once the personal data of the participants has been recorded, the answers to each question of the survey are analysed:

Question 1: Do you agree with the introduction of collaborative robots in the healthcare sector?

In this first question there is a clearly differentiated majority for the answer: "*Yes, but only to alleviate the workload and reduce the risk of health personnel and never to replace people".* As can be seen in the graphic 1, total of 79 people has chosen this option, representing 74.53% of the responses. The second most chosen option was: "*Yes, always"*, with 21.70% of the votes and only 4 people said they did not agree with the use of robots in the health sector.

The answers do not depend on the gender of the participants, nor great conclusions based on age or profession can be drawn. It should be noted that the 4 participants who have responded against the use of robots are under 25 years old and two of them are health workers. But because it is such an unrepresentative minority, it should not be taken into account.

From this first question, it should be noted that almost all the participants responded in favour of the use of robots in the health sector; if the answers of the two options in favour of robots are added, the percentage reaches 96.23%.

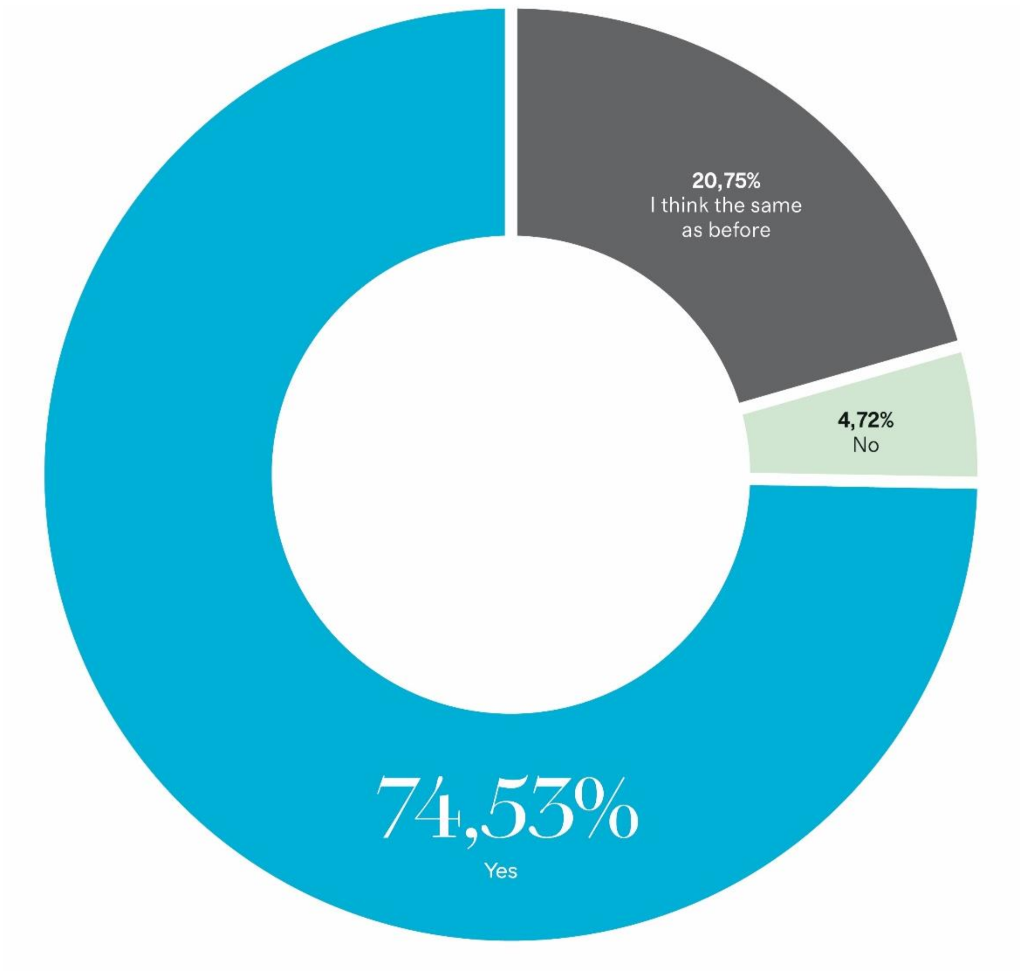


Graphic 1 Introduction of collaborative robots in the healthcare

Question 2: After having lived, and still living, the coronavirus pandemic, do you think that robots could be of great help in the health sector?

The answers of this second question follow the tone of the first question, the vast majority of respondents respond that they think robots could be of great help when facing the coronavirus, a total of 79 people have responded with this option, representing 74.53% of the total votes. 22 people say they think the same as before and only 5 have responded that robots would not help in this situation. The percentages are shown in graph 2. There is nothing remarkable about this question in terms of gender, age or profession of the respondents.

The answers to this second question show that society, after having suffered the coronavirus crisis, is in favour of the use of robots in the healthcare sector, thus corroborating that this moment in history could be a turning point after which all the knowledge developed in the industry on HRC can be transferred to the healthcare sector, as commented in section 4.2 of this Master Thesis. These first two questions have shown that society is in favour of the introduction of collaborative robots in the health sector.



Graphic 2 Help of robots afer the Covid-19

Question 3: What do you think is the purpose of introducing robots into the healthcare sector?

The answers to this question were more disparate than the previous ones, as can be seen in the graphic 3, the most chosen option was: "*To solve the problem of lack of personnel, to alleviate the workload and to increase the quality of the service*", with 56 votes, representing 52.83% and the second most chosen option was: "*As an experiment to advance the development of technology and research*", with 43 votes, representing 40.57%. Only 7 people have chosen the other option which indicated that the purpose of the collaborative robots is none other than to save money, saving people's salaries.

With regard to the data of the participants in each option chosen, it should be noted that 10 of the 11 students who carried out the survey have chosen the option that indicates that the purpose of the introduction of robots in the health sector is that it be an experiment to advance the development of technology. This is a curious fact and must be due to the spirit of research that is instilled in the universities. And of the 17 health workers, 10 have chosen this option, which is somewhat worrying because health workers should be the first to think that collaborative robots are introduced into the health sector to help them in their work and not with any other intention, freeing them from the heavy workload and performing the most repetitive and physically demanding tasks for them.

