Escuela Colombiana de Ingeniería Julio Garavito

Master Thesis

DEVELOPMENT OF A PATIENT-ROBOT INTERFACE FOR A LONG-TERM INTERACTION IN CARDIAC REHABILITATION AT FUNDACIÓN CARDIOINFANTIL - INSTITUTO DE CARDIOLOGÍA

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"Imagination is more important

than knowledge.

Knowledge is limited.

Imagination encircles the world"

Albert Einstein

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Abstract

According to the World Health Organization, Cardiovascular diseases (CVDs) are the first cause of death worldwide. An estimated of 17.9 million people die each year because of CVDs. In order to treat the consequences and improve the quality of life of the patients affected by these diseases, Cardiac Rehabilitation (CR) is developed. CR is a strategy which consists commonly in different phases with an established number of sessions (e.g., 20-36 sessions). CR is based mainly in exercise procedures and educational approaches. The main goals of CR are to achieve a full patient recovery, in terms of reach optimal physical, mental and social status, and modify the coronary risk factor to reduce subsequent mortality due to cardiovascular illnesses. However, there is an evidence that the adherence to the CR programs is very low, less than 50% of patients assist actively to the rehabilitation. This limitation can cause major public health issues and negative effects on the patients' health. In this context, different applications can be used to motivate the patients and enhance the engagement to the rehabilitation.

This master thesis presents the evaluation and integration of a patient-robot interface for CR in two studies. The first study (*Study I*) assess the effects of the social assistive robot in a control vs a robot without personalized behavior scenario, through *qualitative* and *quantitative parameters*. The second study (*Study II*) present the integration of a multi-modal open set identification system and the evaluation of this strategy within a memory scenario. A total of 36 patients were evaluated in this master thesis (15 for the control and robot scenario; and 6 for the memory robot scenario). These patients perform in average 36 sessions of the phase II of CR program.

Overall, the results regarding the physiological parameters do not show differences between groups due to the variability of the data and its high dependence of external factors. In contrast, qualitative results show that the patients recommend the use of the robot in CR and they feel more secure thanks to the on-line monitoring. However, the clinicians and patients suggest to improve the social behaviors of the robot. Thus, in the Study II a memory module was implemented. In this case, the outcomes show that the patients perceive the social presence of the robot as they elucidate positive and negative attitudes towards the robot role. Concluding, this master thesis presents the results of the patient robot interface in a long-term/ real world scenario, demonstrating that SAR holds promising potential to be a feasible approach that enhances CR programs, increase the adherence to these programs and help improving the quality of life of cardiac patients.

Keywords: Socially Assistive Robotics, Human-Robot Interaction, Social Interaction, Cardiac Rehabilitation, Robot-Therapy.

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Chapter 1

Introduction

This work is focus on the development and evaluation of a Patient-Robot interface for Cardiac Rehabilitation (CR). First, a complete analysis of a first study (**Study I**) which evaluates *Control* (i.e., patients who assist to the conventional therapy) and a *non-relational robot* (i.e., patients assisted by the social robot without personalized behaviors) scenarios were implemented. Statistical analysis of quantitative and qualitative data was discussed in order to observe the effects of Social Assistive Robotics (SAR) between scenarios (Chapter 4) . The quantitative data represent the main physiological parameters in CR (i.e., training heart rate, recovery heart rate and Borg scale) and the interaction parameters acquired by the patient-robot interface (i.e., cervical posture corrections and Borg response time). On the other hand, the qualitative data represent the perception of the users towards the system in several dimensions (i.e., usefulness, social presence, utility, safety, among others) . Second, a personalized robot system is proposed in order to enhance the capabilities of the patient-robot interface. This proposal includes the integration of a multi-modal person recognition in a modular-based software architecture (Chapter 5) in order to improve the interaction between the robot and the patient in longer periods. Subsequently, the effects of personalized robot are evaluated in a second study (**Study II**) at the clinic *Fundación Cardio Infantil-Instituto de Cardiología (FCI-IC)*. Overall, 36 patient's (control, non-relational robot and memory robot scenario) data was analyzed.

This Chapter introduces the motivation of this master thesis and the research goals. Finally, the main contributions, publications and structure of this document are presented.

1.1 Cardiovascular Diseases and Cardiac Rehabilitation

Cardiovascular diseases (CVDs) are disorders of the heart and blood vessels and include cerebrovascular diseases, rheumatic heart diseases and other conditions [1]. CVDs are the cause of 17.7 million deaths every year, approximately 31% of the world population [1]. In the same way, in 2015, CVDs lead the causes of the death in the world : ischemic heart disease (8.76 million deaths) and stroke (6.24 million deaths). In addition, more than 75% of CVDs occur in low- and middle-income countries [2]. Between the risk factors associated to the cardiovascular diseases, two categories can be described: (i) *behavioral risk factors* and (ii) *metabolic risk factors*. *Behavioral risk factors* refer to risk profiles acquired by the daily habits of a person (e.g., tobacco use, sedentary lifestyle, unhealthy diet and harmful use of alcohol). On the other hand, *metabolic risk factors* are described by inherent conditions of the person (e.g., raised blood pressure, raised blood sugar and cholesterol and obesity) [3]. In Colombia, CVDs are the first cause of death. The percentage of people in Colombia with CVDs will increase (with a general mortality rate of 6.9%), by the year 2000 onward, 96000 people die due to a CVD. Of every 100 deaths from CVDs in Colombia, 37 are due to acute myocardial infarction, 25 due to heart failure, 22 due cerebrovascular disease and 10 due to hypertension [4].

In this context, the WHO proposes three strategies: *Surveillance*, *Prevention* and *Management*. *Surveillance* is necessary to map and monitor the epidemic of CVDs, allowing to understand its development and reach solutions. *Prevention* is related to the reduction of the risk factors mentioned before and *Management* is a strategy focused on the provision of equitable health care for people with CVDs [3].

CR is a management strategy that combines prescribed exercise training with a coronary risk factor modification for patients with established heart disease [5]. The main goals of CR are to achieve a full recovery, in terms of reaching optimal physical, mental and social status, and modify the coronary risk factor to reduce subsequent mortality due to cardiovascular illnesses [6]. CR is focused on two aspects: (1) physiological aspects focus on the physiological performance of the patients such as cardiovascular functioning, aerobic capabilities during exercise etc, and (2) cognitive aspects related to the cognition processes that involve language, perception, motivation, attention and memory [7]. These aspects are essential to evaluate the patient throughout the rehabilitation time and also measure their long-term performance. Exercises include walking and cycling. The number of sessions are typically 36 depending on the phase (outpatient/phase II and maintenance program/phase III) and the exercise intensity changes according to the patient's level of exertion.

Despite the evidence of the benefits of CR, about one third of patients participate in the programs [8]. For example, Iran and Australia statistics suggest that only 15%-30% of patients participate in such programs [9, 10]. In Colombia the outlook is more critical, the latest data obtained since 2010, show that less than 10% of patients attend actively to CR programs [11]. Some factors that can act as an adherence barrier include: belief variables, age, annual income, healthcare system, level of education, cardiac functional status, mood state, social support [12, 13], physician endorsement [14, 15] and intrinsic motivation [16]. Low adherence to the programs can cause major healthcare problems, second coronary events with a higher risk and even death.

Due to this reason it is important to increase the adherence in CR programs to achieve a full rehabilitation. Currently SAR have been used in several areas (e.g, industry [17], education [18], healthcare [19], among others). Different SAR studies demonstrate relevant results in the improvement of the: rehabilitation adherence [20], intrinsic motivation [21], therapy engagement [22, 23], patient's mood states [24] and social interaction [25]. Based on this evidence, SAR could be used as a complementary tool to aid and improve rehabilitation procedures, assists patients' performance and support cognitive and physical processes during the therapy.

1.2 Background

This thesis is developed in the context of the project entitled, *Human-Robot Interaction Strategies for Rehabilitation based on Social Assistive Robotics* **(IAPP51537)** funded by the Royal Academy of Engineering, and the *SORCAR* project (in spanish *Evaluación del impacto de la intervención de un robot social en las respuestas cardiovasculares de los pacientes del programa de Rehabilitación Cardiaca de la Fundación Cardioinfantil-Instituto de Cardiología*, **grant 813-2017**), leaded by the FCI-IC and the Colombian School of Engineering Julio Garavito. This last project was founded by the *Ministerio de Ciencia, Tecnología e Innovación*

The *SORCAR* project seeks to evaluate the impact on the chronotropic, pressor and adherence response in patients attending to CR programs, when they are stimulated and monitored by a social robot during CR sessions. This project is carried out in the FCI-IC in Bogotá Colombia. The main contributions of this master thesis are located in the assessment of the patient-robot interface in two studies:

Study I: The evaluation of a non-relational robot in the phase II of CR was performed. *Control* and *Robot* scenarios were analyzed. ***Study II***: The evaluation of a personalized social robot platform in the Phase II of Cardiac Rehabilitation was performed (Memory Scenario). In this case, improvements of the system, the experimental procedure and measurements were implemented considering the lessons learned in the Study I.

1.3 Objectives

1.3.1 General Objective

To develop a patient-robot interface based on SAR for cardiac rehabilitation in order to provide motivational feedback and enhanced interaction through rehabilitation sessions within the phase II at the FCI-IC.

1.3.2 Specific Objectives

- To conduct a detailed literature review to understand human-robot long-term interaction based on SAR and its relationship with adherence factors during rehabilitation scenarios.
- To analyze the effects of the social robot in cardiac rehabilitation during the Study I in order to design long-term interaction strategies for the patient-robot interface.
- To integrate a robot model based on SAR in order to promote a natural and personalized interaction using face recognition, random verbal and non-verbal gestures.

- To evaluate the long-term effects of the personalized robot model on cardiac rehabilitation patients within the Study II.

1.4 Contributions

The key contributions of this work are the experimental validation at CR, the processing and the analysis of the results obtained in the Study I and II; and the development of a patient robot interface to promote long-term interaction. A series of technical and scientific contributions are described below.

1. Experimental validation at the FCI-IC of the scenarios proposed during the study.
2. Analysis of the qualitative and quantitative data of Study I.
3. Integration of a multi-modal face recognition in the Patient-robot interface software architecture.
4. Development of a patient-robot interface, which include the *Recognition Plugin* and a *Memory Robot Module* explained in detail in the Appendices.
5. Development of a Protocol for the qualitative evaluation of user's in the personalized scenario, regarding the interaction with social robotic agents and technology in general.
6. Analysis of the qualitative and quantitative data in the Study II.

1.5 Publications

The work presents in this thesis has been subject of the following scientific publications:

1. (Conference Proceeding) Jonathan Casas, Nathalia Céspedes Gómez, Emmanuel Senft, Bahar Irfan, Luisa F. Gutiérrez, Mónica Rincón, Marcela Múnera, Tony Belpaeme, and Carlos A. Cifuentes. “Architecture for a Social Assistive Robot in Cardiac Rehabilitation." In 2018 IEEE 2nd Colombian Conference on Robotics and Automation (CCRA), pp. 1-6. IEEE, 2018. https://doi.org/10.1109/CCRA.2018.8588133

2. (Book Chapter) Jonathan Casas, Nathalia Céspedes Gómez, Marcela Múnera and Carlos A. Cifuentes. “Human-Robot Interaction for Rehabilitation Scenarios" published in Control Systems Design of Bio-Robotics and Biomechatronic with Advanced Applications, Academic Press, 2020, p 1-31, Elsevier. https://doi.org/10.1016/B978-0-12-817463-0.00001-0.

3. (Journal Article) Jonathan Casas, Nathalia Céspedes Gómez, Luisa F. Gutiérrez, Mónica Rincón, Marcela Múnera, Tony Belpaeme, and Carlos A. Cifuentes. “Expectation vs Reality: Attitudes Towards a Socially Assistive Robot in Cardiac Rehabilitation". Applied Sciences, 2019. https://doi.org/10.3390/app9214651.

4. (Review Article) Carlos Cifuentes, Maria Jose Pinto, Nathalia Céspedes Gómez, Marcela Múnera. “Social Robots in Therapy and Care ". In Current Robotics Report Journal. Springer,2020. https://doi.org/10.1007/s43154-020-00009-2

5. (Journal Article) Nathalia Céspedes Gómez, Marcela Múnera, Catalina Gómez, Carlos A. Cifuentes. “Social Human-Robot Interaction for Gait Rehabilitation", IEE Ttansactions on Neural Systems and Rehabilitation Engineering, 2020. https://doi.org/10.1109/TNSRE.2020.2987428

6. (Conference Article) Bahar Irfan, Nathalia Céspedes Gómez, Jonathan Casas, Emmanuel Senft, Luisa F. Gutiérrez, Monica, Mónica Rincón, Marcela Múnera, Tony Belpaeme, and Carlos A. Cifuentes. “Using a Personalised Socially

Assistive Robot for Cardiac Rehabilitation: A Long-Term Case Study". In 2020 International Symposium on Robot and Human Interactive Communication (RO-MAN).

7. (Journal Article- under writting) Nathalia Céspedes, Bahar Irfan, Luisa F. Gutiérrez, Monica, Mónica Rincón, Tony Belpaeme, Carlos A. Cifuentes, and Marcela Múnera . "A social Assistive Robot for Cardiac Rehabilitation"

8. (Journal Article- under writting) Bahar Irfan, Nathalia Céspedes Gómez, Luisa F. Gutiérrez, Monica, Mónica Rincón, Tony Belpaeme, Carlos A. Cifuentes, and Marcela Múnera. "A Personalized Social Robot for a Real Scenario in a Cardiac Rehabilitation Setup"

1.6 Organization

This Master Thesis document is structured as follows:

Chapter 2 introduces the context of Cardiac Rehabilitation and the service at the FCI-IC.

Chapter 3 introduces the context of socially assistive robotics in long-term scenarios, going from a general approach up to the applications in the health care context. Additionally, the strategies commonly used to extend the lifetime of the relationship between robots and users.

Chapter 4 presents the description and the results of the patient-robot interface in the Study I (control and robot scenarios). The control scenario includes patients who perform conventional CR program and in the robot scenario the patients are assisted by a social robot. Two measurements we considered: (i) Quantitative measurements to evaluate the effect on the physiological conditions of the patients and the interactions with the robot, and (ii) Qualitative measurements to evaluate the perception of the robot. These measurements are based on specific questionnaires. The conclusions, the lessons learned and the recommendations for next studies are presented.

Chapter 5 Addresses the integration of the multi-modal open set person recognition in the patient-robot interface and its assessment in CR rehabilitation (Study 2). The Quantitative measurements remains the same as the Chapter 4, and the Qualitative measurements are modified by adding a questionnaire and a video analysis to assess the patient's perception and attitudes towards the personalized robot.

Chapter 6 presents the overall conclusions of this master thesis and recommendations to improve the patient-robot interface development and assessment in future studies.

Chapter 2

Cardiac Rehabilitation at Fundación Cardioinfantil Instituto de Cardiología

2.1 Introduction

Cardiac Rehabilitation (CR) is a healthcare strategy that seeks to improve the quality of life of persons who presented a CVD [3]. According to the WHO, the CR is focused on three main approaches: (i) education approach aimed to teach the patients healthy habits, self-care procedures and diseases information, (ii) exercise approach aimed to recover the health status of patients trough physical exercise plans and (iii) pharmacological prescription [3].

Overall the CR benefits include the improvement of the cardiovascular and respiratory functioning, the reduction of risks factors and comorbidities, restore the sex life and improve the mental health care [26, 27]. In the last decades, these benefits have been evidenced. For example, in Germany the mortality rates are being reduced after CR implementation, about 118.4 deaths are reduced to 36.7 deaths per 100.000 population [28]. Similar results were found in [29] where CR improves patient's exercise capacity and performed secondary prevention against CVD's.

Despite the positive evidences of CR, the attendance and adherence to these programs are significantly low. The adherence can be defined as the degree of which a patient follows up a health care treatment [27]. Among the factors that affect the adherence to the therapy, the most relevant are a lack of interest in rehabilitation, a reluctance to make lifestyle changes, and depression [29]. In this context, it is important to increase the adherence to the patients who present an CVD, by encouraging them to acquire a healthy live style and habits.

This Chapter describe the structure of the CR service at the clinic FCI-IC and the details of the exercise-based therapy implemented in this service.

2.2 Cardiac Rehabilitation Programs

The structure of CR programs depends on the country and institution where it is carried out. Nevertheless, CR programs commonly consist in three phases: Phase I or Inpatient Phase, Phase II or Outpatient Phase and Phase III or Maintenance Phase.

Phase I occurs immediately after the cardiac event, and regularly has a duration of 7 to 10 days. In this phase the medical staff aid the patients to regain mobility and recover muscular tone. The goals of this phase include the assessment of mobility and its effect in the cardiovascular system, prescription of adequate exercises to improve cardiac fitness and education to reduce cardiovascular risks associated to the medical treatment [30].

Phase II is the first outpatient phase that begins after the patient leaves the hospital. This phase is based mostly in physical exercise on treadmills or cyclo-ergometers and education oriented to prevention of risk factors (e.g. controlling blood pressure, cholesterol, weight and stress management). This phase has an average duration of 3 months and is designed to provide a safe monitored environment for exercise [30]. Within the monitoring, the healthcare staff measure the patient's blood pressure, heart rate, exertion level and eventually heart and lungs sound [31, 32]. As result from the phase II, the patient should be able to self-monitor its physiological parameters and exertion levels. This aspect will return the confidence to the patient to continue a normal life, being aware of its health condition and the healthy lifestyle that is required to prevent from a second cardiac event [33].

Phase III is considered as a long-term maintenance period. The main objective of this phase is to provide reinforcement to the already-acquired routines in previous phases and to provide advice concerning secondary prevention. In this phase the patient can be prescribed with a tailored set of exercises that include flexibility, strengthening, and aerobic exercises. At the end of this phase, the patient has increased its exercise tolerance and independence, and is ready to continue with the normal routine at home [33].

2.3 CR service in Colombia

In Colombia, the CVD's represent the first cause of death and hospitalization in the population older than 45 years [34]. Despite that CVD's are critical in Colombia, a lower number of studies are focused on this problematic [35]. In the literature the growing number of the CR services in Colombia can be seen. By 1980 to 1985, CR programs are being implemented in the country. Nowadays, 44 CR programs are registered in Colombia [36].

Few studies showed the impact of CR programs in Colombia. In 2012, a study was conducted in Santander, Colombia. The results shows that the rehabilitation reduce the mortality and hospitalization rates [37]. However, it was also highlighted the high desertion rates, also supported by [36], estimating that less than 10 % of patients attend to the programs. Additionally, low remission from the medical service (65,9% of patients are not remitted to the CR programs) has been reported [37].

2.3.1 CR service in the FCI-IC

As this study is focused on the development and implementation of a patient-robot interface in CR to improve the conventional therapy effects and increase the adherence; it is important to describe the service where this development was carried out. The interface is applied in the Phase II of CR in the FCI-IC.

The CR service is located in Bogotá, Colombia. This service receive patients, aiming to improve their quality of life, functionality, physical endurance, to perform exercise, and reduce cardiovascular risk factors. The unit has an interdisciplinary group conformed by physiatrist, cardiologist, nurses, physiotherapists, and occupational therapists. The unit has provided rehabilitation services for the last 25 years, allowing patients to adapt their lives to the new physical conditions and optimize their health state, with an intervention based on three elements: physical activity, continuous control and monitoring of medicament, and specific education provided by a diverse team of professionals [38].

The service (Figure 2.1) has with 9 treadmills and 10 static bikes available for patients that attend the sessions of the phase II and III of the CR program. The facility operates from Monday to Friday, starting at 7:30 until 17:30 and each session is programmed to have a duration of 1 hour, providing attention for an average of 620 consultants/month as well as 1450 inpatient sessions/month and 3200 outpatient sessions/month. The schedule of the facility is designed to receive patients from different groups at specific time slots (e.g. phase II, phase III, spirometry patients that present heart failure and geriatric patients).

Figure 2.1: Cardiac Rehabilitation Service at the FCI-IC.

Approximately 15-20 patients assist to each CR session. Most of the patients present cardiovascular conditions or have underwent procedures that involve: post-coronary miocardial revascularization, angioplasty or stent, patients with implants (pacemakers, defibrillators), patients at high risk for CVD's among others. Within each CR session 2 to 7 healthcare professionals monitors the patients.