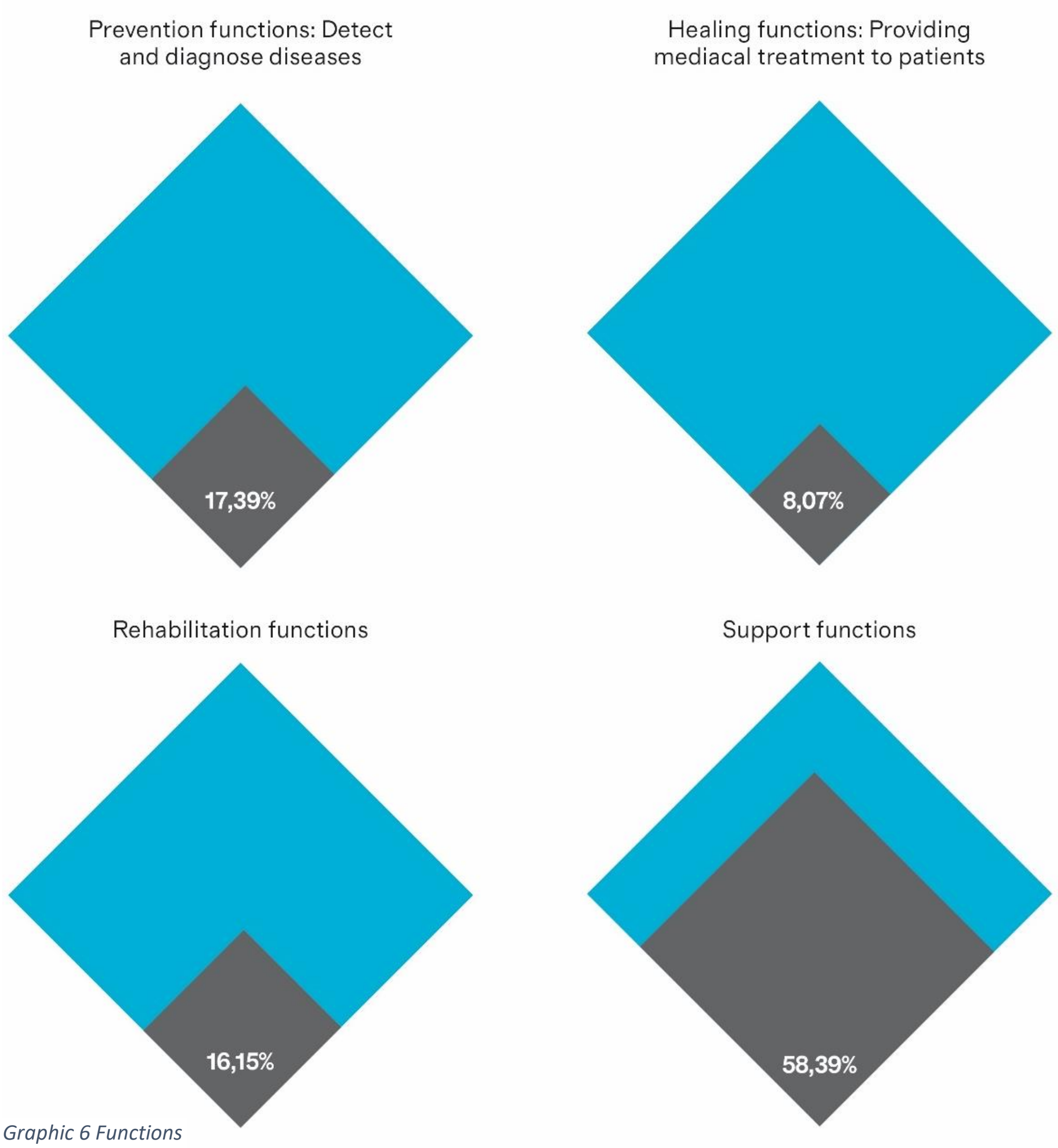
For collaboration between robots and humans to be fully accepted and welcomed in the health sector, it must be made clear what its intention is. And for acceptance to be as high as possible this intention should be none other than to help the health personnel, not to replace them and at the same time to offer a better service.

Graphic 4 Purpose of introducing robots

Question 4: What kind of functions do you think a collaborative robot could perform in a hospital?

This question is about possible functions that could be performed by a collaborative robot within a hospital. In the previous section, it was explained that the functions had been divided into four. It is a question in which you can select as many boxes as you want, which is why a total of 161 votes have been counted, as there have been participants who have selected more than one option. The clear winner, as shown in the graph 4, was the support functions with a total of 94 votes, representing 58.39% of the total number of respondents. The next two top choices were prevention functions with 17.39% of the vote and rehabilitation functions with 16.15% of the vote. Finally, the least chosen option was that of healing functions with only 13 votes.

No significant conclusions have been reached regarding the gender, age or profession of the participants.

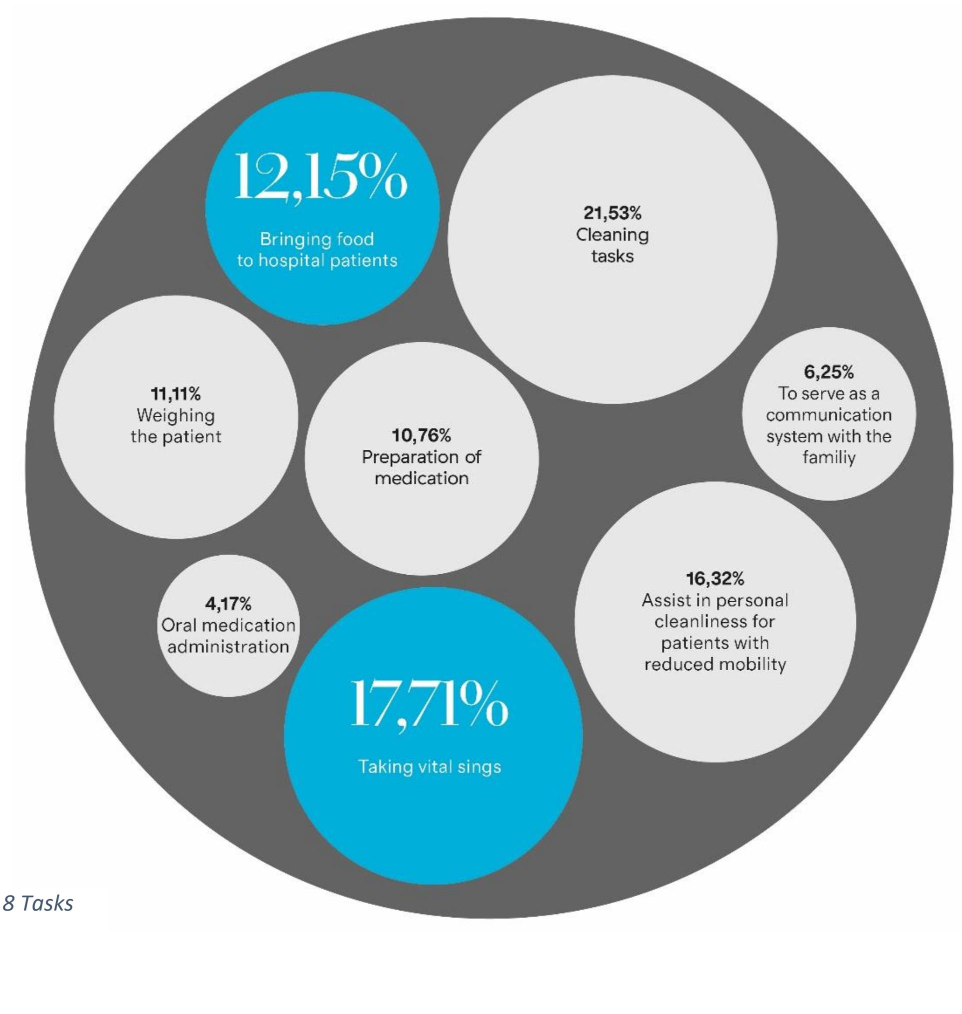


Graphic 6 Functions

<u>Question 5: What kinds of tasks do you think could be performed by robots in the healthcare sector?</u>

In this question, the respondents had to choose among the 8 tasks proposed to be performed in a hospital by a collaborative robot mentioned above in section 4.3 of this paper. They were invited to choose two of the eight applications that they felt were most suitable for a collaborative robot, but some of the respondents chose more than two applications so the total number of votes given in the count was 288. The votes, as shown in graph 5, were fairly evenly distributed among all the applications and there was no clear winner as in other questions, so the applications were ordered from highest to lowest percentage of votes: Performing cleaning tasks with 21.53%, Taking vital signs with 17.71% of the votes, Assisting in personal hygiene for patients with reduced mobility with 16.32%, Bringing food and drink to hospitalized patients with 12.15%, Weighing patients with 11.11% and Preparing medication with 10.76% of the votes. Finally, the two applications with the lowest percentage of votes were: Serve as a means of communication with the family with 6.25% and administer oral medication with only 4.17% of the votes.

The answers to this question position quite well the two proposals described in sections 4.3.1 and 4.3.2 of this Master Thesis. Using a collaborative robot to take vital signs was the second most voted application and bringing food to the rooms was the fourth most voted option. It is important that possible applications developed for collaborative robots in the health sector are accepted by society.



Graphic 8 Tasks

Question 6: As for the level of autonomy of a healthcare robot, which of these options would give you less confidence when being treated in a hospital?

Another issue that creates ethical dilemmas when introducing robots into the healthcare sector is the level of autonomy that the robot must have. This has already been discussed in section 5.1. It seems that the greater the autonomy of a robot, the greater the possibility of fear of being replaced by robots in people, which causes a negative reaction to the robot. But on the other hand, the less autonomy the robot has, the less useful people perceive the robot to be, which also causes a negative reaction. Furthermore, the greater the autonomy of the robot, the more ethical dilemmas arise, such as those regarding responsibility for the robot's actions, as discussed above.

Thus, this sixth question deals with this topic and offers four options for autonomy, based on the four types of interaction described by Cencen et al. (2015), which have already been discussed in section 2.3 of this Master Thesis. Respondents should choose the option that gives them the least confidence. The results, that can be seen in graph 6, have shown that this option is clearly that of a robot that acts totally autonomously without the need to be supervised by people. This option should be discarded. When introducing a collaborative robot in the health sector, the actions carried out by the robot must be supervised by the people and vice versa, thus achieving greater control and quality of the actions carried out.

Graphic 10 Autonomy

Question 7: If the function of the collaborative robot in the hospital was to relieve the workload of the staff, what kind of tasks do you think would be most suitable for the robot?

This question is based on the idea that collaborative robots will be introduced in the health sector to alleviate the workload, and respondents were asked to choose from four possible tasks for cobots. These tasks are the type of tasks typically performed by collaborative robots in industry, performing repetitive tasks, lifting heavy loads or performing transport tasks from one workstation to another. In this way, such tasks could be easily transferred from the industrial to the health sector. An option has also been added for cleaning and disinfection tasks since they could easily be performed by collaborative robots and are really useful in hospitals and more so nowadays because of the coronavirus.

The purpose of this question was to see if any of the options got a very different percentage of votes than the others. This did not happen, as can be seen in the graphic number 7, and the votes were almost equally divided. If any option had come out with many more votes or many fewer votes it could have been analysed and some kind of conclusion drawn. As this has not been the case, it is concluded that any of the options is valid for an HRC application in the health sector.

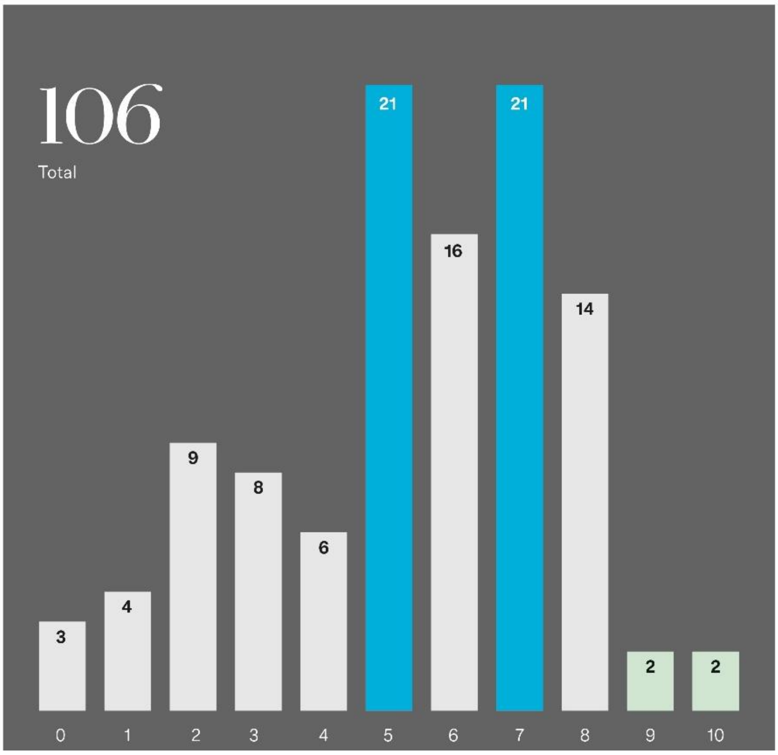
Graphic 11 Kind of tasks

Question 8: From 0 to 10, how would you rate your fear of being replaced by robots?

The fear of being replaced by robots, is a subject that has been widely discussed by many authors and is one of the great ethical dilemmas that the development of technologies such as HRC is causing. The purpose of this question is to check whether this happens, thus asking respondents to assess the fear of being replaced by robots from 0 to 10.

The results, shown in the graphic 8, show that the majority of respondents evaluate the fear of being replaced by a robot with a grade of five or higher, with the most repeated grades being 5 and 7, both with 21 votes, representing 19.81% of the votes each. The band of notes representing most of the votes is between notes 5 and 8, both inclusive, collecting a total of 72 votes, representing 67.92% of the votes. This shows that the fear of being replaced by robots really exists and is present in society.

As for the data from the participants, no major conclusions can be drawn regarding gender. It should be noted that the most extreme results with scores of 0 and 1, as well as 9 and 10, were given by participants under 30 years of age. This may be due to the moment of uncertainty that exists in people under 30 until they manage to find a stable job. It should also be noted that all respondents with teaching, journalism, administrative and commercial professions have assessed fear to be replaced by robots with high marks, equal or higher than six, and none of them with marks lower than five. Some jobs can be done by robots, and it is normal for people who do such jobs to have a greater fear of being replaced. This kind of jobs are where the exclusive skills of the human being are dispensable, skills such as the ability to reason, to detect changes quickly, to know how to act in the face of unforeseen events, to learn, to face ethical dilemmas, and also skills related to feelings such as empathy. This concludes that the profession and the fear of being replaced are indeed related.