2.3.2 CR session in the FCI-IC

The conventional therapy in CR at the clinic can be divided in 5 phases, depending on the patient's and clinician's tasks. First, as soon as the patient arrives, the clinicians take the *Initial Measurements* at resting. As it can be seen in the Figure 2.2, the measurements taken during this phase are the blood pressure, the heart rate and weight. This data is recorded by the clinicians in order to know the patient's

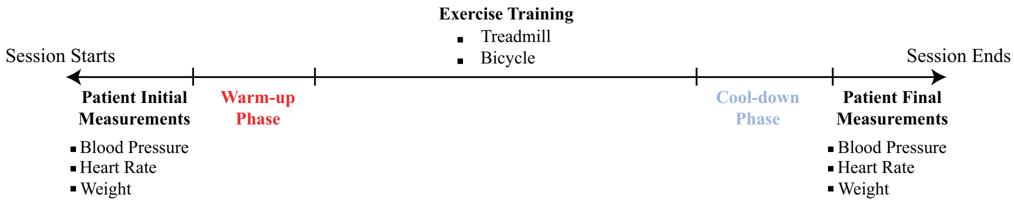

Figure 2.2: Timeline regarding the conventional CR sessions. Each sessions contains a total of 5 phases. Within two phases the clinicians take the initial and final measurements; the physical activity phases which include the warm-up, the training and the cool-down.

general health status. Then the *Warm-up Phase* begins. During this phase, the patients are physically prepared (e.g., running, jumping, and other moderate exercises) to the exercise that will be performed in the *Exercise Training Phase*. As it was mentioned previous, during the training exercise the treadmills or bicycles are the most used devices. Approximately, this phase lasts 25-30 minutes. During this phase, the clinicians check the heart rate and the exertion rate once, these measurements are taken to follow the patient's health status within the exercise. Then a *Cool-down Phase* begins, aimed to recover the normal health status of the patient. Finally, the *Final Measurements* are taken by the clinicians. During this last stage, sometimes the clinicians give "small educative talks" to teach the patients about nutrition, health recommendation, disease information- among the others.

2.4 Conclusions

As it can be seen during this Chapter, CR is an essential tool to maintain and improve the health of the patients who presented or are in risk to preset a CVD. However, in the literature the evidence demonstrates that the adherence to the rehabilitation procedures is very low. Several factors can contribute to this phenomenon (e.g., low motivation, social support, low incomes, cultural barriers, among others). In order to increase the adherence and enhance the CR strategy, different technologies can support the patients in their processes. SAR is one of the technologies commonly used in health care to provide social support, motivation, physical assistance and other benefits. As CR is a long-term process is important to maintain the relationship between the patient and the robot during a greater number of sessions. Next chapter describe the literature review of SAR tools used in long-term scenarios (i.e., scenarios with includes interactions for extended periods of time, usually greater than 1 month).

Chapter 3

Socially Assistive Robotics in Long-term Applications

3.1 Introduction

Social assistive robotics (SAR) shares with assistive robotics (AR) not only the goal of providing assistance to patients, but also aid the user from a cognitive support and social interaction. Social robots performs tasks with a high degree of autonomy for a natural interaction with the patient [39,40]. SAR based applications have been developed in multiple clinic and home-based areas, providing physical, cognitive and social support, as well exercise training, education and monitoring. SAR focuses on the use of sensory data from resources such as: cameras, tactile sensors, inertial measurement units, among others. These sensory platforms give to the robot the capability to understand its environment and, therefore, be able to aid, monitor and motivate patients [39]. This chapter presents a brief literature review which includes the studies on SAR focused on experiments developed in long-term periods. The databases used to implement this state of art were: IEEE Xplore, Google Scholar and Scopus and the key words used were: "social robots", "social robotics", "long-term", "exercise", "health care" and "rehabilitation".

3.2 Social interaction for Long-term applications

To understand social robotics, is important to have clear the meaning of social interaction. As it was mentioned at the beginning of this chapter, the main objective of a social robot is to assist the patient not only in a physical way but also in a cognitive way. Over time, social interaction has been studied and it has been represented through a variety of theories. However, a general definition of a social interaction from a sociology approach is: "*social interaction* is a dynamic, changing sequence of social actions between individuals or groups" [41]. As a product of the social interaction, the partners can modify their actions and reactions.
In this context, social robots have several ways to change and share actions. The channels commonly used for social robots are verbal and nonverbal communication [40]. Verbal communication is consider as the exchange of symbols that can be spoken or written [42] and nonverbal communication can be produced trough gestures, gaze, among others [41]. For long-term periods this interaction has to be stronger and very similar to the human-human social interaction. Currently SAR applications for long-time experiences still represent a challenge. Factors such as robot embodiment, social emotional intelligence and socio-cognitive skills [43], has to be considered during the design of social robots and its applications.

Social Robots Embodiment: Social robots are developed to interact with users in a human centric way. The robot embodiment is not always the same, robots can have a variety of external appearances (e.g., human-like, animal like or abstract designs), but they share the aim of engaging users in an interpersonal manner [43]. Despite the several styles of social robots, people tend to have a greater acceptance to anthropomorphic robots [44]. This preference occurs as humans attribute their mental stages (e.g., thoughts, emotions and desires) to this kind of robots [45]. The design of the robot depends in their final application. In some areas it is important to include whole body motion proxemics, facial expression, linguistic vocalization and touch-based communications. To achieve the correct embodiment features is important to use methodologies as inclusive participative design [46], where the participants contribute in the decision making process to increase the acceptance and effectiveness of the impact caused by the robot.

Social-emotional intelligence: Human communication and social interaction often integrates effective and emotive cues. Thus, social robots need to be able to recognize and interpret affective signals from the users. Theorical models of emotions for social robots are currently being developed to derive coherent computational models. Two theoretical models are mainly used in social robotics: *Appraisal theory model* and *Dimensional theory model*.

The *Appraisal theory* emphasize a connection between cognition and emotion. In this model, emotions are evoked from personal significance events (e.g., individual beliefs, desire and intentions) [47]. This theory can be described as a discrete model, where an emotion event cause a response. For example, the Artificial Intelligence (AI) with if-then rules codes are based on this kind of model. On the other hand, *Dimensional theory* is based on continuous dimensional space [48] where the emotional state of the user can be represented in a 3-D space. PAD models are based on this theory [49]. PAD models are represented by P (i.e., pleasure/valence), A (i.e., arousal/intensity) and D (i.e., dominance/coping potential).

Emotional Empathy is another factor relevant in order to achieve long-term interactions between robots and humans. Empathy can be broadly defined as an "affective response more appropriate to someone else's situation than the one's own" [50]. Several works are currently focused on empathy approaches to enhance the social robots' capabilities [51] . Most of these studies use mimicking user's affective states to endorse the effects of social robotics [52].

Socio-cognitive skills: Social robots must understand and predict the human behaviors. Therefore, robots have to be aware of the peoples goals and intentions so the robot's behaviors can be adjusted to help the users in terms of their goals and needs [53]. In this way, several strategies are used. The most common features used in robots are memory (i.e., face recognition) [54, 55] and communicative skills (i.e., speak recognition) [56].
A key challenge in this kind of interactions is the recall of past important events during conversations and activities [57]. *Episodic memory* is a core concept to define this challenge. The *Episodic memory* stores the data related to past events, as well as adds perspective to the robot in terms of how to choose important and emotionally events and preserves temporal labels to use them in future referencing. Several applications consider the use of automatic speak recognition (ASR) to produce casual communication and social exchanges [58]. However, this skill remains a challenge. Limitations on the environment characteristics and the self-properties of the voice are highlighted in a variety of research studies [17, 59].

3.3 Long-term SAR Applications

As aforementioned, SAR has been used in multiple fields and applications with the aim to aid and support users by means of social interaction. However, several studies observe the interaction in short periods of time. Short-term studies do not allow to have a complete perspective of the interaction between humans and robot. *Novelty effect* can decrease in time affecting the quality of the interaction.

A variety of researches have been focused in research strategies to achieve and maintain human-robot long relationships. Bickmore and Picard [60], evaluate a series of interactions that can potentially span the lifetime of the relationship between humans and robots. Their approach was to develop a relational agent (Figure. 3.2) for a health care application. This agent presents speech recognition and memory in order to establish a conversation with the users through socio-cognitive skills (e.g., humor, social dialogue, empathy dialogue and appropriate social deixis (politeness strategies)). Also, a range of nonverbal behaviors were implemented, including hand gestures, body posture shifts, gazing, facial expressions among others.

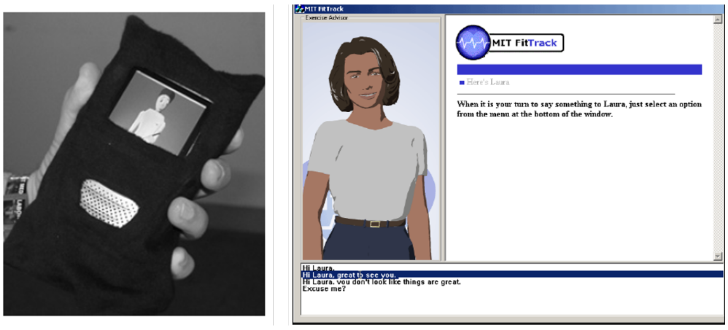

Figure 3.1: MITFitTraker relational agent. The left image present the device used to interact with the users and monitor their physical activity and the right image present the virtual agent used to motivate the users [60].

The assessment of the advisor agent was conducted used healthy subjects during a six-week intervention. Results of the study demonstrated that users were engaged with the agent thanks to the dialogues and the capability to remember information. The memory of the robot was a positive appeal to maintain the interaction during the intervention time.

Affective models were also investigated in order to establish a long-term human-robot interaction. Kirby et al, deploy a Roboceptionist [1], the robot used expressive moods and emotions based on the fact that human-human extended interactions depend strongly on shared emotional experiences [61]. The model is divided into emotional behaviors (i.e., joy, sadness, disgust and anger) expressed through the face and language; and mood factors achieved by posture (tilt of the head). This mood status depends on the emotions experienced on the day. The study shows

[1] https://www.ri.cmu.edu/project/roboceptionist/

that people were able to understand robot's expressions which allows the interaction. However, the researchers recommend to add features as user identification in order to personalize robot's attitude with specific users and improve the interaction.

Finally, the empathy is also a strategy commonly used to achieve long-term interaction. Leite et al [51], present an emphatic model for social robots that aim to interact with children in extended periods of time. The platform uses *Affect Detection*, *Emphatic Appraisal*, *Supportive Behaviors*, *Memory of past interactions* and *Action Selection*. *Affective Detection* was in charge of making a real-time prediction of the current state of the user taking into account visual cues and user information. *Emphatic Appraisal* where the robot appraises the situation and generates an empathic response using "perspective taking" (i.e., appraising the situation the user is experiencing from his point of view). *Supportive Behaviors* that occurs when the user have a negative mood. The robot reinforces the other's sense of competence or perform expressions of caring. *Memory of past events* gives to the robot the skill of remembering past interactions which is crucial in long-term interactions. Remember past events allows the robot to develop future information to generate dialogues with the user. The researchers conclude that using emphatic models affects positively the long-term interaction between the robots and the children. The rating of engagement and social presence remained similar after 5 weeks.

3.3.1 SAR long-term studies in Health

Kidd and Breazel, studied the long-term effects of the human-robot interaction in coaching with the aim of reducing the rates of overweight and obesity. Autom [2] was the robot used in this case to interact with people 3.2. As mentioned in the study, three factors to create a relationship with the users were important: (i)

[2] `http://robotic.media.mit.edu/portfolio/autom-papers/`

engagement, (ii) trust of the system and (iii) motivation to use the platform. To achieve this long-term interaction several key features were used (e.g., eye contact, hand/head and arms gestures, speech; and speech recognition). Also, to generate a more natural interaction with users, Autom talks to the persons and guides them while discussing about some topic talked in a previously interaction with the user.

Figure 3.2: Autum robot used in a long-term study to coach adult users aimed to reduce the rates of overweight and obesity [62].

The study was conducted during 50 sessions, with 45 subjects. To measure the interaction the indicators were: weight loss, WAI (Working Alliance Inventory), usage of the system and questionnaires. The experimental design includes three scenarios (i.e., robot assistance environment, tablet registration scenario and paper-conventional scenario) that allowed the analysis of the robot's effects. The results showed that the participants assisted by the social robot used the system for longer periods than those who use the tablet and paper registration. Also, these users have a closer alliance with the robot and were more interested in knowing the calories consumption and exercise performed. [62].

In elderly care population the long-term effects of social robots have been studied. A variety of researches of PARO [3] a seal-robot (Figure 3.3) showed the positive impact within this community [63, 64] and its capability to maintain the benefits

[3] http://www.parorobots.com/

for more than one year [65].

Figure 3.3: Paro robot in an Elderly Care Center. This robot is mostly used to treat the dementia and the mental healthcare of the elderly [65].

One of the most important work with PARO was made by Wada et al, who performed an animal-robotic therapy in a care house. The sociopsychological and physiological effects on the residents were evaluated in the study. The robot behavior contains a three layers architecture. First, a reactive layer for responding to stimulus (e.g., touch, sound and light); second, a proactive layer triggered by the robot internal needs; and finally, a physiological layer that describes animal behaviors considering the diurnal rhythm (e.g., sleep and eat). During the study, 12 subjects were recruited. Effects such as: degree of social interaction, stress levels, videos and urinary test were evaluated during 30 sessions were PARO interacts approximately during 9 hours a day. The results indicated that PARO allows stronger social ties among elderly patients of the care house and that most of the residents have a moderate or strong interaction with the robot. In the case of the urine test, the results showed that the use of PARO decreases the levels of stress [66].

More recently, an ethnographic study that uses a conversational robot within an elderly care center, was developed to observe the interactions of the elderly and medical staff with the robot. Robovie interacted with 55 aged patients for $3-5$ months. The robot routines includes, to welcome the elderly as they arrive at the center and to perform conversation and encouragement tasks. The analysis to the interviews and the observation suggested that the robot has a positive impact and acceptance within the center. Also, behaviors (e.g., greetings, calling persons by their names and child role) were significant for this result [67].

Finally, a pilot study using a Ryan Companion bot [4] was developed in order to investigate the subject's engagement and enjoyable attitudes towards a robot [68]. Potential outcomes of this study show that: (i) Elderly users kept the interest of having conversations with the robot, (ii) they still were interesting on spending time with Ryan, although the users had regular group activities (e.g., playing games , occupational and physical therapy) (iii) the robot helped users to maintain their schedule and improve their mood. And finally, (iv) patients felt happier when they had Ryan as their company.

3.3.2 Memory Strategy in SAR

As it was mentioned in previous sections, social skills are relevant in order to achieve long-term interaction with human users. Several strategies are currently developed to achieve this goal (e.g., speech recognition and face recognition). In this context, this section presents studies which are focused on the development of *memory strategies* for social robots in different applications.

R.Agrigoroaie and A.Tapus, propose the development of a healthcare robot with personalized behaviors and social skills for patients suffering from mild cognitive impairment. The main aim of the framework is to provide customized interaction using episodic memory, learning and adaptation. The platform's integrated in the Komapai robot [5] allow the planning of future actions considering previous events [69]. In the same way, in [54] the researchers introduce a model for episodic memory mixed with a decision-making module and a finite-state machine system to produce appropriate responses in healthcare scenarios. The model was tested

[4] `http://dreamfacetech.com/`

[5] https://kompairobotics.com/es/robot-kompai/

with two users, who interact with the robot two times. The robot was capable of collect personal data and remember remarkable events of the interaction. The researchers recommend the application of this method in areas such as: health care for children and elderly care, in order to create long-term intelligence. Belpaeme et al [55], suggested a multi-modal Human-Robot interface to building social bonds in the ALIZ-E [6] project context. The objectives of the multi-modal structure were to allow adaptive social interaction with young users diagnosed with metabolic disorders. A module consists in the use of memory. The memory module was applied in a "SandTray" scenario. This scenario provides a collaborative experience based on the sandplay techniques in child psychotherapy. A study carried out with 19 children was performed. Overall, participants reported positive reactions to the robot, children described to feel happy with the robot companionship and mentioned that they would like to interact in the future more times with the robot.

As it can be seen, memory is a fundamental strategy to enhance the interaction between human and robots. Other researchers are focused on the integration of memory control architectures in a very natural way. For example, Mafaz et al, present a biological inspired architecture for a social robot (Maggie [7]). This study presents the integration of two kind of memory systems: (i) *short-term memory* and (ii) *long-term memory*. The *short-term memory* is a temporary memory of specific events and skills; and the *long-term memory* refers to a permanent repository of durable knowledge. In this type of memory, the knowledge is acquired from learning processes obtained through Reinforcement Learning Algorithms. The robot was tested in a real scenario (in a school area) and the results showed that the robot was able to select appropriately the skills required during the interaction.

Table 3.1, summarize the studies focused on the development of memory strategies to achieve a long-term interaction. The objectives, results and robots used during these studies are presented. As it can be seen, the memory strategies are greatly

[6] `http://www.aliz-e.org/`

[7] `http://roboticslab.uc3m.es/roboticslab/robot/maggie`

Table 3.1: Literature Review of Memory strategies for Social Assistive Robotics

Authors	Strategy Description	Robot	Objectives	Results
R. Agrigoroaie and A.Tapus., [69]	Episodic memory, learning and adaptation.	Kompai Robot (Robosoft)	To develop a general framework for a behavior control architecture that is capable of provide customized interaction between the robot and an elderly individual suffering from mild cognitive impairment (MCI).	The system was capable to provide a personalized interaction and care the elderly by adapting its behavior based on their specific needs. The episodic memory allowed the reaction of the robot in future events, triggered by past events.
Belpaeme et al., [55]	Memory structures for long-term interaction	Nao Robot	To develop an adaptive social interaction with child users in a hospital setting. The users are children diagnosed with metabolic disorders (e.g., diabetes and obesity).	Overall, the patients' reported very positive reactions; children described themselves as feeling 'happy' in its company and found the interaction entertaining. These data indicated that participants continue to be interested in the robot.
Kasap and Magnenat., [54]	Episodic memory mixed with HTN and a FSM dialogue manager.	Eva Robot	To develop a model of episodic memory and integrate it with a decision-making module based on a Hierarchical Task Network (HTN) planner. Plans generated by the HTN planner are executed by a Finite-statemachine (FSM) based dialogue system in order to produce appropriate responses.	Eva was capable of interact with different users, using the episodic memory. The robot collected al the relevant data (i.e., users names, date and answers). The researchers highlighted the potential of the system to create long-term intelligence.
Dautenhahn et al., [70]	Episodic memory	Homecare Robot	To analyze how memory visualization can support the user (elderly patients) in remembering past events from the human-robot interaction history.	The results showed that people appreciate the memory, as it remember the user important daily activities. However the management of the data needs to be improved in the future.
Sánchez et al., [71]	Episodic long-term memory	Bender Robot	To propose a framework for providing an episodic longterm memory for a robot, which includes methods for acquiring, storing, updating, managing and using episodic information.	The results showed that people who interacted with the robot could feel a greater closeness and empathy with him seeing that he could answer their questions satisfactorily.
Malfaz et al., [72],	Short-term memory and Long-term memory	Maggie Robot	To design a bio-inspired control architecture for an autonomous and social robot, which tries to accomplish some social skills using a prior hybrid control platform.	The robot was tested in a real scenario, the results showed that the robot was able to select appropiately the skills required during the interaction.

used in healthcare scenarios as a lot of medical treatments required long-term interactions and personalized features. Most of these methods use *Episodic Memory* in order to achieve natural communication with the users. The results present in general positive effects in different types of populations (i.e., adults, elderly and children). The effects include the willingness of the users to continue to interact with the robot, maintain the robot's intelligence perception, higher empathy, among others. However, various studies remark the need of a continuous research in this topic as it stills have technical limitations.

3.4 Conclusions

This chapter present the literature review of SAR in long-term scenarios. In order to maintain the relationship and achieve natural interaction between human and robots, several strategies are currently applied. However, *Episodic memory* is one of the most advanced, this kind of memory is in charge of remember specific events at specific time and places. In this context, this strategy will be applied to the patient-robot interface to enhance the patient-robot interaction during Cardiac Rehabilitation.

Chapter 4

Patient-robot interface for CR Program

4.1 Introduction

Patient-robot interfaces are currently widely used in different kind of applications. These interfaces often combine measurements systems that use data acquire by a set of sensors to aid and support several activities. For example, in health care areas, telemetry systems are used to monitor physical conditions of patients [73]. Satija et al [74], proposed a real-time ECG telemetry system for IoT-Based Health Care monitoring. The system was described in three modules: (i) ECG sensing module, (ii) signal quality assessment module and (iii) ECG analysis and transmission module. Experimental results show that the system is promising regarding its functionality and the quality of the transmitted signal. In [75], researchers validate a telemetry system for measure blood pressure (BP) in long-term periods. The findings showed that the system could be used to accurately measure BP.

Additionally, telemetry systems are also used to detect alarms and risk events. Nolan et al [76], design a leadless implantable sensor to assist cardiac emergencies and warning alarms. The telemetry system was capable of sensing the impedance measurements of heart, respiratory system and patient motion to generate an alarm corresponding to arrhythmia events. Medical applications such as E-ambulances based in telemetry systems are emerging to support the clinical staff work [77]. This kind of system use a sensor network that deliver health status information and can spawn alarms using a decision maker unit. In terms of usability, the software was effective to handle all the real-time aspects integrated in the system. Likewise, Social Assistive Robotics (SAR) uses monitoring systems to enhance the capabilities of the robots. SAR uses sensory data from resources such as: cameras, tactile sensors, inertial measurement units among others, to achieve a natural interaction [39].

This kind of interfaces have been used before in health care applications. For example, Céspedes et al [78] developed a patient robot interface which monitors physiological data (i.e., cardiovascular parameters and cervical posture) in Neurological Rehabilitation. The main robot roles were: (i) give feedback about the cervical and thoracic posture, (ii) provide motivation and (iii) support the patient's performance. The interface was tested in two conditions (control and robot session). Results showed that the healthy posture improve when the patient's were assisted by the robot. Mataric et al, described a pilot study that involves an autonomous mobile robot for post-stroke rehabilitation, which monitors and encourages the patients during upper-limb exercises. The results showed a well-received behavior by the stroke survivors and a positive impact on their willingness to perform prescribed rehabilitation [79].

In this chapter, a description and the assessment of the patient-robot interface for the Cardiac Rehabilitation (CR) program is presented. First, the interface architecture designed is explained regarding the sensors and the robot module developed. Second, the methodology carried out to evaluate the interface in a real set-up in the FCI-IC is presented. In this study, two scenarios were observed (control and non-relational robot), quantitative and qualitative parameters were measure through the rehabilitation procedure to compare the scenarios. Finally, the results and conclusions obtained during the first stage of the study are discussed.

4.2 Patient-Robot Interface Description

In order to evaluate the effect of a social robots in CR, a study to compare two scenarios (control and non relational robot) was performed. A patient-robot interface based on two modules was developed. The first module includes a *sensory interface* that allows the monitoring of relevant physiological variables. The second module integrates a *social robotic platform*, in charge of the interaction and the cognitive approach (i.e., motivational and feedback support).

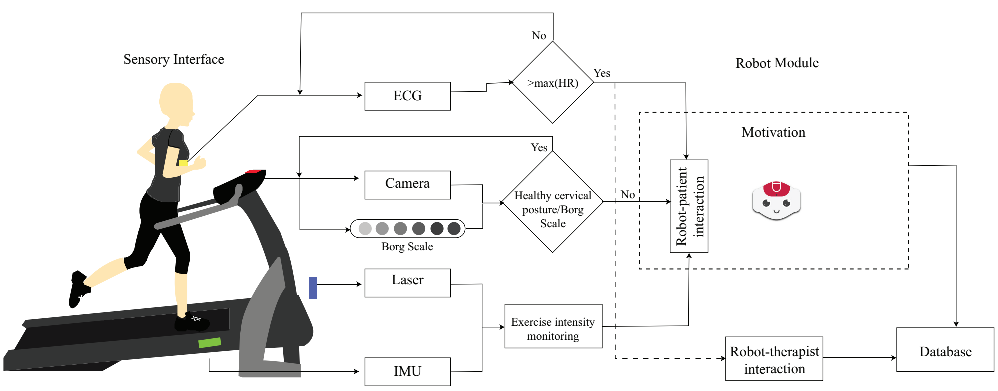

Figure 4.1: Patient-robot interface diagram for Cardiac Rehabilitation program. In the left side of the image the sensory interface overall structure is presented. The right side present the social robotic platform used to interact with the patients.

Figure 4.1 shows the architecture of the patient-robot interface. The *sensory module* measures four parameters to follow the patients' performance:

Cardiovascular Parameters: In cardiac physiology, several physical parameters are useful for studying the activity and regulation of the heart [80]. In CR, there is an increased interest to measure these parameters as they reflect the performance of the patient. Consequently, our study analyses these parameters at different phases of the exercise:

- *Training Heart Rate* [bpm]: The average of the Heart Rate values acquired during the treadmill exercise (15-20 min) . The heart rate values were measured using a heart rate sensor namely Zephyr HxM sensor[1] placed on the patient's chest.

- *Recovery Heart Rate* [bpm/bpm]: This value (*Recovery HR*) represents the difference between the *Training Heart Rate* ($HR_{training}$) and the average of the Heart Rate (60 values [2]) after the patient finish the training ($HR_{post-training}$) (eq. 4.1). :

$$RecoveryHR = HR_{training} - HR_{post-training} \tag{4.1}$$

  This value was normalized ($RecoveryHR_{Normalised}$) with the initial resting heart rate, which was taken by the clinicians when the patient arrives to the clinic (eq. 4.2). This normalization was calculated to reduce the subjectivity of the measurements that change between the patients and increase the homogeneity.

$$RecoveryHR_{Normalized} = RecoveryHR/InitialRestingHR \tag{4.2}$$

- *Blood Pressure* [mmHg]: Systolic and diastolic blood pressure were measured at the beginning and end of each session by the clinicians. The measurement is performed with an analog tensiometer.

[1]Medtronic, New Zealand, `https://www.zephyranywhere.com/`
[2]The sample frequency of acquisition corresponds to 1 Hz, 60 values represent 1 minute data.

Gait Spatiotemporal Parameters: Healthy gait is described as a series of rhythmical, alternating movements of the trunk and limbs which results in the progression of the center of gravity and the body [81]. The patient's gait performance is analyzed by the gait components, which can be categorized under the following distance measurements (spatial) and time (temporal parameters):

- *Cadence* [steps/min]: The total number of full cycles taken within a given period of time [82], which we express as steps per minute.
- *Step Length* [m]: The distance between the point of initial contact of one foot and the initial contact of the opposite foot [82].
- *Gait Speed* [mph]: This variable refers to the habitual walking speed adopted by a person in everyday life [82].

In this case, a Hokuyo-URG 04LX-UG01[3] Laser Range Finder (LRF) was used to acquire these parameters during the session.

Interaction Parameters: Two indicators were used to measure the interaction: (i) *Cervical posture Corrections* involves the flexion of lower cervical vertebrae and its inclinations [83]. To measure this parameter the front camera of the tablet [4] placed in the treadmill screen; and a gaze estimator algorithm is used. During the exercise, a proper cervical posture is given when the patient look straight. As the CR sessions are performed in a treadmill, the proper posture is important to avoid dizziness, falls and nausea. This measure represents the counting of a binary ("look-straight, notlook-straight") value extracted of a gaze vector. (ii) The *Borg Scale Response time* [s], which measure the time between a robot request and the patient answer through the tablet screen.

[3]Hokuyo, Japan, `https://www.hokuyo-aut.jp/`

[4]Microsoft, USA, `https://microsoft.com/es-es/surface`

Physical Difficulty Activity Parameters: Two indicators were used to measure the intensity of the exercise: (i) The inclination of the treadmill and (ii) the perceived exertion of the patient. An Inertial Measurement Unit MPU9150 [5], that was placed on the treadmill floor measures the inclination in a range of 0 and 5 degrees angle. The perceived exertion was measured using the Borg Scale. The Borg Scale is a subjective measurement commonly used in CR that allows the evaluation of the effort and intensity made by a patient during the exercise. At FCI-IC the scale is composed of numbers between 6 and 20, where 6 corresponds to a very low level of exertion and 20 corresponds to a very high level of exertion. The safe range is considered by the clinicians to be between 6 to 12.

Figure 4.2: Patient-robot interface for Cardiac Rehabilitation set up at FCI-IC.

In this context, the patient robot interface presented in this section was tested in previous works of our group. In first place, the system was developed and evaluated under laboratory conditions [84]. Second, the system was introduced at the clinic FCI-IC and tested with real patients during a short-term study. Results

[5] InvenSense, USA, `https://invensense.tdk.com/`

of this intervention are presented in a subsequent work [85]. Finally, the system was assessed for a larger number of patients during the complete Phase II of the CR program. This assessment is presented through this chapter.

4.3 Robot Module

The Robot Module is focused on the interaction between the user and the robot. The robot used in this study was the NAO V4 [6] robot. This interaction is provided by means of three robot roles: (i) *Motivational support*, (ii) *Performance monitoring* and (iii) *Online feedback*.

A therapy with the robot starts with an initial greeting, where the robot made an introduction of its functionalities during the CR. Then, when the patient starts the exercise on the treadmill, *Performance monitoring* state is activated. During this state, sensory information is analyzed. Depending of the values given by each sensor the current state can turn to the *Online feedback* state or remain in the same state. In this case, if the *Online feedback* is activated two robot behaviors can be triggered, when the system detects an increment in the physiological parameters such as: *Training Heart Rate*, *Borg Scale* and *Cervical posture*.

Heart rate Feedback: This feedback is given by the robot when two types of alerts are activated. Before the session starts, the doctor must configure two heart rate thresholds for each patient, the *first threshold* corresponds to the heart rate value where patients have a normal increase due to the exercise. The *second threshold*, is defined as the maximum heart rate allowed for the patient. Normally, the second threshold is calculated from the Karvonen formula (4.3) [86]. The Karvonen formula uses the maximum heart rate (HR_{max}) and resting heart rate (HR_{rest}) in combination with the desired training intensity ($\%Intensity$) to obtain a target

[6] https://www.softbankrobotics.com/emea/en/nao

heart rate ($Target_H R$).

$$Target_H R = ((HR_{max} - HR_{rest}) * \%Intensity) + HR_{rest} \tag{4.3}$$

The robot behaviors change according to the current value acquire by the sensor and the corresponding threshold. In the first case, the robot only asks the patient if he/she is okay. The patient has to answer through a button in the screen to provide the information. In the second case, the robot calls the medical staff and ask for help.

***Borg Scale* Feedback:** This feedback is given when the patient enters the *Borg Scale* in the tablet. According to the value of perceived exertion, three robot behaviors are activated during the session : (i) if the *Borg Scale* is on a normal range (6-10) the robot say "thanks" to the patient, (ii) if the patient enter a high *Borg Scale* (> 10) but the current heart rate is normal, the robot asks for a second verification and (iii) when the *Borg Scale* is high (> 10) and the heart rate overcomes the first threshold, the robot calls the medical staff in order to provide immediate clinical support.

***Cervical posture* Feedback:** This Feedback is given by the robot when the patient is watching the treadmill floor. In this case the robot gives verbal feedback to the patient asking to maintain a straight posture.

4.4 Performance Assessment

In this section the detailed information of the patient-robot assessment and the protocol carried out in this study are presented. A longitudinal study is conducted during the phase II of CR (36 sessions), where *Control scenario* and *Robot scenario* were designed to compare the results and observe the robot's influence over the patient performances.

4.4.1 Participants and Demographic data

According to the experimental design of the study, 15 patients were recruited per scenario. However, as stated in the introduction, the adherence to CR is low due to several factors. Therefore, were there dropouts in the study, as well as incomplete therapies due to the aforementioned factors presented in the Chapter 2. Consequently, we had 9 patients in the *control* condition and 11 patients in the *robot* condition, who actively participated in the rehabilitation and completed the outpatient phase (II) of the CR program. Table 4.1 shows the demographic of these patients.

Table 4.1: Demographic data of the patients who have finished the outpatient phase (II) of the CR program within the study.

	Control	*Robot*
Participants	9	11
Gender	9 males	10 males,1 female
Age (years), mean ± SD	56.6 ± 7.8	55.7 ± 11.2
Body Mass Index, mean ± SD	26.2 ± 2.6	29.2 ± 3.9
- Obese	0.0%	54.5%
- Overweight	66.7%	36.4%
- Healthy weight	33.3%	9.1%
Level of education		
- Elementary school degree	22.2%	18.2%
- High school degree	22.2%	27.3%
- Technologist	0.0%	18.2%
- Bachelor's studies/ degree	55.6%	18.2%
- Postgraduate studies/ degree	0.0%	18.2%

4.4.2 Inclusion criteria

The patients considered within this study, were those who start the Phase II of the CR program and that attended twice a week to the sessions. In order to have an homogeneous sample, patients with Acute myocardial infarction, Percutaneous Coronary Intervention and Post-Operatory Procedure from coronary artery bypass graft and valvular replacement were chosen.

4.4.3 Exclusion criteria

Taking into account the requirements of the system, possible participants that present limitations or any impairment to work on a treadmill can not perform the experiments. Additionally, patients with any visual, auditive or cognitive impairment that impede the manipulation and correct understanding of the system cannot take part of the study. Finally, patients that present a different cardiovascular pathology from the pathologies, mentioned in the inclusion criteria, will not be considered for the experiments.

4.4.4 Dropout criteria

There are two cases where a dropout will be considered: (i) In case that the participant does not attend to 4 unjustified session in a row, they must be excluded from the study and is considered as a drop-out. (ii) In case that the health conditions of the patient reach a critical point that impede the realization of the physical activity the patient must abandon the study.

4.4.5 Incomplete Sessions criteria

Some patients present incomplete CR sessions, due to strong medical reasons and financial support of their health care provider. In the case of the patient who was performing in the *Robot* scenario, the sessions were suspended due to the COVID-19 pandemic.

4.4.6 Scenarios

To observe the effects of the social robot, two scenarios were applied in the experiment. The details of each scenario are described below:

Control Scenario: Within this scenario the participants perform a conventional therapy of CR. As this scenario is consider a baseline, the patients of the control scenario were monitored by the sensory module of the interface. In this case, the patient interacts with the tablet to deliver the *Borg Scale* without the presence of the robot. Therefore, the patients of the control scenario does not receive any type of feedback or motivation.

Robot Scenario: Under this scenario, the robot module is applied to the sessions. As it can be seen in the Figure 4.2, the robot is placed next to the patient below the eye level. Once the therapy begins, the robot fulfills the functions of support, monitoring and motivation of the patient during the exercise.

4.4.7 Quantitative Assessment

This approach contemplates the quantitative variables analyzed during the study:

Dropout rate: The desertion rate is the number of patients who desert within the total of participants proposed for each scenario. A desertion case occurs when a patient misses 4 or more sessions without justifying its absence as the elimination criteria mention.

Physiological parameters: The main physiological parameters evaluated during the study are the *Cardiovascular* and *Physical Difficulty Activity Parameters*. In order to analyze the data, 6 stages were proposed. Each Stage contains 6 sessions, which represent the complete CR program. The analysis per stage was performed to reduce the greater variability of the data between the patients. This variability can be due to that the physiological data depends of the patient's self-care and the events occurred on each session.

Interaction Parameters: To measure the interaction of the patient with the robot two variables were analyzed, the *Cervical Posture Corrections*, and the *Borg Scale Response Time*

Statistical Analysis: Three approaches to analyze the data were implemented: (i) a Chi-Square Z test was implemented with the purpose of determine whether the observed frequencies (exclusive) markedly differ from the frequencies that we would expect by chance, (ii) Wilcoxon Ranked Signed Test to observe the behavior inter-scenario ,(iii) a Mann-Withney U Test to compare the differences between groups .

4.4.8 Qualitative Assessment

The second assessment made during the study, evaluates the acceptance and perception towards the social robot. In this case, the health care staff and the patients involved in the study perform the qualitative assessment. Aiming to achieve this goal, a questionnaire based on the model proposed by Heerink et al [87] is conducted. This model seeks to evaluate acceptance of the robot as a cardiac therapy assistant in different dimensions (i.e., Utility/Advantages (U/A), Usefulness (U), Perceived utility (PU), Safety (S), Ease of Use (EU), Perceived Trust (PT), Perceived Sociability (PS) and Social Presence (SP)). Each question was scored with a 5 points Likert scale (being 1 strongly disagree, 2 disagree, 3 neutral, 4 agree and 5 strongly agree). Additionally, 3 open questions are integrated in the questionnaire to measure the perception of the patients towards the robot (Appendix Table 1, Table 2). The study has been divided in two parts. The first, focuses on the perception and attitudes carried out with patients, and the second implements a focus group to analyze acceptance and perception of this technology with clinicians. Table 4.2 showed the participants who go through the qualitative assessment. In the case of the patients, 8 patients answer the questionnaire, 2 patients could not be contacted, and 1 patient is still performing the study (suspended due to the COVID-19 pandemic).

Table 4.2: Participants in the perception study

	Study	Participants
Patients	Intervention: long-term study (N=8) Control: interviews (N=20)	Patients attending Phase II Patients attending Phase II-III
Clinicians	Focus Group (N=15)	3 Nurses 4 Doctors 6 Physiatrists 2 Occupational Therapists

Statistical Analysis: A Mann Whitney-Wilcoxon (MWW) test was applied to determine significant differences on each construct between scenarios. This test has found to be suitable for five-points Likert scale, since it presents minimal type I error rates and equivalent power with the 2-sample t-test [88]. Furthermore, it has been demonstrated that the MWW test provides better results for small sample sizes than the t-test [89].

4.5 Results

This section presents the results regarding the assessments performed across the study. Taking into account the performance assessment, *Quantitative* and *Qualitative* approaches are presented.

4.5.1 Quantitative Results

A total of 30 patients were included within the study (Table 4.1). Figure 4.3 shows the adherence between scenarios. According to the results, 6 patients who were in the control scenario and 3 patients of the robot scenario did not complete the phase II of CR. As it can be seen the patients who abandon CR, perform 10-12 session in average before withdrawing from therapy.

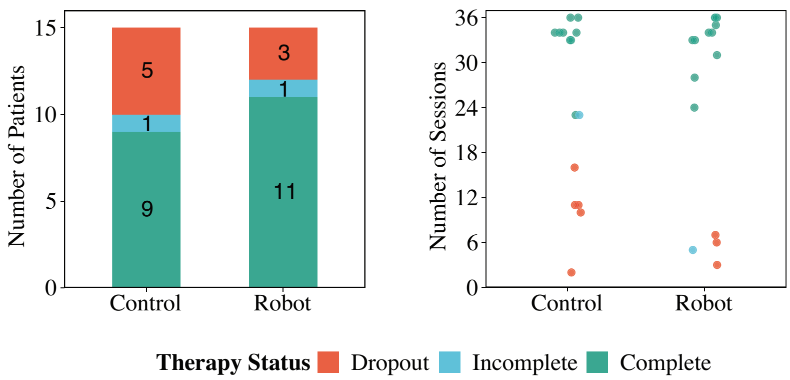

Figure 4.3: The therapy status of the users in the *Control* and *Robot* scenarios: *complete* refers to the completed cardiac rehabilitation therapy as determined by the clinicians; *incomplete* is when patients need to stop the therapy due to reasons beyond their control, and *dropout* refers to dropping out of the study or not attending 3 sessions in a row without a justification.

Figure 4.4 shows the physiological progress of 2 patients (1 control and 1 robot) across the CR program. As it was mentioned in previous sections a set of sensors

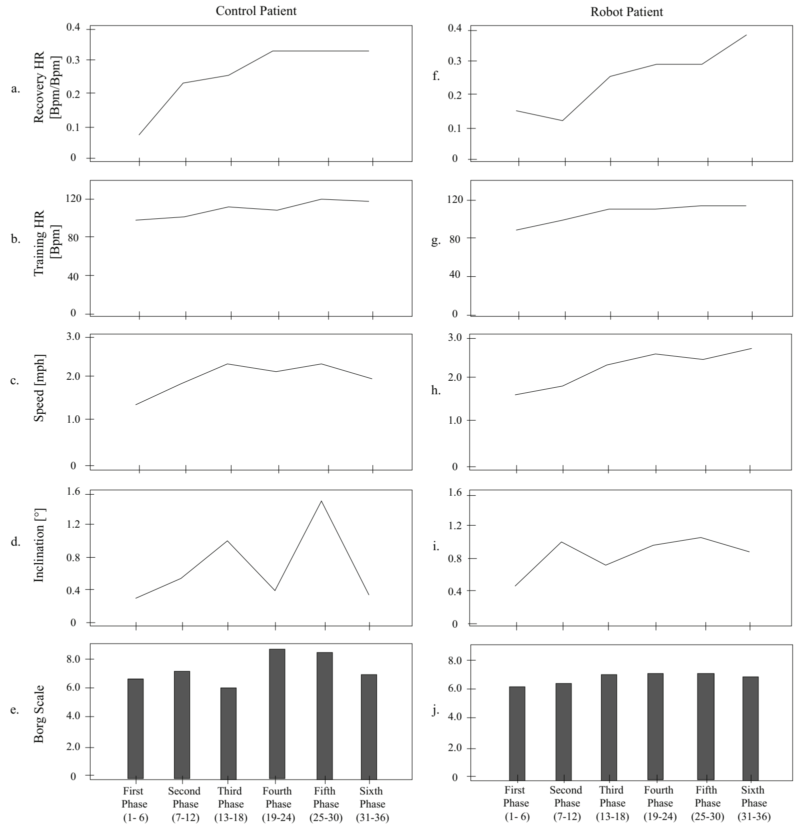

Figure 4.4: Physiological parameters (averages) behaviors between Control and Robot scenarios (1 patient). Figures (a) and (f) describe the *Recovery Heart rate*. Figures (b) and (g) represent the *Training Heart Rate*. Figures (c),(h) and (d),(i) shown the *Gait Velocity* and the *Treadmill's Inclination* respectively. Figure (e) and (j) describe the *Borg Scale*.

measure several parameters in order to describe the patient's performance during 36 sessions divided in six stages. Figure 4.4 (a,f,b,g,e,j) represent the cardiovascular performance outcomes, while Figure 4.4 (c,h,d,i) represent the input variables in the CR program. These input variables influenced the outcomes of the therapy and modify the physical activity features of each patient.