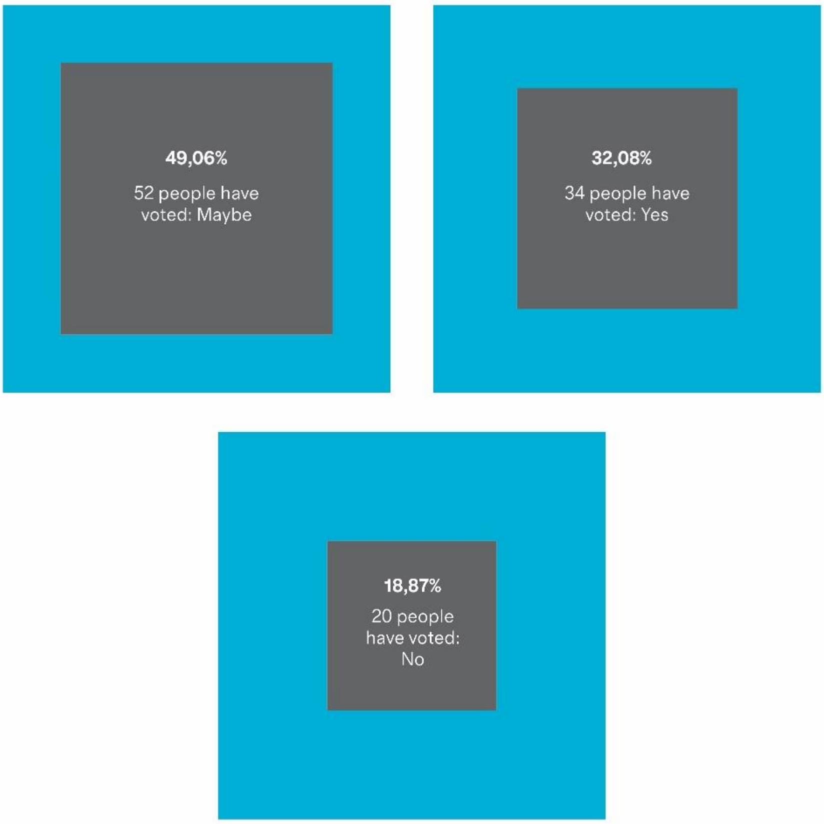
Graphic 13 Fear of being replaced

Question 9: Do you think that if the introduction of robots in the health sector continues, it could lead to a dehumanization of care?

Many people are somewhat against the use of robots in the health sector because they can lead to the dehumanisation of care. Health care has always been a service in which the staff stands out for its human capacity, especially in nursing, which has been the profession that has tried to help by proposing two possible applications of collaborative robots. As has already been commented on at the beginning of section 4.3, nursing without the human factor is meaningless.

Therefore, through this question, the purpose is to express people's concern about this issue. Can the use of robots cause the dehumanization of health care? As can be seen in the graphic 9, only 18.87% of the respondents answered "*No*", most of the answers were "*Maybe*" with 49.06% of the votes and 32.08% answered in the affirmative. This shows that this issue is of concern to most people and that is why in order to achieve greater acceptance by society of collaborative robots in the health sector, it must be made clear that the human factor in health care will not be abandoned, only that health personnel will be freed from repetitive tasks or those that involve physical fatigue.

No conclusions could be drawn from the answers based on the gender or age of the participants, but it should be noted that of the 17 people surveyed who work in the health sector, none of them answered "*No*" to this question, 11 of them think that "*Maybe*" there will be a dehumanisation of care and 6 of them say “*Yes*”, that it could happen.



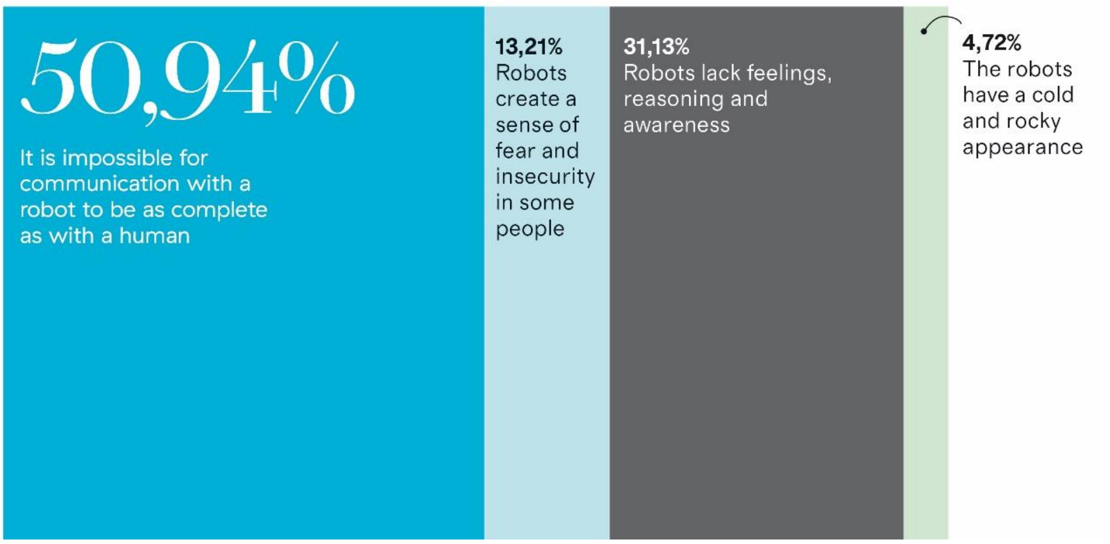
Graphic 15 Dehumanization of care

Question 10: Which of the following do you think is the main disadvantage in using robots in the healthcare sector?

There is always a trade-off, the use of collaborative robots also has disadvantages. In this question, respondents must choose between four possible disadvantages of using robots in the health sector. The purpose is to check which aspect of robots society sees as most problematic or will be most inconvenient.

The results, as can be seen in graph 10, show a clear winner, 54 of the 106 participants have selected as the greatest disadvantage the difficulty in communicating, representing 50.94% of the votes. The second most voted option was that the robots lack the ability to reason, feeling and awareness, with 33 votes, representing 31.13% of the votes. These results show that more importance should be given to achieving a highly developed human-machine interface that allows good communication between robots and humans, as well as through artificial intelligence, to achieve abilities as similar as possible to human ones. And the results leave the appearance of the robot as something secondary, this does not mean that it is not important, because it has been demonstrated that it influences, but it should be something secondary, the main thing should be to achieve a robot that fulfils its functions and that allows an interaction as human as possible.

When dealing with the data of the respondents, in this question it should be highlighted that if any conclusion can be drawn by looking at the gender of the participants. It should be noted that, of the 39 women surveyed, 24 have selected the option of communication as the main disadvantage, being the option that receives most of the votes. On the other hand, the responses of the men surveyed are more distributed between the option of communication and that of the capacity to reason, with 30 and 25 votes respectively. Something similar occurs when it comes to age, with those surveyed over 30 years old mostly choosing the option of communication, but the responses of those under 30 years old are distributed between the option of communication and that of the capacity to reason and feel. No conclusion can be drawn from the professions of the respondents.