Figure 4.5 shows the comparison between the *Recovery Heart Rate* in both scenarios. *Recovery Heart Rate* is the main parameter of the physiological data as it is considered by the clinicians the main result of the CR. Taking into account this type of rehabilitation is based on the exercise, it is expected that this parameter get higher values when the therapeutic procedure advances. In order to analyze the

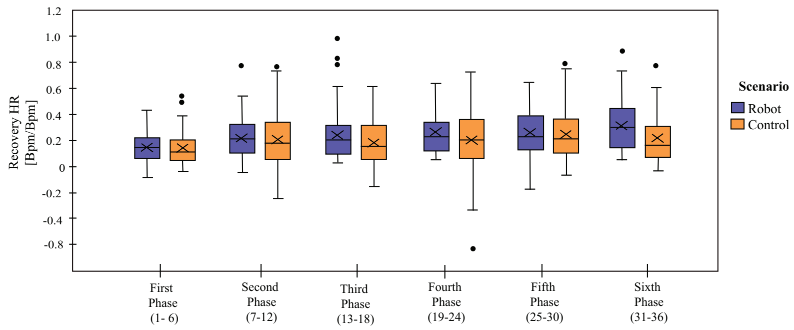

Figure 4.5: *Recovery Heart Rate* rate on each stage in control and robot scenario. Data are normalized with the value of initial resting hear rate on each session.

Table 4.3: Recovery Heart Rate Wilcoxon Signed Rank Results

	Robot pValues	Increment %	Control pValues	Increment %
Stage1/Stage 2	**0.01**	54.89	0.07	49.35
Stage 1/Stage 3	**p<0.01**	82.43	0.20	34.24
Stage 1/Stage 4	**p<0.01**	98.96	0.30	48.55
Stage 1/Stage 5	**p<0.01**	96.93	**0.04**	92.44
Stage1/ Stage 6	**p<0.01**	135.82	0.16	68.24

data regarding the *Recovery Heart Rate* three types of analysis were developed. In first place a Wilcoxon Ranked Signed Test was performed to observe the progress of the patients along the time in each group (Table 4.3). As it can be seen, the *Recovery Heart Rate* in the robot group present significant differences between the Stage 1 and all the other Stages; the increments show that the patients of the robot group increase their *Recovery Heart Rate* greater than the patients who participated in the control scenario. For instance, the control group only present a significant difference between the Stage 1 and Stage 5. If the Figure 4.5 and the Table 4.3 are observed, the results show that the patients of the control scenario have a *Recovery Heart Rate* that tends to increase but in a lower rate than the patients of the robot group. This can be due to two patients in the control scenario, who present a negative performance (decrement on their *Recovery Heart Rate*). Although, these results showed the behavior in a longitudinal way (comparison between stages of the related samples) present changes, the comparison between scenarios does not show

Table 4.4: Mann-Whitney U results between Control Scenario and Robot Scenario (Physiological Parameters)

	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6
Recovery Heart Rate	0.61	0.98	0.44	0.32	0.51	0.28
Training Heart Rate	0.59	0.98	0.81	0.49	0.82	0.53
Borg Scale	0.25	0.76	0.38	0.98	0.44	0.53

Table 4.5: Chi-cuadrado Z test for the Recovery Heart Rate Parameter

	Control Scenario	Robot Scenario
Recovery Hr $>$22	9	20
Recover HR $<$22	43	42
Number of Sessions	52	62

significant differences (Table 4.4). Additionally, the *Training Heart Rate* and the *Borg Scale* were also compared showing no significant differences between scenarios (Table 4.4).

A Chi-Square Z test was also implemented to observe the clinical relevance of the *Recovery Heart Rate* between the groups. According to the literature, a *Recovery Heart rate* greater than 22bpm represent a healthy value and a successful rehabilitation process [90]. The results show that exists a difference between the *control* and *robot* group. As it can be seen in the Table 4.5, in the robot group a higher number of the patients exceeded the threshold, showing that the patients in the robot scenario have a better physical activity performance.

Regarding the interaction, two indicators were measured within the robot scenario: *Borg Scale response time* and *Cervical posture feedback*. Figure 4.6 shows the behavior of the *Borg Scale response time*, as it can be seen this parameter tends to decrease in the time. A Wilcoxon Signed Rank Test was performed in order to observe if there is an statistical difference across the time. Table 4.6 show that the difference between the stages are significant in the Stage1 vs the Stage 2 and 4. For the next stages, the differences are not significant this can be due to the reduce number of sessions in the end of the rehabilitation (Figure 4.3). However, it can be seen that this parameter decreases in the time. These results could indicate an adaptation to the technology across the time.

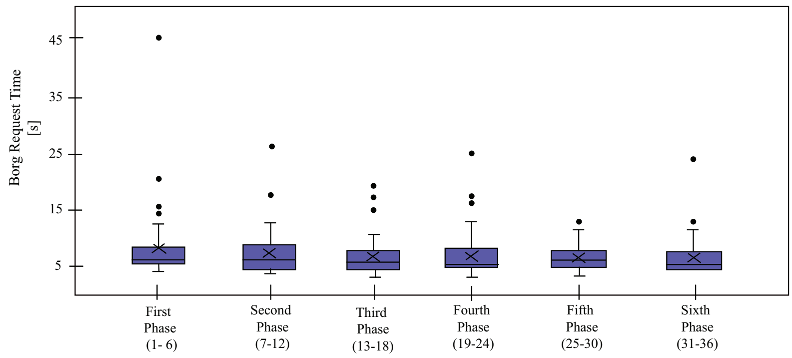

Figure 4.6: *Borg Scale Response* time regarding of the patients who perform the robot scenario in the Cardiac Rehabilitation program.

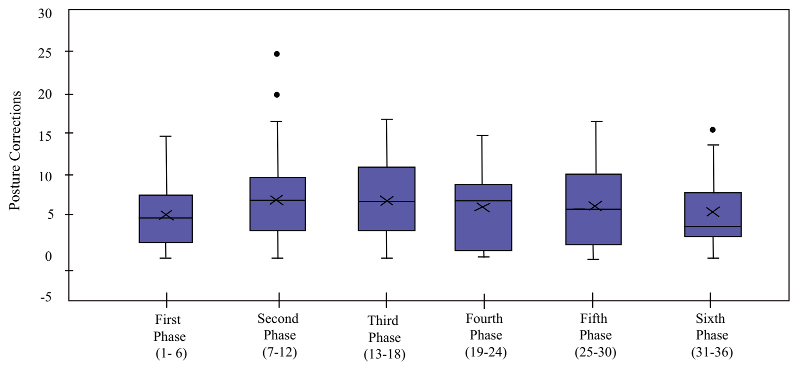

Figure 4.7: *Cervical posture correction* count of the patients who perform the robot scenario in the Cardiac Rehabilitation program.

In the case of the *Cervical Posture Feedback* (Figure 4.7), the results show that this parameter varies over the time. Analyzing the Figure 4.7 and the Table 4.6 it can be seen that it exists a difference only between the Stage 1 and the Stage 3 with an increment of 30.81% . The other stages comparison does not show differences. As a preliminary observation, the *Cervical Posture Feedback* parameter tends to maintain in the time. The increments presented between stages can be due to the physical activity intensity performed in the rehabilitation procedure. When the treadmill's speed and inclination increase, the cervical posture can be negative

Table 4.6: Interaction Parameters Wilcoxon Signed Rank Results

	Posture Corrections pValues	Increment[%]	Borg Response Time pValues	Increment [%]
Stage1/Stage2	0.08	30.51	0.24	-10.89
Stage1 /Stage3	**0.01**	30.81	**0.01**	-20.04
Stage1 /Stage 4	0.882	8.45	**0.05**	-14.40
Stage 1/Stage 5	0.738	17.19	0.23	-20.17
Stage 1/Stage 6	0.988	-0.77	0.57	-17.45

affected.

4.5.2 Qualitative Results

Table 4.7: Mann-Whitney-Wilcoxon test p values(*Qualitative Measurements*)

Construct	Control vs Intervention
SP	0.16
PS	0.08
PT	**p<0.01**
EU	**0.02**
S	0.13
PU	**p<0.01**
U	**p>0.01**

The perception questionnaires were completed by 28 participants (8 participated in the long-term study, and 20 in the interviews). Answers were grouped by category to perform the analysis for each construct defined in the questionnaire. Results of this test are depicted in Table 4.7, where the p value corresponds to each category computed.

As Table 4.7 shows, in most of the constructs defined in the questionnaire a significant difference (i.e., p value < 0.01) was found. These categories are (Perceived Trust (PT), Ease of Use (EU), Perceived Utility (PU) and Usefulness (U)). On the other hand, Safety (S), Perceived Sociability (PS) and Social Presence (SP) do not present a significant difference between scenarios. The distribution of the Likert questions grouped by category is presented in Fig. 4.9. Each category contains

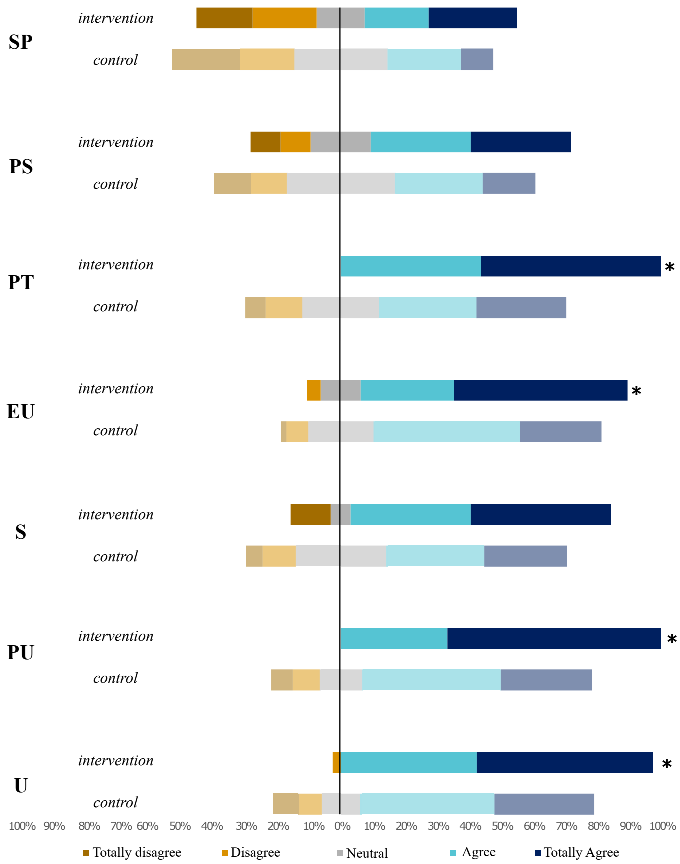

Figure 4.8: Likert scale distribution for each construct of the acceptance and perception questionnaire applied to patients. (*) Statistical Differences between scenarios.

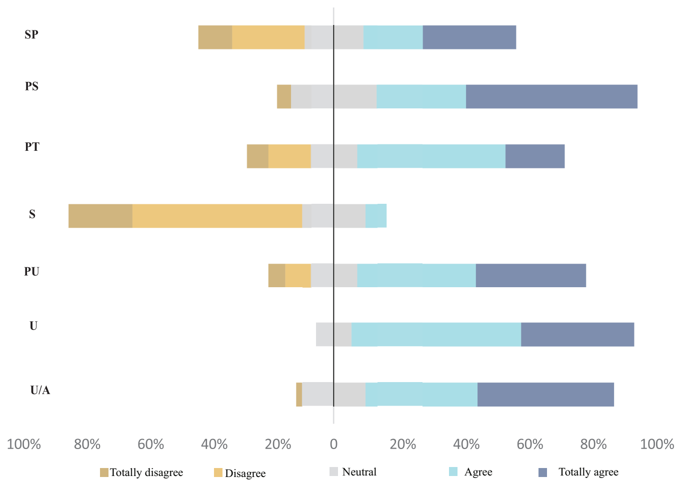

Figure 4.9: Likert scale distribution for each construct of the acceptance and perception questionnaire applied to therapists

the results obtained from control and robot scenario. This graphic is presented with a central axis, indicating a neutral position regarding the question (positive perceptions are plotted on the right side of the graph, while negative perceptions are represented on the left side).

Considering the open questions in the long-term study, all participants showed a high interest in the robot-based therapy, 100% of the participants would recommend the therapy to incoming patients. On the other hand, in the interviewed group 75% of participants found the therapy interesting and functional, and would recommend the system for future use, while 25% demonstrated no interest in the application and would not recommend the therapy due to different reasons that are considered and analyzed in the discussion.

For the clinicians, the UTAUT results are illustrated in Figure 4.9. Each construct represents a percentage of the total responses. Remarkable results in (U/A), (U), (PU), (PS) and (PT) categories showed positive scores. For (S) construct, the result is negative due that the question refers to the robot as a risk during CR therapies.

Commentaries of the pre and post discussion, regarding clinicians' opinions on social robotics and the proposed interface, were recorded. Pre-discussion results showed that clinicians were worried about being replaced by the robot, this was expressed in commentaries as: *"The robot can measure all the parameters that I usually monitor"* and *"The robot can replace my work"* . Also doubts in the functionality and features of the interface were expressed (*"Why a robot? Can not be other device?, Sensors could fail in the measurements and report wrong data"*). After the demo presentation and the introduction of SAR in healthcare, these commentaries turn positive as a detailed explanation of the interface was given.

Results of the post-discussion showed an interest of the clinicians to improve and add features to the interface. Positive commentaries as: *"Personally, I'm very interested in the capabilities of the robot to help me measure some parameters so I can focus more on the other patients' needs"*, *"It could be nice if the robot can be more sociable and less repetitive with its behaviors"*, *"I'm very interested in knowing the performance of the patient at specific times, this feature can be added"*, *"the online measurement that the robot provide is useful, this is important when a patient has an elevated heart rate"* and *"The use of robots can improve the techniques of CR. As the robot is constantly watching over patients' parameters, it is possible to perform high intensity training"*. These results are supported by 80% of the clinicians group, who consider that using a robot during CR could be useful and adequate.

4.6 Discussion

Along the study, 30 patients were recruited in the therapies. However, only 21 patients continue the treatment, one patient in the robot scenario is currently assisted by the robot. The results concerning the *qualitative measurements* includes the analysis of 19 patients (9 in the control scenario and 10 in the robot scenario) who finish the treatment. A total of 684 session were recorded.
The drop-out rate between the scenarios shows that in the control scenario the adherence was lower than the robot scenario. This first result shows the potential of SAR regarding the adherence. Low adherence is a common factor in CR and represent a risk for the health of the patients [91]. The negative impact of interrupt the therapy can cause a second coronary event more dangerous than the previous one and even the death [92]. Several factors are associated with this low adherence rate. One of them is the psycho-social factors related to the motivation, engagement, anxiety among others. In this case, we believe that the robot had a positive effect over the engagement of the patients during the therapies due to the contin-

uous monitoring, the feedback and the motivation given to the patient to improve their exercise quality . Some commentaries of the patients during the study were: *"I'm feel more compromised to do the exercise because the robot is monitoring me"*, *" I was very insecure at the beginning of the rehabilitation and thanks to the robot I got confidence"," I want to come to my rehabilitation, I have the advantage that the robot watches over my health status every second and I feel more secure"*.

The adherence has been investigated in several applications were social robots are involved. Winkle et al, [23], present a qualitative study which includes therapists. In this study the users were informed about SAR and the Human-Robot interaction (HRI) in rehabilitation therapies. The results showed a growing evidence related to the role of socially assistive robots to increase the adherence. Likewise, [20] and [93] evaluated social robots in physical rehabilitation and dementia treatments. Conclusions on both studies exhibit changes in the engagement of the patients when they were accompanied by the robot. In the case of the physical exercise presented in [94], motivation was an important key to achieve better results during the exercise, as our study suggest.

Taking into account the physiological data, it was initially expected to find changes in these parameters between scenarios. *Recovery Heart Rate* is one of the most relevant data associated with the physiological performance of the patients. Figure 4.5, shows the recovery rate between the scenarios. At first sight, the patients in the robot scenario tends to increase more than the robot group. In order to observe the behavior of this parameter an inter-group test was performed. As it was presented in the Table 4.3, the patients of the robot group elucidate significant differences between the Stage 1 and the next stages. The increments show that the robot group at the end of the rehabilitation increase their *Recovery Heart Rate* in a 135.82%, while the control group starts to present significant differences at the Stage 5 with an increment of 92.44%. However, in the posterior stage for the control group this parameter decremented. These results in the control group can be due to the behavior of the *Recovery Heart Rate* of two patients, which show a decrease over the rehabilitation procedure. The Chi-Square Z test show that patients of the robot group exceed the healthy threshold more than the control group, showing a successfully rehabilitation.

Despite the results obtained within the inter-group analysis, the statistical analysis between scenarios (Table 4.4) show that there are not significant differences between scenarios for the physiological parameters.
We believe that these results are due to the number of parameters that can affect the behavior of the heart rate. For example, the patient's fatigue levels prior to starting the session. On many occasions patients arrived at the session agitated or tired due to poor sleep or flu. In addition, the physiological state is highly dependent on the self-care of the patient (i.e., meet plan and home exercise).
Since our study only monitored the patient in the rehabilitation session, we cannot warrant that all patients behaved the same way in an outpatient setting. Currently, the evidences of SAR in CR are not clear. A study guided by Mataric et al [95], use a hands-off physical therapy assistant in cardiac patients in spirometry exercises. The results presented by the authors highlighted the satisfaction of the patients towards Clara robot but the analysis of the physiological data was not presented.
Despite the lack of difference between the scenarios, measurements as *Cervical posture* and *Borg Scale* response time gave an evidence of the positive effects where social assistive robots can contribute. As it can be seen in the Figure 4.7 and the results of the statistical analysis presented in the Table 4.6, that the *Cervical Posture feedback* maintains across the rehabilitation. This result is encouraging as it represents that the patients managed to keep their cervical posture in the time with a percentage of increments very low between different stages and a decrease at the end of the rehabilitation. A correct *Cervical posture* during treadmill exercise reduce the risk of dizziness and falls. Although, this indicator was not measure in the control scenario, the behavior of the *Cervical posture* for the robot scenario

improves according to number of sessions performed by the patient even when the exercise intensity increase.

Otherwise, the *Borg Scale Response Time* also decrease with the sessions of CR (Figure 4.6 and Table 4.6). These results elucidate the adaption of the users to the technology. During the observations that researchers did in the study, at the beginning of the rehabilitation the patients take more time to understand the voice and the indications of the robot. Along the time, this interaction becomes more fluid due to the experience they acquire. This result shows the importance of the learning curve and how they successfully overcome it. As Leite et al [96], mentioned, an adaptation towards this technology allows long-term interactions and a positive acceptance.

On the other hand, the *Qualitative Results* obtained are also important. In the case of the patients acceptance towards the robot, the perceived trust (PT) were higher in the group where the robot assist the patients. The group where the patients were not intervened by the robot, most of the commentaries were: *"The robot is not trustable"* or *" I would trust more in human therapists"*. This difference between scenarios was expected due to the lack of experience with the robot. The utilitarian factor which includes Ease of use (EU), Perceived Utility (PU) and Usability (U) was also assessed. Overall, the comments regarding this factor were positive for the patients assisted by the robot. The results showed that patients perceive the robot as a beneficial tool within CR.During the therapies, they expressed to be motivated and encouraged to perform better (*"I'm very encouraged to complete the rehabilitation"*, *"The robot motivates me to exercise well"* or *"This is a novel tool that could help the rehabilitation of any kind"*). Although control patients perceive a high degree of utility, it can be evidenced that after the interaction, this expectation is overcame. For the clinicians group the UTAUT shows positive opinions regarding (U/A), (U), (PU), (PT) and (PS) categories, which means that clinicians think that the robot and the parameters measured are useful and reliable in CR sessions.

The (S) construct was scored negative due the question formulation, however, the results regarding this construct are positive as the clinicians do not consider the robot as a risk for the patients. Regarding perceive sociability (PS), the opinions in some questions were interesting, for example for this construct, clinicians think that the robot has to be only a coach with social cues that feedback the patient, but not a friendly companion as the patients needed to concentrate in the therapy and the exercise. One of the most important aspects that were observed during the focus group, was the change of clinicians' perception as they went through the system's demonstration and received more information. As pointed out in the opening discussion, some clinicians perceived the incorporation of a social robot as a thread, since they regard the robot as a potential replacement. However, after the explanation of the technology and its objectives, it was emphasized that the robot must be considered as a tool that can improve their efficiency during therapy.

A limitation evidenced by patients and clinicians was the social presence (SP) of the robot. This construct refers to the capabilities of the robot to perform social behaviors to enhance the interaction. In this case, there is a neutral opinion for the patients in both scenarios. These results can mean that patients do not notice significant social features in the demonstration (control) and even after a considerable period of interaction (intervention). According to this result, it is necessary to improve this feature, since the impact and outcomes of the therapy can be potentially increased if the robot is more socially engaged to the patient [97]. Moreover, a higher perception of the robot sociability results in more intense social interactions [98], considering that most of the robot interventions are based on the social interaction and the way that it can develop in a social context. Therefore, more algorithms and features such as memory and vision recognition can play an important role to increase the impact within therapies.

4.7 Conclusions

A patient-robot interface was developed in order to enhance the capabilities of the conventional therapy for CR. The architecture of the software was described in general: two modules take part of the interface (*sensory module* and *robot module*). To evaluate the effects of the patient-robot interface, a qualitative and quantitative approaches were applied. A total of 30 patients were recruited in this study.
The results regarding the adherence of the patient to the rehabilitation procedures are encouraging. For the scenario of patients who used the robot in their CR therapies, the desertion was lower (50% less) than the control scenario. The perception and acceptance towards the robot were also positive. As the results showed, the usefulness, utility, trust and ease of use were evaluated by the patients who use the robot and the clinicians as important factor. Remarkable commentaries were "I feel more compromised when i use the robot", " I want to come to my rehabilitation, i have the advantage of being monitored by the robot, I got confidence".
In the case of the quantitative data (i.e., *Recovery Heart Rate*, *Training Heart Rate* and *Borg Scale*) , no significant differences were found. This result can be due to the variability of thus parameters and its high dependence of the external parameters. However, interaction measurements as: *Cervical posture* feedback and *Borg Scale* response time, evidenced interesting results. The patients tend to improve their *Cervical posture* across the rehabilitation time thanks to the feedback given by the robot. Also, an adaptation of the technology can be seen as the response time regarding the *Borg Scale* decrease.
Limitations on the robot sociability were observed. The patients consider that the robot has to be less repetitive and present more social behaviors in order to improve the quality of the interaction. Taking into account that CR (Phase II) is a long-term procedure, some features of the robot need to be improved to maintain its effects and the interaction.

In this project, a multi-modal memory architecture was used to allow long-term interaction in CR Scenario. Within the next chapter this architecture will be described and the results of the assessment in a real scenario will be explained.

Chapter 5

Personalized patient-robot interface for the CR program

5.1 Introduction

To improve the quality of the patient-robot interface presented in the Chapter 4 and maintain the human-robot relationship across the time, several strategies are proposed in the current state of art (Chapter 3). This master thesis focuses on the integration of a *Memory module* based on a Multi-Modal Incremental Bayesian Network with Online Learning (MMIBN:OL) and the development of software structures that pretend to enhance the interaction.

In the Study I of this work (Chapter 4), we could appreciate the results regarding the physiological and qualitative variables. Within the results, regarding the acceptation and perception tests, the patients and clinicians recommend use more “social cues" in a modest level. Henceforth, the system proposed is not invasive during the exercise, in order to maintain the attention of the patients.

Moreover, aimed to improve the outcomes obtained at the Study I, the measurement protocol was also changed. This chapter presents the assessment of the *Memory Module* in the Study II. The analysis of 6 patients who finished the 36 sessions of CR is performed.

5.2 Personalized Patient-Robot Interface Description

The personalized patient-robot interface proposed in this Chapter includes a multi-modal open set person identification system developed in the Plymouth University. This system is based on Incremental Bayesian Network with an Online Learning (MMIBN:OL), an overall structure of the MMIBN-OL can be seen in the Figure 5.1.

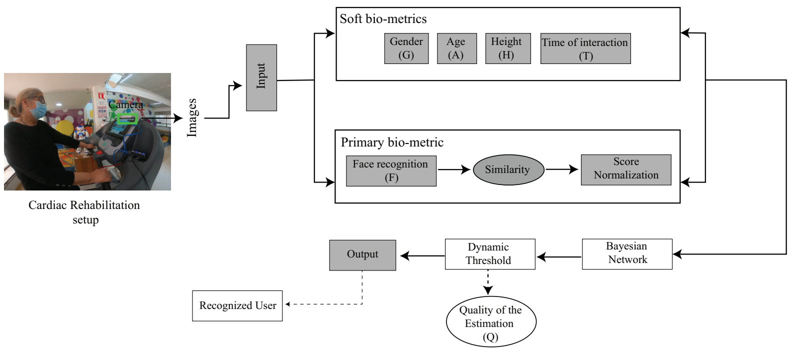

Figure 5.1: Front-end architecture for multi-modal person recognition. Inputs of the system include soft-biometric data and face recognition as a primary biometric data. The output of the system is the probability of a known user in the database.

The features of the multi-modal open set person identification system were deployed according to the needs in Cardiac Rehabilitation (CR) programs. In the first place an *Open-set* identification method was used in the system. The *Open-set* testing method is used when the testing identities are usually disjoint from the testing set [99, 100], which is the case in CR programs. Second, a multi-modal system was implemented rather than a recognition system only based in Face Recognition (FR), in order to avoid the limitation of the uni-modal systems [101, 102] and enhance the systems performance. Multi-modal biometric systems includes commonly two kind of subsystems: (i) The Primary subsystem based on traditional bio-metric identifiers (e.g., fingerprint, face and hand-geometry, among others) and a (ii) Secondary subsystem based on soft bio-metrics (e.g., age, gender and height, among others). Several studies have been show the efficacy of the multi-modal biometric systems over the uni-modal systems, reporting improvements of 10.0% in the recognition rates [103] comparing the two modalities; and accuracy rates of 96.7% [104].

In this context, the system was validated under laboratory conditions [100], showing that the average failure to enroll error (i.e., the fraction of images where the recognition system can not detect a face) was of 0.124. Moreover, the Detection and Identification rates (DIR) and False Alarm rates (FAR) were affected positively when the soft-biometrics were used. Second, an improvement to the system was applied [105] with two main purposes: (i) enrolling new users in the system without their previous information and (ii) improve the recognition based on the features of the interaction with the patient (i.e., number of interactions per week and time of interaction).

Development of the Robot Module for the Personalized Patient-Robot Interface In a previous thesis work [106], the Patient-Robot Interface for the Study I was described. As mentioned in [106], the structure of the interface has a *modular software* design approach. This approach uses *Plugins* components (Figure 5.3), which encapsulates several elements that perform specific processes. The *Plugins* contains three main elements: (1) *Win* which is the graphical component (e.g., views and forms) used to interact with the patient through the tablet. (2) The *Controller*, aimed to connect the signals as well the communication processes to run the *Plugin*. Finally, (3) *Models* are specific libraries or modules that allow the manipulation of the components of the system (i.e., database, robot interface, and sensor interface) as well as general purpose libraries required to perform a certain task.

In this context, two main changes were performed over the patient-robot interface presented in [106] : (i) the integration of *Recognition Plugin* and (ii) the integration of *Memory robot module* into the *Main Therapy Plugin* (Technical Aspects detailed in the **Appendices Section**).

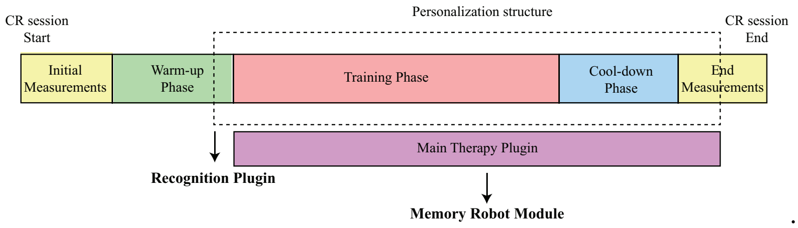

Figure 5.2: Cardiac Rehabilitation Timeline and the integration of the Plugin and Robot Module structure for Memory Strategy.

Figure 5.2 shows the timeline of a CR session and the integration of the modules, according the phases and times planned during these sessions. As it can be seen, the *Recognition Plugin* is activated when the *Warm-up* phase begins. The *Memory Robot Module*, is a library included in the *MainTherapyPlugin*, which runs during the *Training*, *Cool-down* phase and a part of the *End Measurements*. In the following subsections each structure integrated in the patient-robot interface is explained in detail.

Recognition Plugin The *Recognition Plugin* was developed aimed to follow the idea of modular software architecture mentioned before. This *Plugin* is in charge of integrate different components that allow the management of the MMIBN:ON within the patient-robot interface. As it can be seen in the Figure 5.3, the *Plugin* maintains the general structure proposed in [106], explained in the introduction of this section. Particularly, the models (i.e., model 1, model 2 and model 3) included in this *Plugin* are designed to provide the features for long-term interaction.

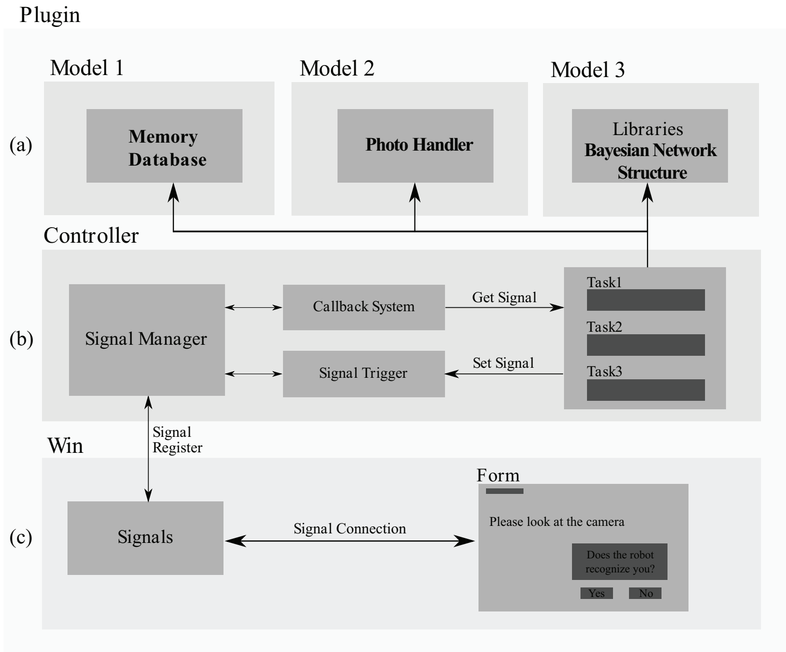

Figure 5.3: Recognition Plugin structure for the patient-robot interface.

The *Memory Database* is a module focused on the storage of important data used in the MMIBN:OL. For example, the soft-biometric data of each patient and the face recognition probabilities on each interaction are saved in the database. Additionally, the data of the sensors and the events that occur in the session are also saved. This information is used in posterior interactions by the robot to enhance its behavior; and used to modify the weights of the BN and the node parameters. Similarly, the *Photo Handler* stores the photos taken to the patients during the recognition. Finally, the most important library integrated in this *Plugin* is the library which contains the MMIBN:OL for the memory feature (explained in previous sections).

Memory Robot Module Structure in the Main therapy Plugin The second modification addressed in this part is the robot module developed for the memory scenario. Figure 5.4, showed the structure of the most complex *Plugin*.

Main Therapy Plugin contains all the modules and signals that control the interface during the training. As it was explained in the Chapter 4, the interface acquires several data, corresponding to the physiological parameters of the patient (e.g., cardiovascular parameters, gait patterns and physical exercise difficulty parameters). Within Figure 5.4 the management of this data is performed, specifically by the *Sensor Monitor*. Furthermore, this *Plugin* also are supported by the robot modules which are related to the behaviors and functionality of the robot during the therapy. In the Study II this Module is divided in two sub-modules. In the Figure 5.4 the red colored squares represent the structures that were modified in the patient robot interface. In this context, the *Memory Robot Module* was developed to achieve the long-term interaction. Thanks to the data saved previous in the database regarding different factors (e.g., attendance and performance) the robot performs specifics behaviors (random verbal and non verbal gestures).

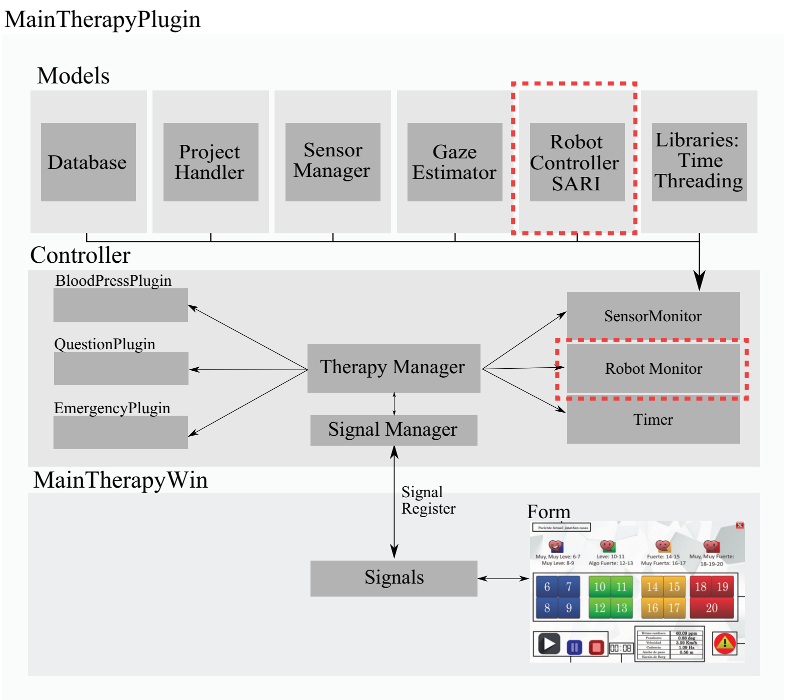

Figure 5.4: *Main therapy Plugin* Structure.

As it can be seen in the Figure 6, this robot contains different libraries that support the robot tasks during the session. The three main parts of this module are: (i)

Robot controller, (ii)*Dialogs* library and (iii) *Database* library which is developed outside this module but used continuously within the robot behaviors. The con-

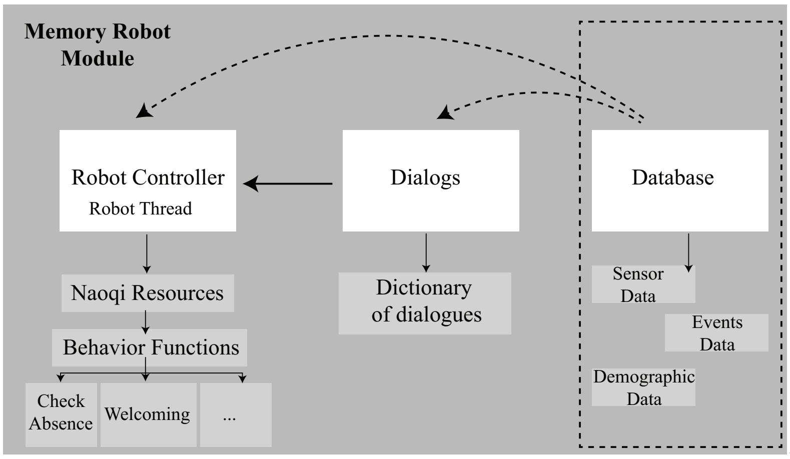

Figure 5.5: *Memory Robot Module* architecture for the patient-robot interface. The main part of this module can be seen: (i) *Robot controller*, (ii) *Dialogs library* and *Database library.*

troller manages the resources of the robot provided by the python SDK for the NAO robot (Naoqi). The resources are used to build the functions for each behavior programmed in the *Memory module.* These functions are related to certain events triggered by the reading of the sensors during the therapy and labels assigned for specific feedback regarding the performance and the attendance of the patient in the sessions. To follow the *modular* design of the architecture, the Dialogues are separated in a model to have a better organization. In this module all the dialogues used by the robot in each function are described. To decrease the repeatability in the interaction given by the robot, most of the dialogues are stored in list with high length and called by a random function on the module controlled. Finally, this module uses the data stored in the *Database* with two main purposes: (i) integrate the demographic data of the patient (e.g., name, age, among others) to perform the verbal phrases and (ii) combine the information of the alerts triggered in the previous session with the inclination and the velocity mean of the session, to provide a feedback of the progress to the patient at the end of the session.

Robot Behaviors for the Personalized Scenario

For the *Memory module* the behaviors were updated and changed into a list of behaviors/phrases that are chosen randomly according to the event. Some of the routines performed by the robot in the session were developed in the Choreographe (a graphical user interface for NAO developers) with the timeline tool. The behaviors programmed on the robot can be divided according to the *Plugin* when they take place (i.e., *Recognition Plugin* and *MainTherapy Plugin*). As it can be seen in the Figure 5.6, the behaviors depend on the type of interaction performed in each *Plugin*.

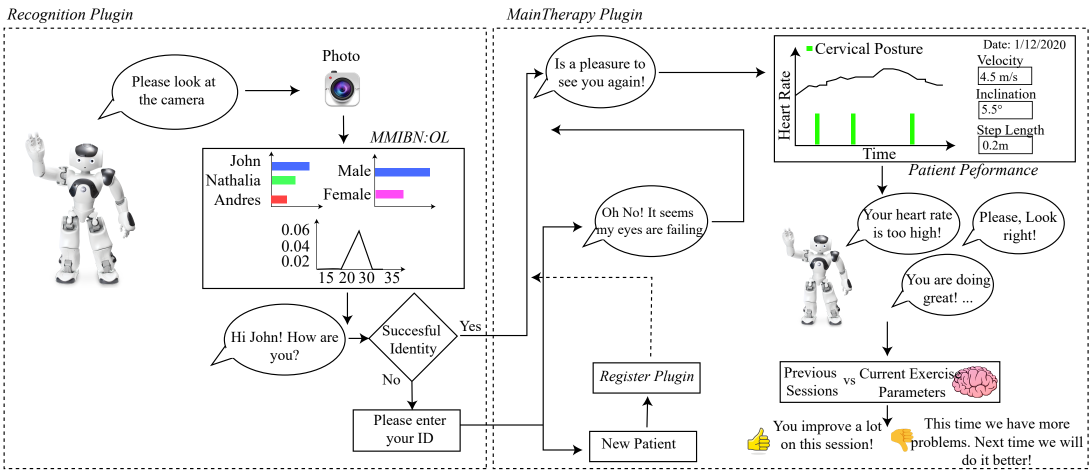

Figure 5.6: Robot behaviors for the *Memory Module* regarding the multimodal open set person identification developed for the *Memory Scenario*. The left side shows the robot's behaviors in the *Recognition Plugin* and the right side the behaviors for the *MainTherapyPlugin*.

In the case of the *Recognition Plugin* the robot's behaviors are designed to identify the person who is part of the interaction. First, the robot asks to the patient to look at the camera of the table to take a photo. Then this photo is analyzed and passed through the MMIBN:ON aimed to match the correct user. After the results of the recognition, the robot greets the patient and asks for confirmation. At this stage, the outcomes of the recognition can be correct or incorrect, depending on

Table 5.1: Robot's behavior within the *Memory Module*

Event	Robot's Feedback
Performance improve comparing the previous session	Today you do it great ! You've improved in this session! It seems that we didn't have any problems today!
Performance decrease and the Physical Difficulty Activity remains the same.	Today we have more problems! Dont worry we can do it better the next time! I'm sure you can improve the next sessions!

the result the robot continues the interaction taken in the *MainTherapy Plugin*. However, if the result is wrong, the patient-interface request the ID of the patient. Finally, a third situation can occur. If it is a new patient the robot requests a registration in the database to continue the thread of the interface.