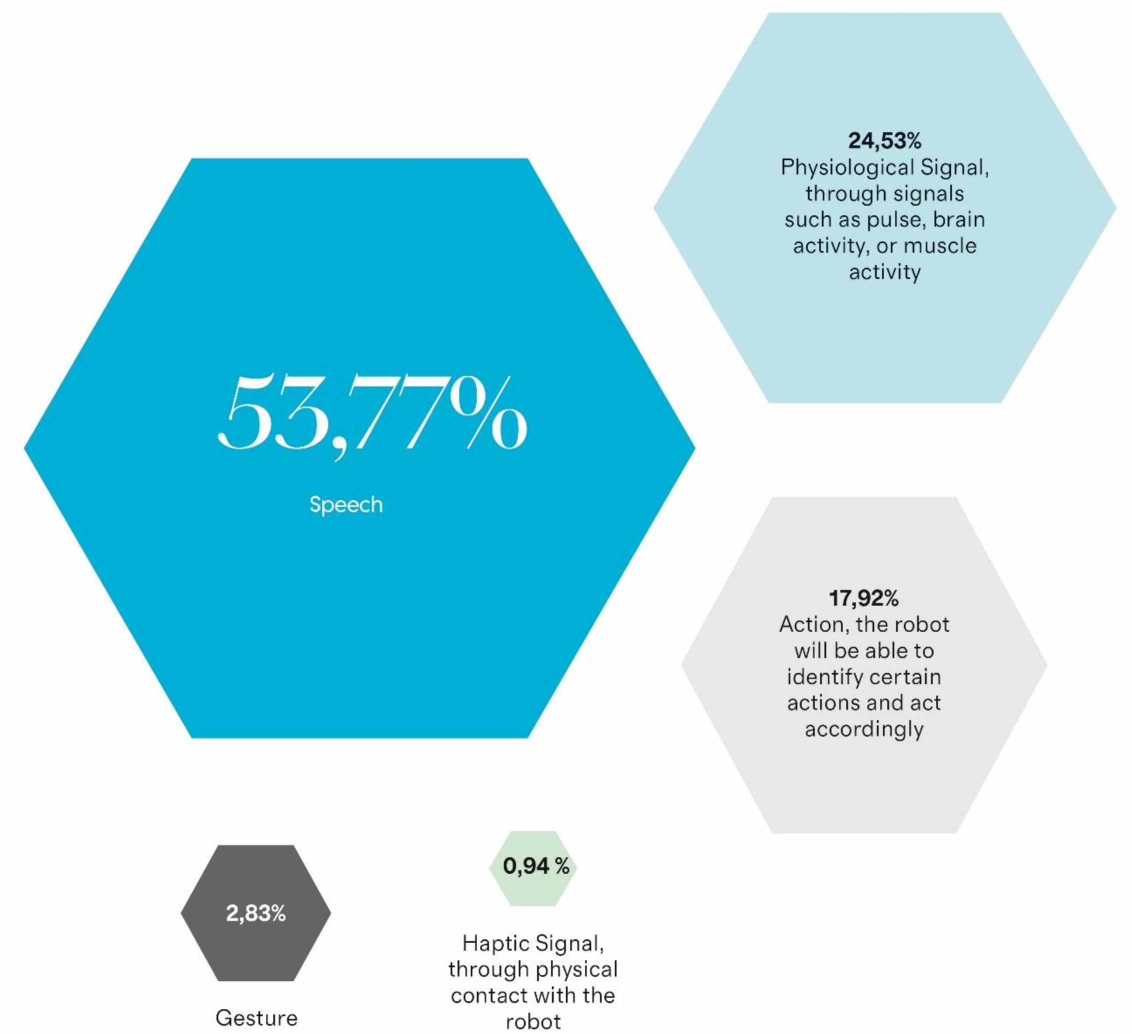


Graphic 16 Disadvantages in using robots in the healthcare sector

Question 11: Which of the following forms of communication do you think is most appropriate between a robot and a patient?

After having verified in the previous question that most people attribute the main disadvantage to communication when using robots in the health sector, in this question number 11 of the survey participants must choose the most appropriate communication method when interacting between a robot and a patient in a hospital. The modes of communication chosen are those indicated by Bauer et al. (2008) already cited in section 2.3 of this Master Thesis and which appear in Fig. 7.

The results, shown in graphic 11, show that the most chosen option has been communication through speech with a total of 57 votes, representing 53.77% of respondents, the second most chosen option has been through physiological signals such as pulse or brain activity, with 26 votes, being 24.53%. The third most popular option was communication through actions with 19 votes, representing 17.92% of the votes. The two remaining options have received very few votes.



Graphic 18 Forms of communication

In this way, the respondents see speech as the most appropriate means of communication, which is logical since it is the way people communicate when they are being treated in a health care setting, it is the most natural means of communication and allows them to express themselves in great detail. The second most voted option makes sense since the type of application for which the collaborative robots are going to be used is in the health sector. In this way, it would be very useful for the robots to have access to the physiological signals of the patients to be treated.

No relevant conclusions could be drawn on the basis of the gender, age or profession of the respondents, as their answers followed the general trend.

<u>Question 12: If you saw such a robot in a hospital, what would you find most pleasing?</u>

The last two questions of the survey focus on the appearance of the robots. This topic has been discussed by many authors and there are famous theories about the appearance of robots such as Mori's "Uncanny Valley", cited in section 3.4 of this Master Thesis. Based on this theory the following Fig. 42 has been made in which 6 robots are presented ordered in a linear way from less to more similar to human beings, in this way the first robot does not have any similarity with a person, the second is formed by an articulated arm, the third has a head and arms, the fourth robot is bipedal, the fifth has facial gestures and a kind of skin simulating the human and finally the sixth robot is a humanoid so similar to a human that it can be hard to tell it's a robot.

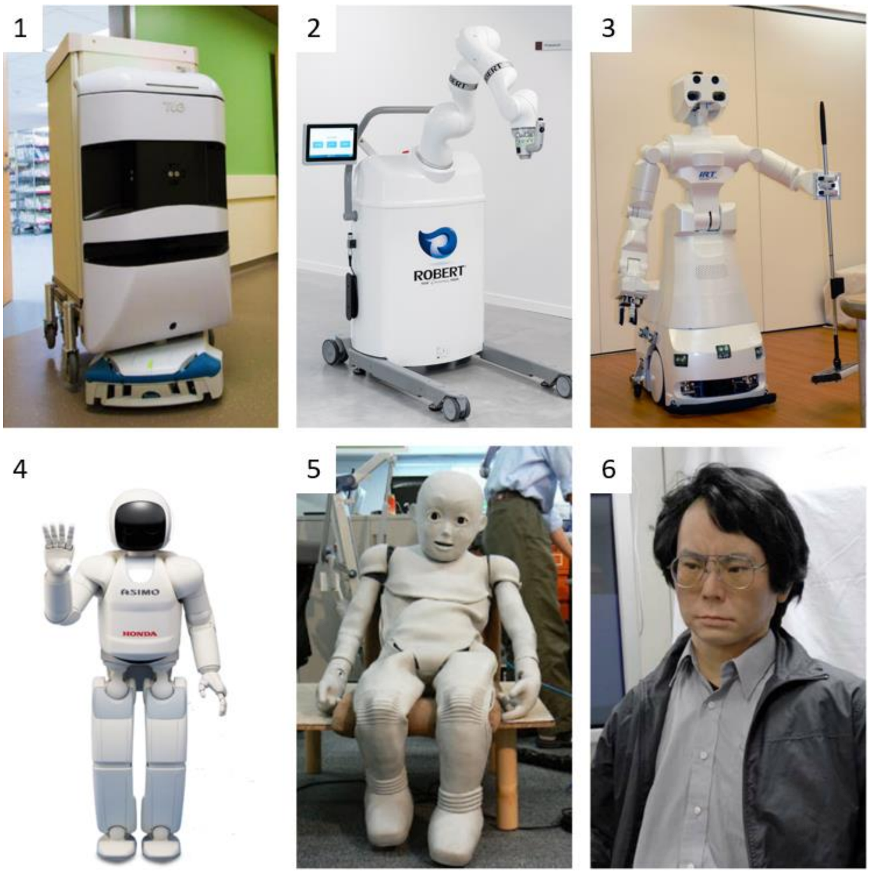


Fig. 42 Appearance of the robots

The robots are presented in this way to see if the votes in any way reflect the graph made by Mori to represent the idea of Uncanny Valley.

In the first of these two questions, in question number 12 of the survey, respondents had to choose the robot that would be most pleasant or pleasing to the eye if found in a hospital. The most chosen option, as can be seen in the graphic 12 in the next page, was robot number 2, the Robert Therapeutic robot, with 37 votes representing 34.91% of the votes. Followed by Robert with only 3 votes, the second most chosen option with 34 votes in total is the robot ASIMO representing 32.08% of the votes. Next in third place is the Assistant Robot with 25 votes and well below the other three options. Of these, the option with the fewest votes is the fifth, the CB2 robot with only 2 votes.