Within the *MainTherapy Plugin*, the robot stills giving feedback to the patient. As was mentioned in the Chapter 4, the robot has different behaviors triggered by alerts and events developed in a session. In this stage, following the results of the first stage and the clinician's recommendations we improve the robot model, by adding new behaviors and performing random sequences. Additionally, as it can be seen in the Figure 5.6 at the end of the session the robot gives feedback to the patient taking into account his/her performance. This "progression" feedback evaluates the exercise performance during the current performance and the intensity features of the physical exercise (i.e., speed and inclination) and the patients' performance in the previous session. Thus, the robot communicates to the patient through two main types of feedback (Table 5.1) : (i) when the patient improves in the current session, the robot greats him/her, (ii) when the patient has more alerts and the intensity remains the same, the robot inform the patient that the progress decrease in a positive way and encourages him/her to perform the next session better.

5.3 Performance Assessment

As it was mentioned in the Chapter 4, during the Study I *qualitative* and *quantitative* approaches were contemplated. For this study (Study II) the *quantitative* measurements remain the same. However, in the *qualitative* approach, some measurements were added in order to perform a deep analysis of the interaction with the robot.

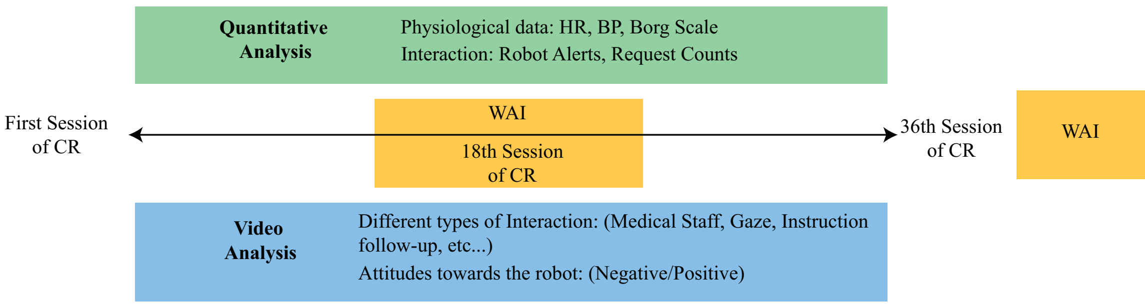

Figure 5.7: Performance assessment (*qualitative* and *quantitative* approaches) during the Cardiac Rehabilitation Timeline. Within the *quantitative* approach the physiological parameters and interaction is measured. The *qualitative* approach includes the WAI, UTAUT questionnaire and the video analysis

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In this context, two measurements were added (Figure 5.7): (i) the Working Alliance Inventory (WAI) questionnaire, which was performed at the middle of the rehabilitation (18 sessions) and at the end (36 session); and (ii) Video recording in every session. The videos were analyzed by two video coders who follow a protocol to analyze the interaction. In the next section, the description of this parameters is elucidated.

5.3.1 Participant and Demographic Data

In order to accomplish a complete analysis of the robot, a study with 6 patients who finished CR and use the personalized robot was performed. Table 5.2, show the demographic data of the participants who performed within *Memory Scenario*. Some patients started the CR therapy without the robot for the first 2-3 sessions, and one patient finished the therapy early (32 sessions) in the *Memory Scenario*. .

Table 5.2: Demographic data of the patients who have finished the outpatient phase (II) of the CR program within the study.

	Memory Robot Participants
Gender	6 males
Age (years), mean ± SD	60.1 ± 7.7
Body Mass Index, mean ± SD	24.9 ± 2.1
- Obese	0.0%
- Overweight	50.0%
- Healthy weight	50.0%
Level of education	
- Elementary school degree	16.6%
- High school degree	0.0%
- Technologist	0.0%
- Bachelor's studies/ degree	50.0%
- Postgraduate studies/ degree	33.3%

5.3.2 Experimental Criteria

The *Inclusion Criteria*, *Exclusion Criteria* and *Dropout Criteria* remain the same as the Study I. To see more detailed information see Chapter 4.

5.3.3 Scenario

At the Study II, the *Memory Scenario* was performed. During this scenario, the robot has a more social behavior that the scenario presented at the Study I. The main contributions to the robot are developed in the *Memory Module*, where a Multi-modal Incremental Bayesian Network with and Online learning and a Social Behavior Architecture were integrated.

5.3.4 Quantitative Assessment

As it was mentioned at the beginning of the section, the *Physiological Data*, the *Drop-out rate* and the *Interaction Parameters* are the same of the Study I (Chapter 4). In the case of this scenario, the Chi-Square Z test was not performed as the frequencies can not be analyzed in a proper manner due to the number of patients. However, in this Chapter the performance of the MMIBN:OL was also evaluated. In this context two measurements were performed:

- Detection Identification Rate (DIR): an estimate of the probability that a subject in the database of a biometric system is detected.
- False Alarm Rate (FAR): an estimate of the probability an alarm is incorrectly sounded on an individual who is not in the database of a biometric system.

5.3.5 Qualitative Assessment

The *Qualitative Data* measures the quality of the interaction. For the *Memory scenario* two additional measures apart from the UTAUT were proposed. The WAI (Working Alliance Inventory) is a questionnaire used usually to evaluate the interaction with health-staff. However, this measurement has been modified by the social robotics experts, so it can be used in this field. On the other hand, the video analysis was performed in order to have another view of the interaction with the patient. These videos record the complete time of the session (30-40 minutes).

Working Alliance Inventory (WAI): The WAI (Appendix, Table 3) was developed by Hovarth et al in 1989. The proposed method seeks to evaluate some generic degree of success in counseling. This measurement is based on Bordin's pantheorical tripartite conceptualization (i.e., bonds, tasks and goals) [107]. In the case of social robotics, this measurement has been analyzed and used in studies based on long-term interaction. The questionnaire is a 36-item-self-report instrument that includes three subscales as it was mentioned before. The *Bond* construct measure the degree which the robot and the patient like and trust each other (e.g., "My relationship with the robot is important to me "); the *Task* construct evaluate the degree to which the robot and the patient agree on therapeutic tasks (e.g., "The things that the robot is asking to me do not make sense); and *Goal* construct aimed to measure the degree to which the robot and the patient agree on the goals of the therapy (e.g., "The robot perceives accurately what my goals are"). The design of our WAI questionnaire was mainly based on the WAI proposed in [60].

Within the literature this method is used widely to asses long-term interaction. Hoffman and Breazeal [108], observe the effects of anticipatory perceptual simulation on practiced human-robot tasks. To measure the robot interaction, the researchers use the WAI without the task construct. Two conditions were implemented, the *Reactive* condition corresponds to a baseline condition in which no anticipatory simulation occurred and the *Fluency* condition, where the simulation subsystems were active with fixed parameters. The results regarding the WAI, showed that the *goal* construct was significantly different in both conditions. The participants performing at the *Fluency* condition showed greater results than the patients at the *Reactive* condition. In [62], the interaction between the robot an the users in a long-term period scenario was measured. The researchers compare the WAI scores of a group who experienced the interaction with a relational-robot with users which use a non-relational robot. The results show that the bond between the robot and the users was significantly better for the relational-robot.

Finally, Abdulrahman and Richards [109], modeled the therapeutic alliance using a user-aware embodied conversational agent that promotes treatment adherence. The WAI was used by the researchers to investigate the influence of the agent in the adherence and therapeutic outcomes after 3 and 6 months of interaction.

Video Analysis: One of the most common measurements used in SAR is the analysis of videos [51, 110, 111]. The sessions were recorded with a GoPro camera[1] installed in the CR service. The analysis of the videos was made by two video coders, the labels used to measure the interaction were unified by a protocol. First, the videos were organized by the name of the patient and the dates. Overall, the labels are divided into two types of interaction: (i) *uni-directional* interaction, and (ii) *bi-directional* interaction.

Uni-directional Interaction refers to the types of interaction that are performed in one way (e.g., the gaze, medical staff interaction). The video coders identified these measurements by counting the number of events and the time of this interaction. The gaze is used as a parameter to measure the attention the patient pay to the robot. In the case of the Medical Staff, the interaction measured includes only doctor-robot interaction. Moreover, *Bi-directional* Interaction describe the type of interaction which are performed in two ways (e.g., execution of tasks required by the robot and the instructions follow-up). An example of the *Bi-directional* interaction is the Borg Scale answer by the patient, touching the tablet after the robot request it. Additionally, the *attitudes* towards the robot are also reported.

[1]GoPro Inc, USA

Negative attitudes encapsulate gestures that express the patients' disagreement to some robot phrases or feedback. On the other hand, the positive attitudes were labeled (e.g., smiles towards the robot, verbal positive responses, among others). Finally, interesting observations outside these interactions were also noted by the video coders. The results regarding these parameters are explained in detail during the next sections.

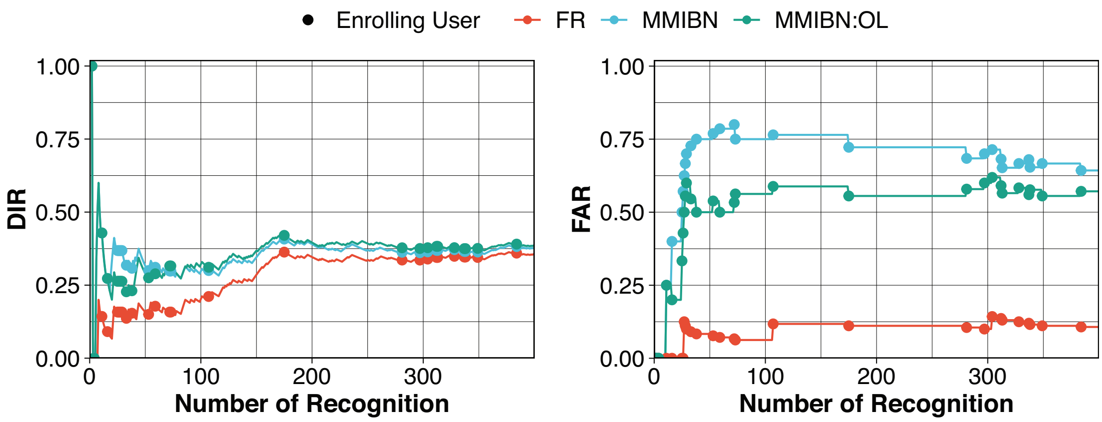
5.4 Results

This section presents the results of the patients who were included in the *Memory scenario*. First, a brief outcome regarding the MMIBN:OL is presented. Second, the *Quantitative Results* are analyzed in order to track the physiological progress of the patients during the Cardiac Rehabilitation (CR). Finally, the *Qualitative Results* which reflects the interaction with the robot in a long-term period of time are presented.

5.4.1 Quantitative Results

In first instance, the multi modal open set identification system presented in the Chapter 5, was evaluated.

The user recognition performance was very low. In the case of the MMIBN:OL the results of the recognition show a DIR = 0.38 and a FAR = 0.56, which shows that the false alarms were higher that the detection rate. These results were caused from failures arising from the face recognition (DIR= 0.35, FAR= 0.11) integrated in the system. The failures influenced negatively the online learning, decreasing the system performance. However, MMIBN:OL performed better overall than FR throughout the duration of the study, as can be seen in Figure 5.8. The figure also



(a) (b)

Figure 5.8: DIR and FAR during the duration of the study. There are greater number of enrolled users (represented with a dot) than the recruited users for the study due to re-enrolment of some users to the system with a different ID at a later time to overcome the face recognition (FR) errors encountered initially. Higher DIR and lower FAR is better. The results show that online learning (MMIBN:OL) performs better than the non-adaptive model (MMIBN) in both aspects, and both of our proposed approaches outperform FR. FR performs better in FAR due to estimating most users to be unknown.

shows how the non-adaptive model (MMIBN) would have performed over the data (DIR= 0.36, FAR= 0.67). MMIBN:OL performs slightly better than MMIBN in identifying known users, and notably better in identifying new users. Both of our proposed approaches perform better in recognising known users than FR, supporting that our proposed user recognition is suitable for real-world interactions, and improves the recognition even when the identifiers are malfunctioning. On the other hand, in comparison with the Stage 1 of the study the robustness of the patient-robot interface improves. The lost of the data in the Study II of the study was greatly minor, this important outcome can be due to the software modular architecture explained in previous chapters.

Regarding the *Recovery Heart Rate* parameter, Figure 5.9 and Table 5.3 elucidate the behavior of this parameter in the *Memory Scenario*. As it can be seen the statistical analysis does not show significant differences between stages as the increments are very low, except for the comparison between the Stage 1/Stage 6.

However, we believe that the statistical analysis does not show significant results in this scenario due to the incomplete rehabilitation performed by some patients that affects the Stage 6. Additionally, one patient has a decreasing tendency showing the difficulties of that patient to perform the exercise. Overall the results are positive, even when the increment were not significant the tendency show an increment.

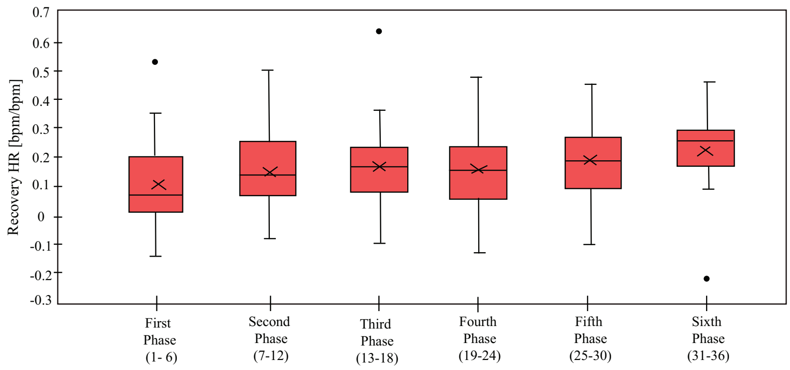


Figure 5.9: *Recovery Heart Rate* of the 6 patients performing *Memory Scenario* during 6 stages of the Cardiac Rehabilitation program.

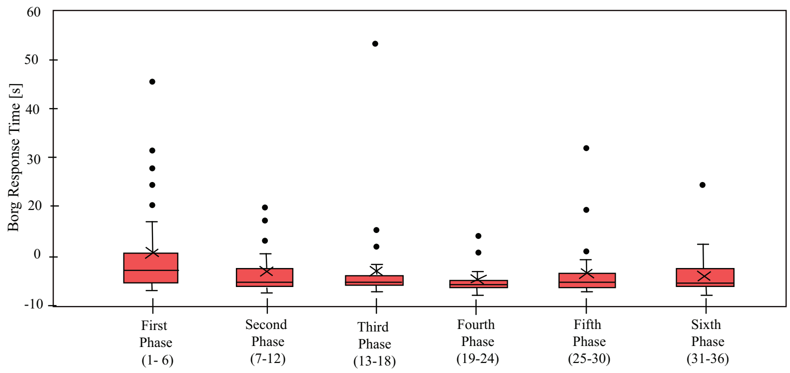


Figure 5.10: *Borg Scale Response Time* of the 6 patients performing *Memory Scenario* during 6 stages of the Cardiac Rehabilitation program.

As was presented in the Chapter 4, there are also two variables where the interaction with the robot can be measure: (i) The Borg Scale response time, and (ii) The counts of the posture correction given by the robot. Figure 5.10, show the time taken by the patients to answer the robot's request regarding the *Borg Scale*. As it can be seen, the time decrease in time. These results show that exists an adaption of the technology as the control and robot without memory scenarios. Also, the statistical analysis show that there are significant differences between the stages (Table 5.3 of the *Memory Scenario* regarding the *Borg Scale Response Time*. Comparing the first sessions with the end of the rehabilitation the patients reduce the time in a 46.02%.

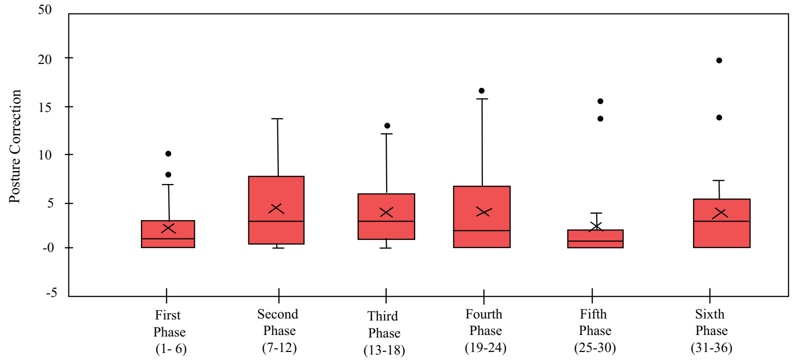


Figure 5.11: *Cervical Posture Correction* of the 6 patients performing *Memory Scenario* during 6 stages of the Cardiac Rehabilitation program.

Figure 5.11 show the Cervical posture correction given by the robot across the CR program. As it can be seen this parameter does not have a clear tendency for the *Memory Scenario*. In the Table 5.3 it can be seen that the difference is not significant between stages. Despite these results, the video analysis show that the patients follow-up the feedback given by the robot.

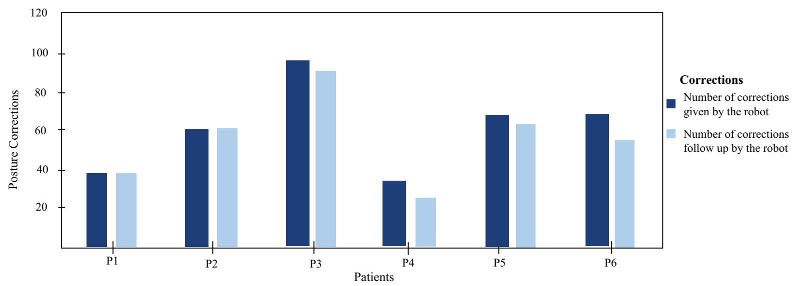


Figure 5.12: Patients compliance to the Cervical Posture Feedback *Memory Scenario*. Dark Blue bars represent the number of requests made by the system regarding the cervical posture. Light Blue bars represent the number of times where the patient follow-up this instruction.

Figure 5.12, show that all the patients fulfill the request of the the robot in order to improve their cervical posture. Overall 94.4% of the corrections were follow-up by the patient. This result show that the patients pay attention to the robot work in the therapy.

Table 5.3: Recovery Heart Rate and Interaction Parameters Wilcoxon Signed Rank Results

	Recovery HR pValues	Increment [%]	Posture pValues	Increment [%]	Borg Response Time pValues	Increment [%]
Stage 1/Stage 2	0.18	40.75	0.10	96.04	**0.01**	-39.70
Stage1/Stage 3	0.39	57.95	0.16	68.47	**0.02**	-38.98
Stage1/Stage 4	0.17	36.66	0.58	74.71	**0.02**	-47.10
Stage1/Stage 5	0.21	60.09	0.36	11.01	**0.02**	-43.39
Stage1/Stage 6	0.13	112.21	0.66	75.80	0.08	-46.02

Table 5.4: WAI Wilcoxon Signed Rank Test.

	Bond	Task	Goal
WAI	0.54	0.47	0.21

5.4.2 Qualitative Results

The *Qualitative Results* present an overall perspective of the interaction. A lesson learned in the Study I was to perform a evaluation of the interaction deeply. Aimed to enhance the interaction assessment, WAI and Video Analysis were recorded during the sessions. Hereunder, the analysis of those measurements is presented.

WAI questionnaire (Appendix Table 3) results (presented in Figure 5.13) show the interactions in three dimensions (i.e., *Bond*, *Task* and *Goal*) with the robot behave along the time.

The results show that the perception at the middle and the end of the therapy has not changed (Table 5.4), this show an important outcome as the positive perception was maintained over the therapy.

On the other hand, the interpretations for each construct can be made. In the case of the positive formulation, *Bond* and *Task* constructs, positive increase during the time; and *Goal* construct it is maintained across the time. For the *Negative Formulation*, the results are very positive too. The patients generally disagree with the negative formulations (e.g., "I feel uncomfortable with the robot."), showing that with the time the disagreement in some kind of the perceptions towards the robot decrease.