According to the participants' data, most of the people under 30 years old voted for Robert as their favourite, with a total of 30 out of 73 votes from people under 30. People between 30 and 60 years old chose the Assistant Robot with 7 out of 19 votes from people within this age range, and for those over 60, their favourite robot is ASIMO, which got 7 out of 14 votes from people over 60.

According to the gender of the respondents, most men have chosen Robert as their favourite robot, being this the most chosen option with 25 out of 67 votes from men, while women's votes are equally distributed among robots 2, 3 and 4, with 30.77%, 33.33% and 33.33% respectively.

Finally, taking into account the profession of those surveyed, it is worth noting that of the 17 engineers who carried out the survey, 41.18% of them prefer the Robert robot, which makes up the majority of those surveyed with this profession.

<u>Question 13: And which do you think will be the most useful?</u>

For the last question of the survey, the same image of the 6 robots is used as for the previous question, but in this case the question is asked about the perceived usefulness of seeing the robots. Respondents must select the option that is most useful to them for a collaborative robot application in the healthcare sector.

Utility, appearance and acceptance go together when evaluating a robot, as has been seen throughout the literature, if a robot has a very positively evaluated appearance but then the functions it performs or the skills of the robot do not meet expectations, the appearance of the robot ceases to be important and the few capabilities of the robot cause it to be evaluated negatively.

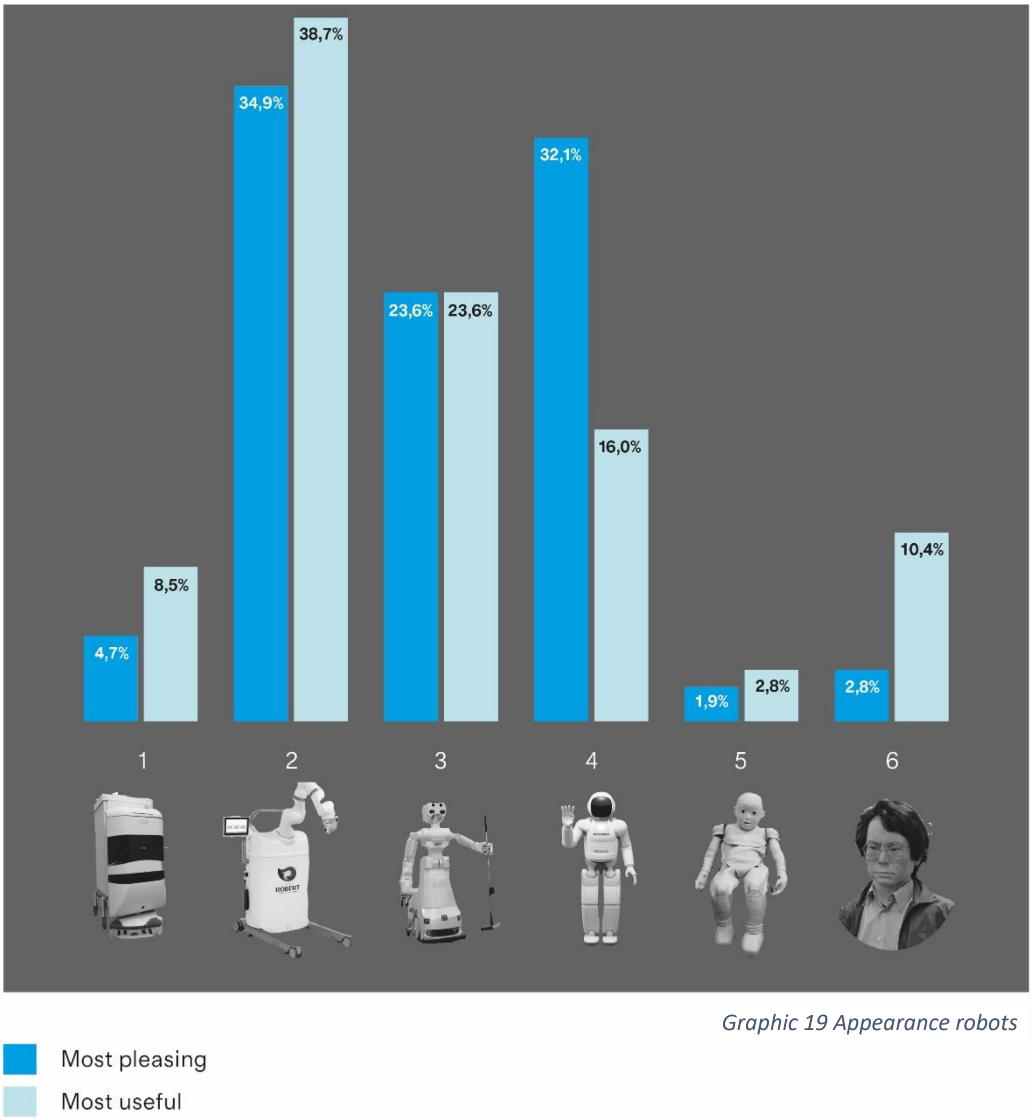
In this way, a robot, besides having a nice appearance and appearing to be useful, must be truly useful and meet or exceed expectations so that acceptance by society increases and the robot is well received.

In this last question, respondents must select the robot that seems most useful for a healthcare application. The most chosen robot again is the Robert robot, as can be seen also in the graphic 12, with 41 votes, representing the majority with 38.68% of the votes, the second most chosen option this time is the Assistant robot with 25 votes and the third is ASIMO with 17 votes. The other three options again are the least voted, but this time the TUG robot and Geminoid have achieved 9 and 11 votes respectively reaching more or less 10% of the votes each. Again, the least voted option was the CB2 robot with only 3 of the 106 votes.

According to the gender of the respondents, both have chosen the robot Robert as their first choice with 43.59% of the votes for women and 35.82% of the votes for men. It is striking that of the 11 votes that Geminoid received, 10 were cast by men.

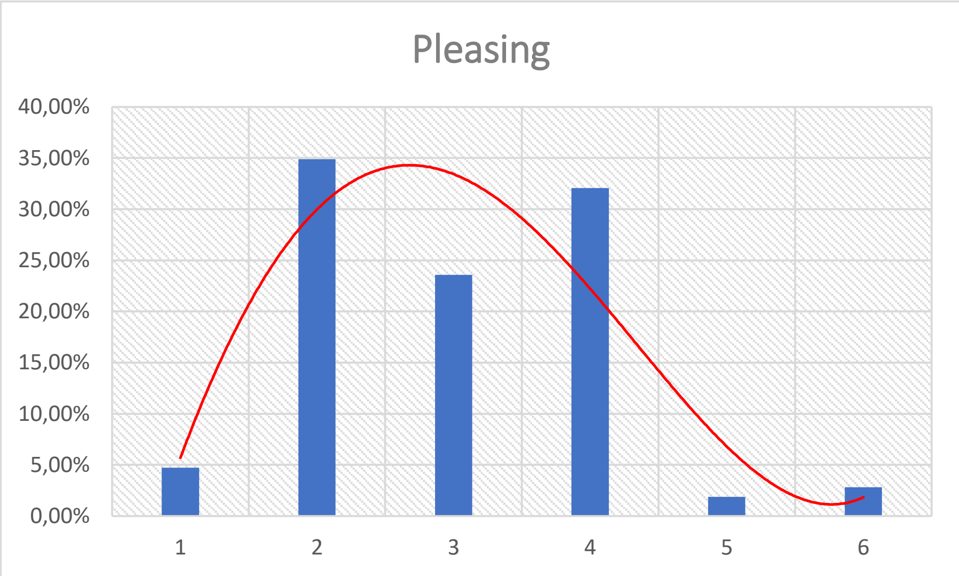
Looking at the age of the participants the results vary a little more, the under 30 years old see more useful the robot Robert with 33 of 73 votes, the participants with an age range between 30 and 60 years old see more useful the Assistant Robot with 9 of 19 votes made and finally the over 60 years old respondents see ASIMO as the most useful robot with 5 of 14 votes made.

Finally, considering the profession of the participants, there is some interesting data to highlight. As a curious fact, most of the students (4 out of 11) chose Geminoid as the most useful robot. However, the most noteworthy fact was that the vast majority of the healthcare personnel surveyed (7 out of 17) selected Robert as the most useful robot.

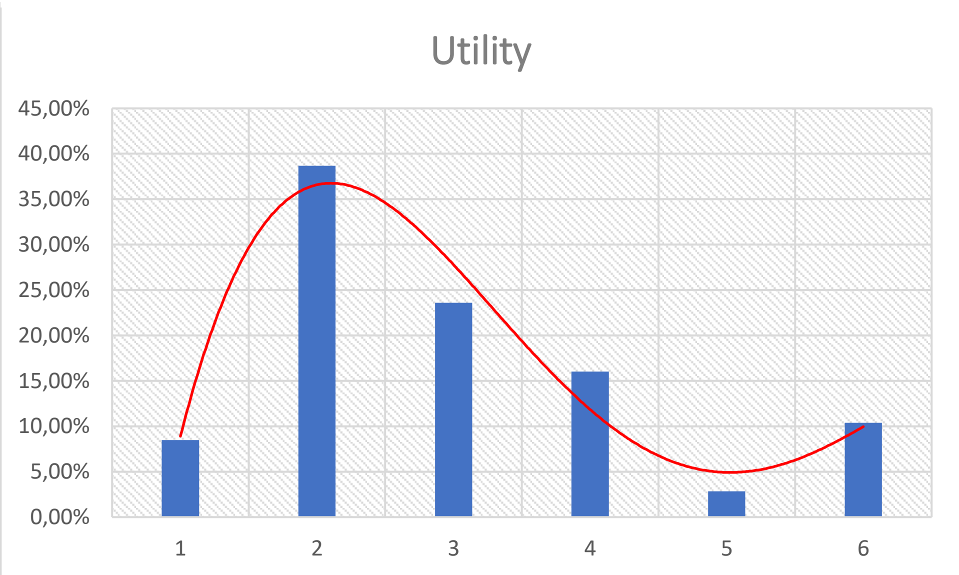


Graphic 19 Appearance robots

Once the results of these last two questions are shown, then proceed to check if any behaviour similar to the Uncanny Valley phenomenon has occurred in any of the two questions. To do this, the results of the two questions are presented separately in column charts and a polynomial trend line is added to represent the variation of the results in a continuous way along the 6 robot options. A grade 4 polynomial line is chosen to best fit the variations between the different options. The two graphs obtained can be seen below.



Graphic 21 Variable "Pleasing"



Graphic 22 Variable "Utility"

As in the graph used by Mori to explain the Uncanny Valley, a maximum appears first, then a minimum, and then a positive slope appears again after the minimum. In this sense the graphs obtained are quite similar to the one presented by Mori. They differ in that the maximum is reached much earlier in those obtained from the survey, according to Mori the maximum is obtained for humanoid robots, in this case the maximum is obtained for an articulated arm. But what is really important about this theory is the

Uncanny Valley, the valley that occurs at the minimum. In the case of the graphs obtained from the survey, this valley has been produced in both cases in the CB2 humanoid robot. This is a robot that, due to its appearance and facial features, can cause certain rejection or negative reactions in some people, as has already been proven in other studies. The same thing has happened in this case, the Uncanny Valley phenomenon has been provoked for this robot.

In the case of these two graphs, as in Mori's, the horizontal axis shows the resemblance of the robots to humans from minor to major. On the vertical axis of the graph proposed by Mori, familiarity is mentioned (although many authors have discussed this variable, as mentioned in Section 3.4). In the graphs made, it has been taken as a variable for the vertical axis in the first case that the robot is more or less pleasant for the respondents and in the second case the utility. It is complicated to determine this type of variables, since they always have subjective connotations because in the end is being evaluated the appearance of a robot. On this occasion, the “Utility” variable worked better, since after the maximum in option 2, there was a negative slope, descending to the minimum in option 5 without stopping. On the other hand, for the “Pleasing” variable, another maximum has been produced in option 4.

In this way, the objective of these last two questions and the image presents the 6 robots from least to most similar to humans, is considered to have been fulfilled, achieving and demonstrating the existence of the Uncanny Valley phenomenon.

5.4. Conclusions of the Survey

After analysing and interpreting the data collected from the survey, a number of conclusions have been reached.

If it is made clear that collaborative robots will be used to assist health workers and not to replace them, the vast majority of people clearly favour the use of cobots in the health sector. It should be made clear that their function will be to relieve workloads, perform repetitive tasks, lift heavy loads and protect staff from possible infections. Having lived through the coronavirus pandemic, society's thinking towards the use of robots in the health sector has improved, it has been shown that they can be of great help and this moment can be a great opportunity to achieve the implementation of this technology in the health sector.

The level of autonomy of robots should not exceed or in any case reach that of a human person, robots should perform tasks of support and assistance to health personnel, so as not to enter into conflicts of responsibility or create fear and insecurity in patients.

The fear of being replaced by robots is real and that is why, in order to achieve greater acceptance by society of robots in the health sector, robots should never attempt to replace people or perform tasks that are characterized by their human factor. The humanisation implicit in health care must not be forgotten.

Much of the HRC research and development applied in the healthcare sector should be focused on improving the human-machine interface, achieving the most detailed robot-patient communication possible.

Finally, the appearance of the robot is also of great importance, in my view and after analysing the data collected in the survey, robots for the health sector should prioritise utility rather than a human-like aspect. This will reduce the fear of being replaced by robots, because if they have a humanoid appearance this fear could be exacerbated. In addition, seeing the results obtained, the articulated robotic arm has been the favourite option, this form facilitates the opportunity to transfer the knowledge developed in the industry for applications of collaborative robots to the health sector, since many of the collaborative robots in the industry have the form of a robotic arm.

6. CONCLUSION

It is a pity that due to the lack of acceptance by society or the poor resolution of the above-mentioned ethical dilemmas that arise when introducing robots in such a humanized field as the health sector, the opportunity that the HRC could offer us is lost. As has been mentioned throughout the Master Thesis, it could free up the workload of health personnel, which on many occasions is surpassed, as well as protect health professionals against the risk of infection from highly contagious diseases such as the coronavirus.

Transferring the knowledge and applications developed in the industry for collaborative robots to the healthcare sector can result in a much more efficient and higher quality healthcare service for both patients and healthcare personnel. This is possible with technologies already developed as demonstrated with the two possible applications proposed for the collection of vital signs and the transport of samples when performing the coronavirus test. These two are just two of the many applications and tasks that could be performed with the help of collaborative robots in the health sector.