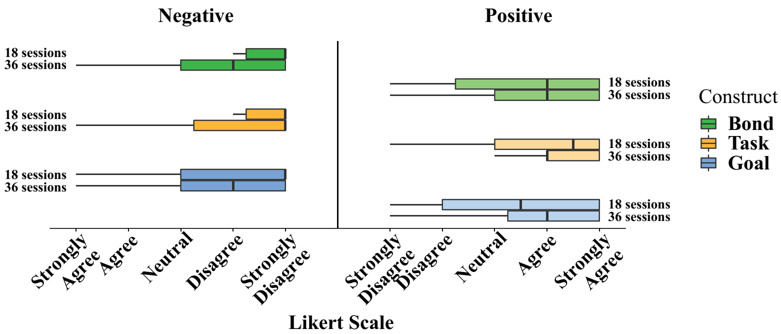


Figure 5.13: Variability of the Working Alliance Inventory (WAI) responses evaluated at the middle of the therapy (18th session) and the final session (36th session). The results suggest that the patients' positive perception of the robot and the therapy was maintained over the therapy.

In the case of *UTAUT* questionnaire the results can be seen at the Figure 5.14. The results confirm our previous findings that the personalized robot was positively perceived by the patients, in terms of perceived usefulness (U), ease of use (EU), utility (PU), safety (S), trust (PT). The sociability (PS), social presence (SP) and Usefulness of Memory module (PU-M) was mostly perceived as neutral.

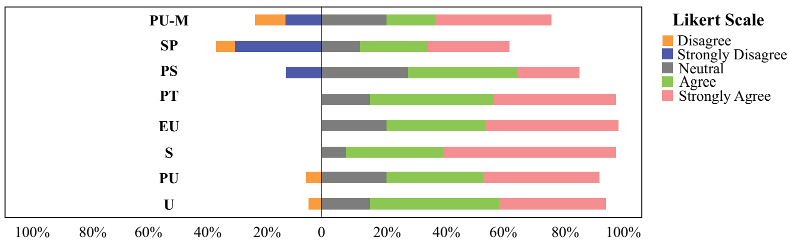


Figure 5.14: UTAUT questionnaire in the *Memory scenario*. (U), ease of use (EU), utility (PU), safety (S), trust (PT) sociability (PS), social presence (SP) and Usefulness of Memory module (PU-M) constructs are presented

Note that some of these constructs presented here include specific personalization questions (PU-M). For instance, the perceived enjoyment (e.g., I am pleased that the robot remembers me.) of the personalization features (i.e., recognition, referring to the patient with the name, tracking and referring to the therapy progress, remembering the user) shows that the *Memory Module* was perceived very positively. On the other hand , it can be seen that the patients disagree or strongly disagree in a small percentage (% 25) regarding the PU-M construct. Analyzing the results this negative percentage is due to the perceived utility regarding the *Memory Module* where some of the patients highlight that the robot recognizes them as other person in some sessions.

Within open questions, the patients noted the need for improving the robustness of the user recognition and sensors. Other improvements for the system that the patients suggested including repetitiveness of the phrases, which was also addressed in the previous study with the *social robot*. In addition, one patient found the appearance and the sound of the robot to be childish. Regardless, all patients recommended the system for future patients, and commented on its usefulness, personalization and effects on user motivation: *"The robot therapy will help you to recover as quickly as possible, and you will be able to progress by being linked to the robot."*, *"I feel confident in doing the therapy with the robot, because I know that it is personalized and constantly monitoring my performance and progress."*, *"Working with the robot motivates me.*, *"Working with the robot makes me feel happy."*.

Finally, the Video Analysis was also performed to observe the patient-robot interaction. Available sessions per patient vary with a minimum of 14 recordings. Hence, we will instead analyze the overall perception with varying session level. Figure 5.15 show the *Gaze* and *Social Interactions* counting during the sessions recorded in the Video Analysis. As it can be seen, the *Gaze* was presented in a greater number of times during the beginning of the sessions than in the end. For example, P5 have a mayor interaction by means of the *Gaze* in the first sessions than the other patients. The commentaries made by the video coders, suggest that some patients tend to see and have more curiosity of the robot at the first sessions.

On the contrary, for the *Social Interaction* the counting in some cases increase with the time (P2, P4, P5). In this type of interaction, the attitudes towards the robot are included (i.e., negative and positive) as they reflect that the patients see the social presence of the robot.

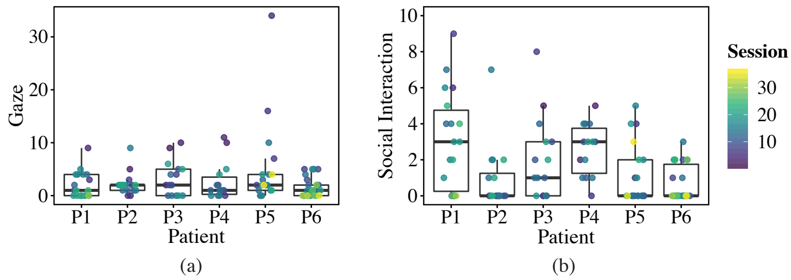


Figure 5.15: Interaction of the patients with the robot, depending on the session: (a) Gaze, (b) Social interaction (e.g., verbal, gesture). The light green and yellow coloured dots correspond to the second half of the therapy, whereas blue and dark green to the first half. The scattered arrangement of these colours shows that the social level of interactions and gaze does not decrease over the long-term therapy.

The preliminary results show an important evidence of the interactions between the robot and the patient, however, it is important to highlight that the lack of the videos due to the situation can have an influence over the conclusions across the time of the therapy. Regarding the interaction of the *Medical staff* with the robot, the video coders reported a low rate ($<$ 3 interactions in a session) of this type of interaction.

Finally, four positive social cues noted from the video coders in the video analysis were highlighted: (i) talking to other patients about the robot's role and its benefits, (ii) mirroring the robot's gesture to the *Call medical staff* alert, (iii) reacting positively (e.g., smiling or thanking the robot) to the motivational feedback of the robot, and (iv) touching (caressing) the robot, which has occurred (once) at the end of a session after the robot "sighed" going into sleep mode, (v) reacting negatively to the robot, in the case of misidentifications from user recognition, posture correction and alert to the doctor.

5.5 Discussion

As it can be seen at the results section, a detailed analysis of the interaction and the physiological data of the patients who perform the memory scenario was presented. A total of 6 patients were assessed during (33-36 sessions) of CR. This number of sessions represent a long-term period of interaction.

First, the results regarding the performance of the *Memory Module* show that the recognition have a lower performance (38% of right detections) than the expected due to the malfunctioning of the robot. A comparison of the MMIBN:OL, the MMIBN and a FR module was developed. As a main result, the person recognition which use online learning perform better than the other two modules. Additionally, the modules that integrates *soft bio-metrics* in its architecture show better results than the FR. These results can be compared with the literature where several studies [103, 112] show that adding other bio-metrics improve the performance of the recognition systems. Although the results regarding the multi-modal open set identification implemented in this study present improvements between the systems (i.e, FR, MMIBN and MMIBN:O), the system has to be enhanced in order to achieve a higher rate of recognition during the sessions.

Concerning the *Physiological data*, the *Recovery Heart Rate* does not present significant changes between the stages. However, a slightly increment was observed in patients who perform in the *Memory Scenario*. As mentioned in the Chapter 4 the physiological parameters vary depending on external factors. These factors can influence over the Recovery Heart rate tendency. The Posture Correction was also presented in the previous sections. The counting regarding this parameter show that this parameter was maintained during the CR program. A positive outcome elucidate the high compliance of all the patients to the posture corrections (94.4%). This result is very encouraging as the patients follow the robot requests in order to improve their performance in the rehabilitation. An indirect result regarding the cervical posture correction is that the patients decrease their self risk to get dizzy or even fall during the exercise, causing additional negative effects.

Furthermore, one of the main outcomes of this study is that the online monitoring provides a clear enhancement in the CR conventional therapies. For example, during the *Memory Scenario* an **Special Case** was given. A male patient (*Age*: 60 years, *Height*: 1.55 m and *Weight*: 70 Kg, and *Level of education*: high school degree) diagnosed with myocardial infarction present an adverse event during the 13th session. During that session, the patient experienced an emergency when his heart rate went over a critical threshold. Thanks to the robot feedback the medical staff could intervene quickly. The patient was referred to the Emergency Service and a second procedure (involving stent surgery) was performed to recover his cardiac functioning. This outcome is very encouraging as this tool allows to increase the quality of the therapy in the monitoring and the provision of the health service.

The *Qualitative Results* are also evaluated in this scenario. The WAI and UTAUT questionnaires were applied to the users to evaluate their perception during the CR program. Also, the sessions were recorded with a camera and then analyzed by video coders. As the *WAI* results shown, the positive perception of the patients towards the robot is maintained during the rehabilitation. These important results showed that the robot is a reliable tool in this scenario. The *bond* construct show that the patients feel comfortable with the robot presence during the sessions and they like the support given by the robot. For the *goal* and *tasks* constructs, the positive results highlight the tasks and goals established in the patient-robot interaction are clear. For example, the performance feedback delivered by the robot (e.g., *This session you will do it better*) is very appreciated by the patient, these results mean that the *goals* and *tasks* are clear during the rehabilitation procedure.

In the same way, the *UTAUT* questionnaire present positive results regarding the perception of the patients. For the construct which evaluate the usefulness of the *Memory Module* the results show a slightly disagree with regards to the other constructs. This result can be explained with the MMINB:ON performance. The open questions also shown interesting results. Most of the patients mention that they feel more secure and confident using the robot than performing conventional therapy. Additionally, the motivation given by the robot is an important factor remark by some patients. These factors can positively contribute to the adherence of the patients during the rehabilitation [23, 55].

The Video Analysis present also the results of the interaction. As it was mentioned in the previous section, several types of interactions were labeled. The *Gaze* was given more times at the begin of the rehabilitation than at the end. This result can be due to the novelty effect presented in the first session when the robot was introduced to the patients. Commentaries on the videos, show that some patients felt curiosity over the robot. Despite, the *Gaze* counts decrease across the time, the *Social Interaction* parameters remains the same during the CR program. These results indicate that the patients interact with the robot using mostly verbal gestures, facial expressions and following the robot's instructions than using the gaze; this type of interaction can be due to the concentration of the patient must have during the exercise. Moreover, it is also interesting the negative and positive attitudes observed by the coders. In the case of the positive attitudes, some patient caress the robot showing affection to it, smiling at the robot's correction and talking to CR partners about the robot. These results show that the patients see the robot as a companion during the rehabilitation. On the contrary, it is important mention the negative attitudes as they are also associated with the robot's social presence perceived by the patients. These negative attitudes occur mostly when the robot fail recognizing the patients, most of the patients show discomfort by hearing another name or even correct the robot.

5.6 Comparison between scenarios

Finally, the comparison between the *Control*, *Robot* and *Memory robot* scenario is discussed. First, the adherence regarding the scenarios show that the use of the robot reduce the drop-outs in CR. In the case of the *Memory Scenario* 13 patients were recruited, however due to the COVID-19 pandemic only 6 patients finish the study and 1 patient drop-out the study. Comparing the three scenarios, it can be seen that the patients assisted by the robot (in both scenarios) fulfill the CR therapy in a higher rate than the patients who perform a conventional therapy. This result gave a positive insight of the effect of the robot in the adherence.

5.6.1 Physiological Parameters

As mentioned in the previous sections, the *Training Heart Rate* and the *Recovery Heart Rate* are the most important physiological parameters of the therapy that determine the patient's health progress. Overall, as expected the progress of the training heart rate throughout the therapy for all scenarios increase, due to the input parameters that affect the cardiovascular functioning (*treadmill's inclination and velocity*), these parameters are configured by the clinicians at the start of the sessions and within the rehabilitation procedure are increased to improve the exercise patient's performance. On the other hand, the results regarding the *Recovery Heart Rate* show that the average heart rate increased during the program in the all scenarios. However, no significant differences were found between the scenarios, showing that neither robot negatively affected cardiac rehabilitation therapy (Table 5.5). On the one hand, this suggests the physiological performance has not changed with the presence of a robot. On the other hand, this also suggests that the robot did not negatively affect the patients' health, which is a very important finding, because it shows that the robot does not take away from the success of

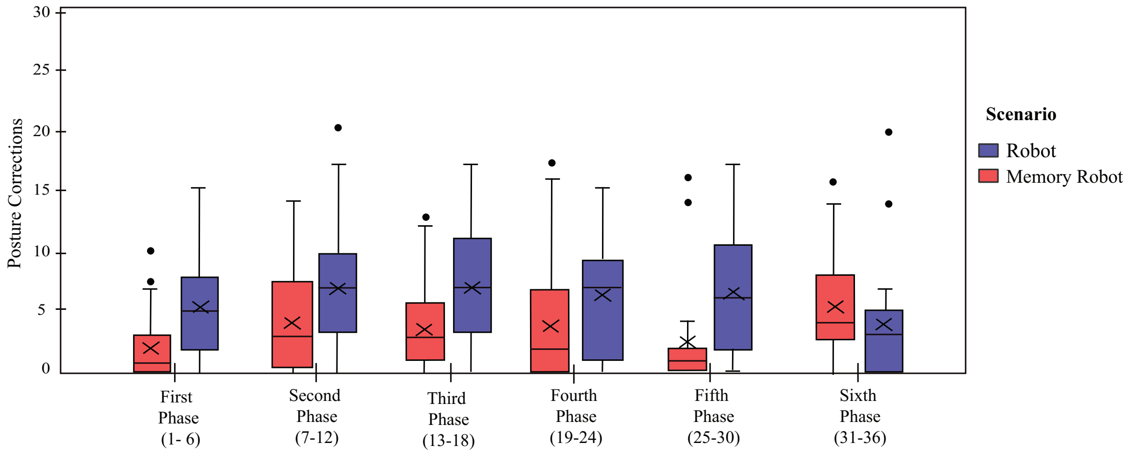


Figure 5.16: The number of cervical posture correction requests by the *Robot* and the *Memory robot* scenarios, depending on the session. The results show that generally, the corrections were less in the *Memory robot* scenarios

the therapy. Finally, the perceived exertion level (Borg scale) stayed within the healthy range (6-12) for all patients, and no significant differences were observed between the scenarios.

Table 5.5: Kruskal Wallis Test results between Control, Robot and Memory Robot Scenario

	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6
Recovery Heart Rate	0.47	0.82	0.63	0.24	0.25	0.31
Training Heart Rate	0.81	0.91	0.75	0.55	0.70	0.47
Borg Scale	0.48	0.89	0.5	0.98	0.61	0.76

5.6.2 Interaction Parameters (robot scenarios only)

As previously described, the patients complied fully to the robot's requests for cervical posture correction in the *Memory robot* scenario. Due to the lack of video data for the *robot* condition, we cannot analyze the compliance between both robots. Nonetheless, we can compare the number of requests that the robot made to evaluate if the patients' posture improved over time. Figure 5.16 shows that number of requests were lower for patients in the *Memory robot* scenario, suggesting that the patients in this condition generally maintained a better posture throughout

Table 5.6: Mann-Withney U -test results fot the interaction parameters (Control and Memory) scenarios

	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6
Cervical Posture Corrections	**0.02**	0.18	0.08	0.44	**0.02**	0.23
Borg Scale Response Time	**0.03**	0.86	0.90	0.26	0.36	0.95

the therapy. However, only significant differences between Stages 1 and Stage 5 comparing the *Robot* and *Memory Robot* were found (Table 5.6). Showing a better performance of the patients assisted by the personalized robot in that stages.

Figure 5.17 shows that patients generally adjust to the robot and the system over time, which is supported by a significant difference between the sessions. While it can be seen that this adjustment was more gradual for the *Memory robot* scenario, there are only significant differences for the response times between the scenarios in the Stage 1.

5.6.3 Qualitative Results

In order to compare the expectations to the experience with the robot, instead of the patients in the *control* scenario, the UTAUT questionnaire was applied to 20 patients at their early outpatient or maintenance phase without any prior experience with the robot or our system. A debriefing was made about the socially

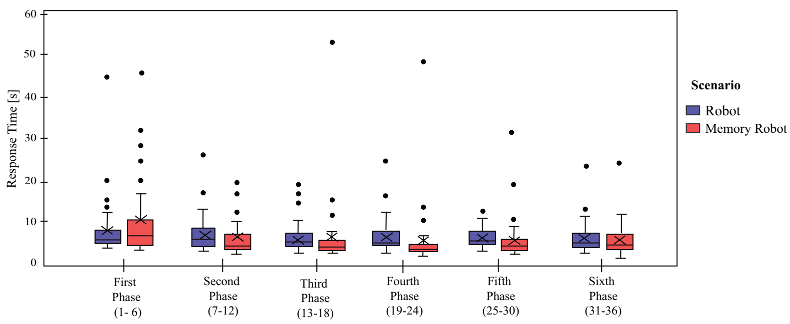


Figure 5.17: Response time of the patients to the Borg scale request of the robot throughout the therapy for *Robot* and *Memory robot* scenarios

assistive robotics systems and the parameters measured in the system, followed by a video presentation of the *social robot* condition, before applying the UTAUT questionnaire to the *control* patients. For the patients in the *Robot* and *Memory robot* scenario, the UTAUT was applied after the Phase II of cardiac rehabilitation therapy end with the robot. Table 5.7 presents the Unified Theory of Acceptance and the Use of Technology (UTAUT) questionnaire results and the significant differences between the conditions.

There are significant differences between the expectations of the *control group* and the perceptions of the patients that completed the therapy with the *Robot*, in terms of perceived usefulness, utility, ease of use, and trust. On the other hand, the patients in the *Memory robot* condition perceived the robot significantly safer and more trusted it more than the *Control* patients. The personalized robot was perceived more positively than the *Robot* in terms of the perceived sociability, ease of use, safety and social presence constructs, however, no significant differences were found. On the other hand, the usefulness, utility and trust were less positive for the *Memory robot* scenario than the *Robot* scenario. We believe this may be due to the user recognition and recall problems experienced in the sessions, which may have caused negative experience. These negative attitudes were also seen in the video analysis and discussed in previous sections. Nonetheless, both *Robot* and *Memory robot* scenarios improved the expectations about the robot and the system.

The additional feedback (through open questions) of the patients in the *Robot* scenario was similar to that of the *Memory robot* scenario. The patients reported that the robot increased their confidence in the therapy, as well as improved their compliance and adherence, and their therapy progress. In contrast, the patients in the *control* had lower confidence in using the robot (e.g., "I would trust more in human physiatrist"), as can be observed from the UTAUT results presented in

Table 5.7: Mann-Whitney U-test results for the Unified Theory of Acceptance and the Use of Technology (UTAUT) questionnaire for the *control*, the *robot* and *memory robot* scenarios.

Construct	Control/ Robot	Control/ Memory Robot	Robot/Memory Robot
Perceived Usefulness (U)	**p<0.01**	0.35	0.07
Perceived Utility (PU)	**p<0.01**	0.49	**0.04**
Safety (S)	0.22	**0.02**	0.28
Ease of Use (EU)	**0.03**	0.13	0.7
Perceived Trust (PT)	**p<0.01**	**0.03**	0.17
Perceived Sociability (PS)	0.1	0.26	0.65
Social Presence (SP)	0.17	0.34	0.78

the Chapter 4. However, some of the patients acknowledged the potential benefits of continuous monitoring, as observed within both the *Robot* and *Memory robot* scenarios.

Overall, these results are very encouraging to us as they present a positive result over the CR therapies. Using the Memory strategy allows the robot to perform socio-cognitive skills and consequently improve the interaction with the patient. Comparing the interaction, our interface achieveS to maintain the patient-robot relationship and engagement in an average of 4.5 months. In comparison with other studies [96, 113], the patient-robot interface proposed for CR program also is reliable for long-term scenarios. Finally, our approach presents the evaluation of a patient-robot interface, in a real-word scenario with long-term characteristics.

5.7 Conclusions

This Chapter presents the preliminary study with the robot using the personalized structure presented in the previous chapter. CR can be considered as a long-term interaction scenario as the rehabilitation consists in 36 sessions. The patients assist twice a week which means that under normal conditions the patient takes approximately 4.5 months time to finish the CR. Regarding the multi-modal open set identification system, the results showed that adding bio-metrics improve the performance of the system. However, it is important to mention that the system needs to be enhance in a future stage to achieve a better recognition performance during the sessions. As it can be seen, the study evaluates different perspectives (i.e., *Physiological parameters*,*Perception towards the robot* and *Interaction*). The results shown that the robot does not have effects over the physiological parameters of the patients due to the several variables that affect the physiological status of the patient (e.g., medication, diet, self-care outside the rehabilitation among others). In the case of the *Cervical Posture Correction* the patients followed-up the robot's feedback in a percentage of 94.4%, showing a positive effect on the exercise performance. The *Borg Scale Response Time* was reduced across the CR program showing a successfully adaptation of the technology.