The results of the survey have shown that society is in favour of the use of HRC in the health sector after having suffered so much during the coronavirus crisis. As already mentioned, collaborative robot applications in the healthcare sector should help healthcare personnel and never replace them.

This Covid-19 crisis has brought with it numerous human and economic losses, but it may also have brought something good. By living through this pandemic and having to stay locked up at home for so long, that negative thinking towards technology discussed above, caused by a lack of acceptance, may change.

It has always been commented that technology separates us more and more, more and more people talk to each other through their mobile phones, computers or social networks and less and less face to face, but during this pandemic technology has been the one that has allowed us to be united thanks to those video calls or video conferences.

It has also been commented throughout this paper that there is a fear of being replaced by robots or losing jobs to robots and technology, but now during this pandemic, technology has been precisely what has allowed many to work from home and thus keep their jobs. Never before has technology been so humane as now, it is time to continue to rely on it and allow human and economic benefits to be achieved in the health sector through HRC.

The time has come to give a vote of confidence to new technologies, such as HRC, by investing in research, developing it and allowing it to enter the health system, in order to achieve a better health care service. Throughout this Master Thesis it has been demonstrated that robots in times of pandemic can be really useful and that many of the problems that are occurring during the coronavirus crisis could have been avoided or occurred on a smaller scale using cobots.

7. REFERENCES

Capek, K. (2004). RUR (Rossum's universal robots). Penguin.

Asimov, I. (1942). Runaround. Astounding Science Fiction, 29(1), 94-103.

Kalan, S., Chauhan, S., Coelho, R. F., Orvieto, M. A., Camacho, I. R., Palmer, K. J., & Patel, V. R. (2010). History of robotic surgery. Journal of Robotic Surgery, 4(3), 141-147.

Nilsson, N. J. (1984). Shakey the robot. SRI INTERNATIONAL MENLO PARK CA.

Sakagami, Y., Watanabe, R., Aoyama, C., Matsunaga, S., Higaki, N., & Fujimura, K. (2002, October). The intelligent ASIMO: System overview and integration. In IEEE/RSJ international conference on intelligent robots and systems (Vol. 3, pp. 2478-2483). IEEE.

Mori, M. (1970). The uncanny valley. Energy, 7(4), 33-35.

Weller, C. (2017). Meet the first-ever robot citizena humanoid named sophia that once said it woulddestroy humans. Business Insider Nordic. Haettu, 30, 2018.

Bauer, A., Wollherr, D., & Buss, M. (2008). Human–robot collaboration: a survey. International Journal of Humanoid Robotics, 5(01), 47-66.

Cencen, A., Verlinden, J., & Geraedts, J. (2015, October). Characterizing the state of the art of human-robot coproduction. In International Conference on Social Robotics (pp. 135-144). Springer, Cham.

Buxbaum, H. (2020) Human-Robot Collaboration. International Journal of Robotic Engineering, 5:021.

Beer, J. M., Prakash, A., Mitzner, T. L., & Rogers, W. A. (2011). Understanding robot acceptance. Georgia Institute of Technology.

Ensley, M. R. (1995). Toward a theory of situation awareness in dynamic systems. Human factors, 37, 85-104.

Endsley, M. R. (1988, May). Situation awareness global assessment technique (SAGAT). In Proceedings of the IEEE 1988 national aerospace and electronics conference (pp. 789-795). IEEE.

Tavira-Mondragón, J., & Cruz-Cruz, R. (2011). Development of power plant simulators and their application in an operator training centre. In Intelligent Automation and Systems Engineering (pp. 243-255). Springer, New York, NY.

Buxbaum, H., Kleutges, M., & Sen, S. (2018, December). Full-scope simulation of human-robot interaction in manufacturing systems. In 2018 Winter Simulation Conference (WSC) (pp. 3299-3307). IEEE.

Buxbaum, H., Sen, S., & Kremer, L. (2019). An Investigation into the Implication of Human-Robot Collaboration in the Health Care Sector. IFAC-PapersOnLine, 52(19), 217-222.

Robla-Gómez, S., Becerra, V. M., Llata, J. R., Gonzalez-Sarabia, E., Torre-Ferrero, C., & Perez-Oria, J. (2017). Working together: A review on safe human-robot collaboration in industrial environments. IEEE Access, 5, 26754-26773.

Villani, V., Pini, F., Leali, F., & Secchi, C. (2018). Survey on human–robot collaboration in industrial settings: Safety, intuitive interfaces and applications. Mechatronics, 55, 248-266.

Pang, Z., Yang, G., Khedri, R., & Zhang, Y. T. (2018). Introduction to the special section: convergence of automation technology, biomedical engineering, and health informatics toward the healthcare 4.0. IEEE Reviews in Biomedical Engineering, 11, 249-259.

Stahl, B. C., & Coeckelbergh, M. (2016). Ethics of healthcare robotics: Towards responsible research and innovation. *Robotics and Autonomous Systems*, *86*, 152-161.

Rosenthal-von der Pütten, A. (2014). Uncannily human: experimental investigation of the uncanny valley phenomenon (Doctoral dissertation, Duisburg, Essen, 2014).

Barho, M., T. Dietz, L. Held, and S. Oberer-Treitz. 2012. "Roboter-Sicherheit auf dem Prufstand: Die ¨Anforderungen an eine sichere Mensch-Roboter-Kooperation". https://www.computer-automation.de/steuerungsebene/safety-security/die-anforderungen-an-eine-sichere-mensch-roboter-kooperation.88886.html, accessed April 26th, 2020

Europa se tiñe de gris. (2018, November 09). Centro Internacional sobre el Envejecimiento. https://cenie.eu, accessed April 29th, 2020

Los datos que reflejan el dramático futuro de una población española cada vez más envejecida. (2018, October 10). El Economista. https://www.eleconomista.es, accessed May 1st, 2020

5 Medical robots making a difference in Healthcare. (2017, December 28). https://online-engineering.case.edu/blog/medical-robots-making-a-difference, accessed May 5th, 2020

NAMA Foundation. (2017). http://www.namafundacion.com/, accessed May 7th, 2020

Coronavirus: estimación de hasta 70.000 enfermeras infectadas en España. (2020, March 14) https://www.redaccionmedica.com/secciones/enfermeria/coronavirus-espana-enfermeras-contagiadas-4226, accessed May 8th, 2020

COVID-19 situation update worldwide https://www.google.com/covid19-map/?hl=es, accessed July 10th, 2020

SZ's 1st da Vinci surgical system in use (2019, December 6) http://www.eyeshenzhen.com/content/2019-12/06/content_22681944.htm, accessed May 16th, 2020

Xenex Disinfection Services https://www.xenex.com/our-solution/lightstrike/, accessed May 16th, 2020

IEEE Spectrum ROBOTS https://robots.ieee.org/robots/paro/, accessed May 16th, 2020

St. Elizabeth Healthcare Enters the Robotic Age Using the TUG Autonomous Mobile Robot from Aethon (2015, May 19) https://www.businesswire.com/news/home/20150519005310/en/St.-Elizabeth-Healthcare-Enters-Robotic-Age-TUG, accessed May 16th, 2020

Affirmation in lieu of oath

I affirm that I have done the above work independently and have not used external help.

I have marked all passages that are taken literally or in substance from published or unpublished literature.

13.07.2020

Jon Irujo Aizcorbe