The results regarding the qualitative data show that the patients enjoy working with the robot and were engaged to the therapy. Additionally, the WAI results show that the interaction was maintained in the time and the perception remains the same. Remarkable results show that the patients recommend the use of the robot to other patients and the patients perceive the social presence of the robot as positive attitudes and negative attitudes during the session were observed. Finally, the comparison between the three scenarios show that the robot scenarios have positive effects over the conventional therapy in terms of adherence to the CR program and perception.

Chapter 6

Conclusions and Future Works

This master thesis presents the development and the assessment of a Patient-Robot Interface in the Phase II of Cardiac Rehabilitation. Overall, three scenarios were proposed to measure the effects of a social robot : (i) control scenario, (ii) robot scenario and (iii) memory robot scenario. Each scenario was developed with different conditions and features that allow to evaluate the differences. The assessment was performed in two studies (i.e., ***Study I*** and ***Study II***). ***Study I*** presents a comparison of the control and robot scenario, where all the patients finish the rehabilitation procedure (36 sessions). The ***Study II*** presents the results of the memory robot scenario where a Multi-modal person recognition algorithm was integrated.

Furthermore, *qualitative* and *quantitative* measurements were observed in order to measure the robot's effects over the patients. Generally, the *qualitative* measurements encapsulates the physiological data of the patient (e.g., *Recovery Heart Rate*, *Training Heart Rate*, *Blood Pressure*, *Spatio-temporal gait patterns* and *Physical Activity Difficulty parameters*). On the other hand, the *qualitative* measurements are focused on the evaluation of the patient's perception towards the robot and the interaction.

The patient-robot interface was developed using a *Modular architecture design* which integrates different modules. This master thesis presents the new modules and main changes made to the patient-robot interface in order to enhance its features and create a long-term interaction with the patient based on personalization. The results trough all this study are overall encouraging as the positive effects of the robot were observed. For the three scenarios the next 8 key positive outcomes can be described:

- The study was made in a long-term health care service (Cardiac Rehabilitation) in a period of 36 sessions (approx 4-6 months). During this time all the dimensions of the robot's effect over the patients can be seen (i.e, perception, influence over physiological parameters and interaction) deeply.

- The study was made in a real-world scenario, in a Cardiac Rehabilitation Center at Fundación Cardioinfantil Instituto de Cardiología.

- The adherence rate increase (13.3%) in the scenarios were the social robot give assistance and motivation.

- The online monitoring of the physiological data allows to have more control of the therapies and a extended knowledge of the performance of the patients. This outcome was highlighted by the patient's perception and the special case presented in the *Memory Scenario.*

- The patient-robot interface allow the clinicians to intervene faster during emergency events.

- The patients have a positive perception of the robot. This perception was demonstrated trough the questionnaires, where the patients recommend the use of the robot to other patients and expressed to feel more secure during the CR sessions.

- The results obtained with the Working Alliance Inventory (WAI) show that the interaction between the patient and the robot is maintained across the rehabilitation procedure.
- The observations made in the *Memory Scenario* suggest that the perceived social presence of the robot by the patient increases with the personalization.

In SAR a few studies are focused on the measurement of the long-term interaction which entails to a lack of analysis regarding the users and robot interaction. Additionally, the literature shows that most of these studies are tested under laboratory conditions were the environment is very controlled. Our study presents the evaluation of a social robot in a real world scenario during extended periods of time, allowing us to observe the complete behavior of different measurements that are important for the developers, the patients and the health care staff involved in the project. The *Adherence* increased (30 %) by the usage of the robot in the *Control* and *Robot without Memory* scenario. This outcome is very important as the patient reduce their own risk to present a posterior cardiovascular problem or even death. This positive influence in the adherence can be due to the robot assistance, continuous monitoring and motivation. This results can be supported by the comments of the patients which used the robot. More than 70% of patients feel more secure and motivated working with the robot as the robot triggered alerts in adverse events and told them about their performance. Moreover, this assistance also helps the clinicians to have a higher control of the therapy. As it was mentioned in the Chapter 5, thanks to the robot the clinicians can perform quicker in a special case of risk.

In the *Memory Scenario*, the results showed that the interaction between the robot and the patients is maintained in the time for 4.5 months. This result can be seen in the patient's engagement throughout the CR program and the follow-up of instructions given by the robot. Additionally, the results regarding the social presence suggest that the positive perception increase with the personalized robot's features (UTAUT). This can be substantiated with the analysis of the videos, where positive attitudes (e.g., smiles to the robot, touching the robot) and negative attitudes (e.g., serious face gestures when the robot fails during the recognition) were performed.

Regarding the physiological data, difference between scenarios cannot be found. In spite of the expected changes in these parameters, a lot of external variables affect the results. As we mentioned before the self-care of the patient, the medication, among others affect the cardiovascular functioning and its behavior during each session. However, in the three scenarios the main medical variable (*Recovery Heart Rate*) elucidate positive results as it present and increasing tendency which show the CR successful. In the case of the posture the results show that the robot contributes positively to this parameters and adaptation of the technology can also be seen.

Additionally, it is important to mention the changes that have to be addressed in the feature to improve the quality of the patient-robot interface:

- The performance of the MMIBN:OL has to be improved for further evaluations. In the case of the *Memory Scenario* failures in the system do not allow a correct operation.
- Increase the robustness of the interface so the loss of data can be minor.
- To analyze deeply the *Memory Scenario*, greater number of patients have to be assessed. This master thesis present the results of 6 patients who interact with the personalized robot. However, to complete the evaluation, 9 additional patient have to be analyzed.
- The social presence of the robot can be increased using additional strategies such as: speech recognition, gestures recognition among others.

Finally, in order to increase the social interaction future strategies can be addressed (e.g., speech recognition, gesture recognition among others). The integration of this new features requires to understand the scenario, as it can be applied in some specific times of the therapy.

Appendices

Technical Aspects Patient-Robot interface for Long-Term Interaction

Taking into account the aim of promote the interaction in long-term periods an interface was proposed. This interface was developed in **Python 2.7** and libraries such as: PyQt4, PyAgrum, Threads, among others were used; the structure of the interface is based in **OOP (Object-oriented programming)**. Moreover, in the case of the Robot Module a NAO V4 robot was used. In this case the **Naoqi sdk** for python sdk was used and the **Coreographe** to develop body gestures regarding the robot interaction.

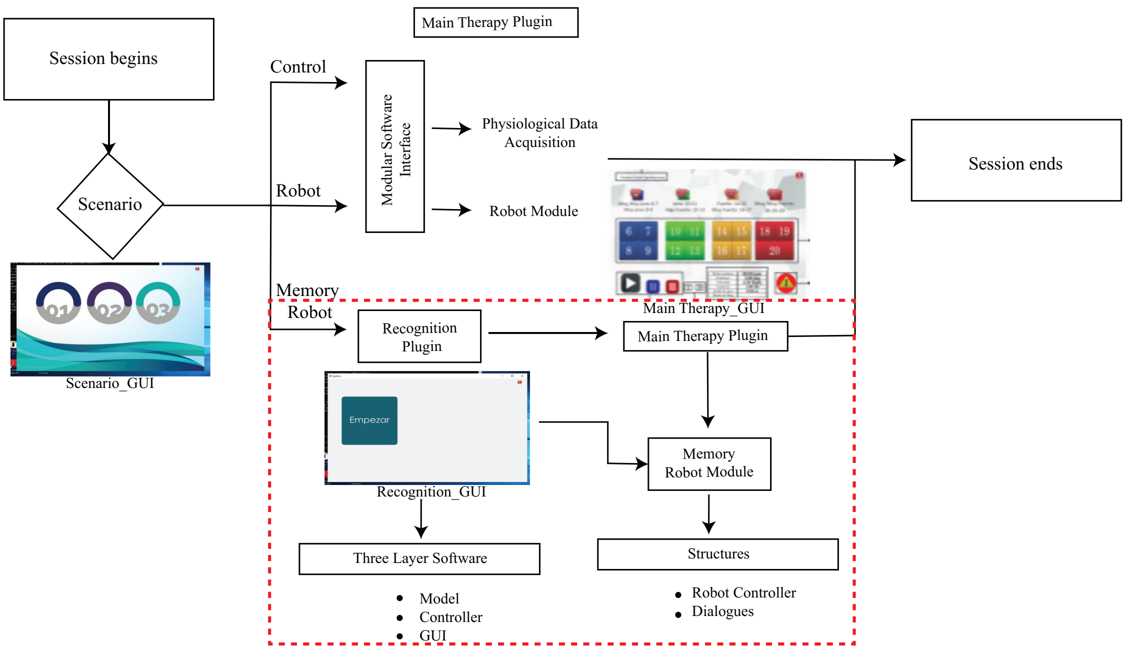


Figure 1: Patient-robot interface diagram for Cardiac Rehabilitation program taking into account the scenarios and phases of the CR.

Figure 1 show the flow diagram of the interface taking into account the scenarios and Cardiac Rehabilitation. Within the red square the interface proposed in this master thesis is represented. As it can be seen the *Recognition Plugin* and a *Robot Module* are implemented. This patient robot-interface for long-term interaction follows the modular architecture presented in [106]. Next subsections describe in detail the modules and the architecture elucidate in the Chapter 5.

Recognition Plugin Architecture

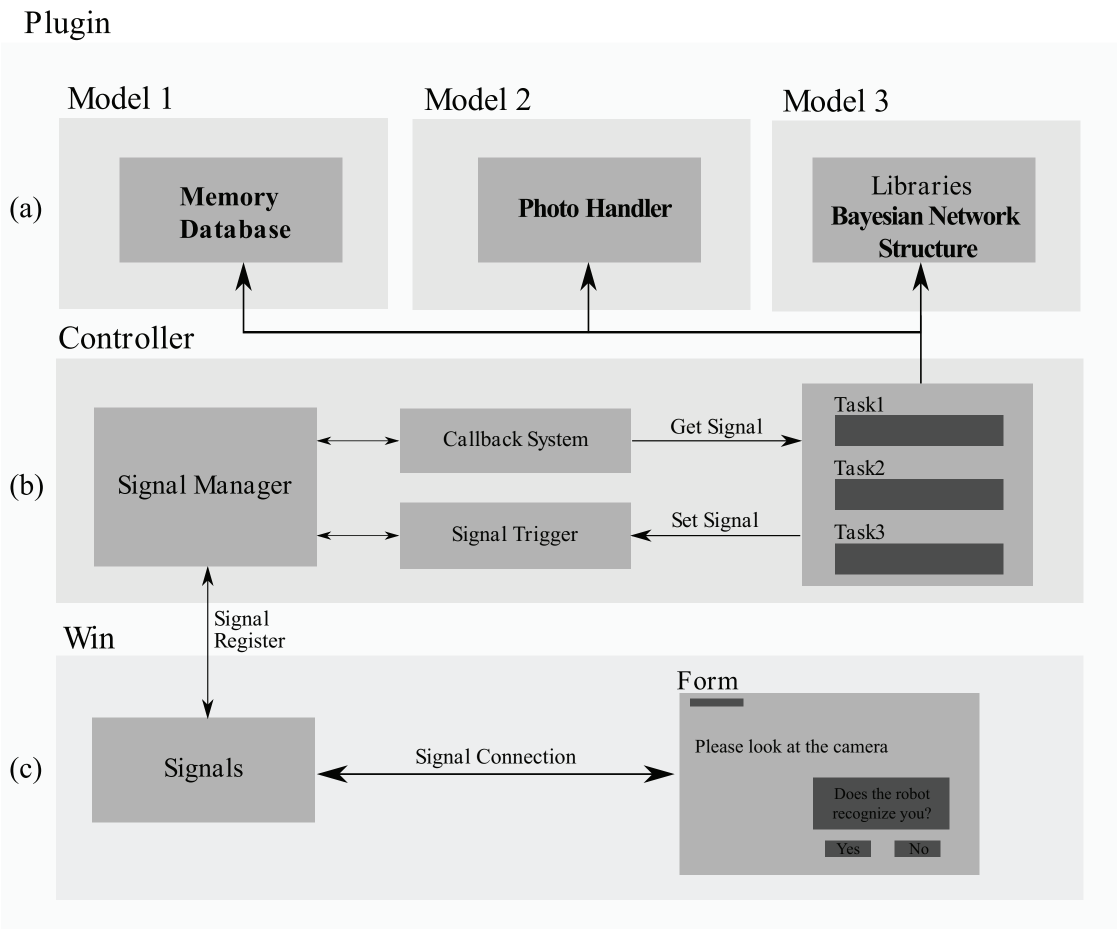


Figure 2: Three layer architecture software for the Recognition plugin in the patient-robot interface.

As mentioned in this work, the structure of the interface has a modular software design approach. The *Recognition Plugin* (Figure 2) encapsulates several elements to perform specific processes. The *Plugins* contains three main layers: (i) *Win*, (ii) the *Controller* and *Controller*. The ***Win Layer*** is represented in the Figure 3. In this case, several functions are created with the purpose of start the recognition and follow the the therapy. As it can be seen, signals are developed in order to control the flow of the interface depending the recognition analysis and they are connected by the ***Controller Layer***. Depending on the data acquired by the *Models*, *ID Plugin* or *Main Therapy Plugin* are activated.

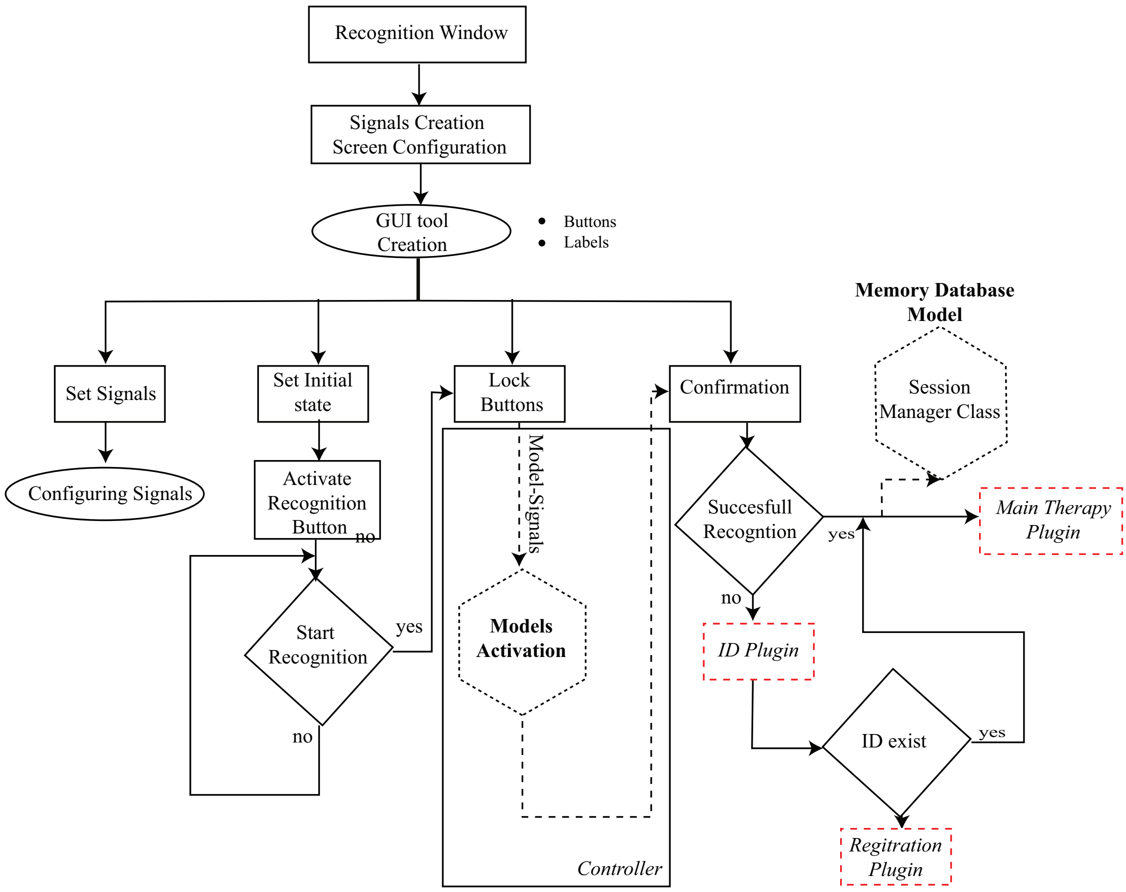


Figure 3: Win (Graphical User Interface) Component for the Recognition Plugin.

The ***Model Layer***, contains the main libraries that are involved in the recognition. (i) The *Photo Handler* model is the first step before the recognition. This Model includes the photo capture using OpenCV library (Figure 4), these photos are analyzed through the second model.

(ii) The Multi-Modal Open set Person Recognition is integrated. This model contains the incremental Bayesian network used for the recognition explained in the Chapter 5. Then, the development of (iii) the database for the memory scenario is presented. In the Figure 5, the software structure is presented, depending on the user existence two objects are created: (i) *Session Manager Class* integrate

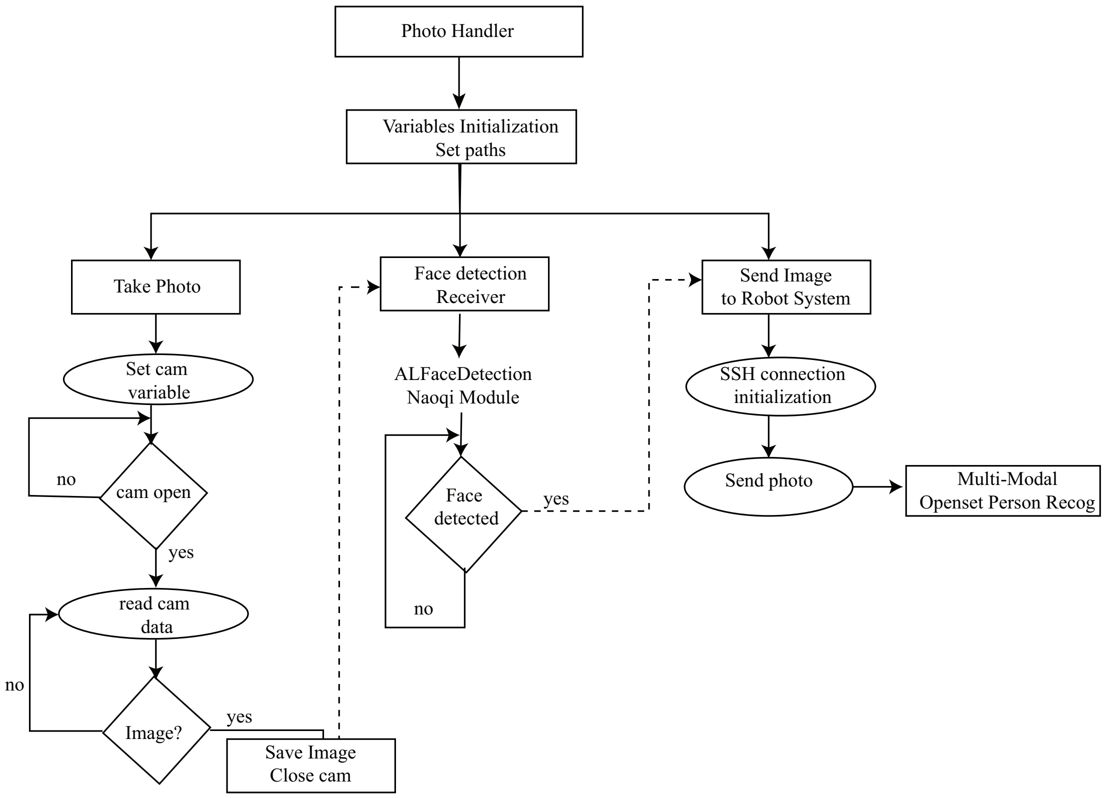


Figure 4: Photo Handler Model for the Recognition Plugin

several functions to storage main data such as users' data, MMIBN:ON data (e.g., probabilities, weights) and the physiological progress data (e.g., cardiovascular parameters, gait spatio-temporal parameters, among others). (ii) *Database Class* is in charge of update the data of new users throughout *Registration Plugin*. This data is stored in folders with the ID of the users, each folder includes sub-folders with the dates of each session. Data regarding the events (e.g., robot alerts, patients responses and events label), physiological progress and MMIBN:OL data are saved in cvs files.

Memory Robot Module

The Memory Module was developed in order to promote the long-term interaction and increase the randomness in the robots behaviors. This module uses the sdk for

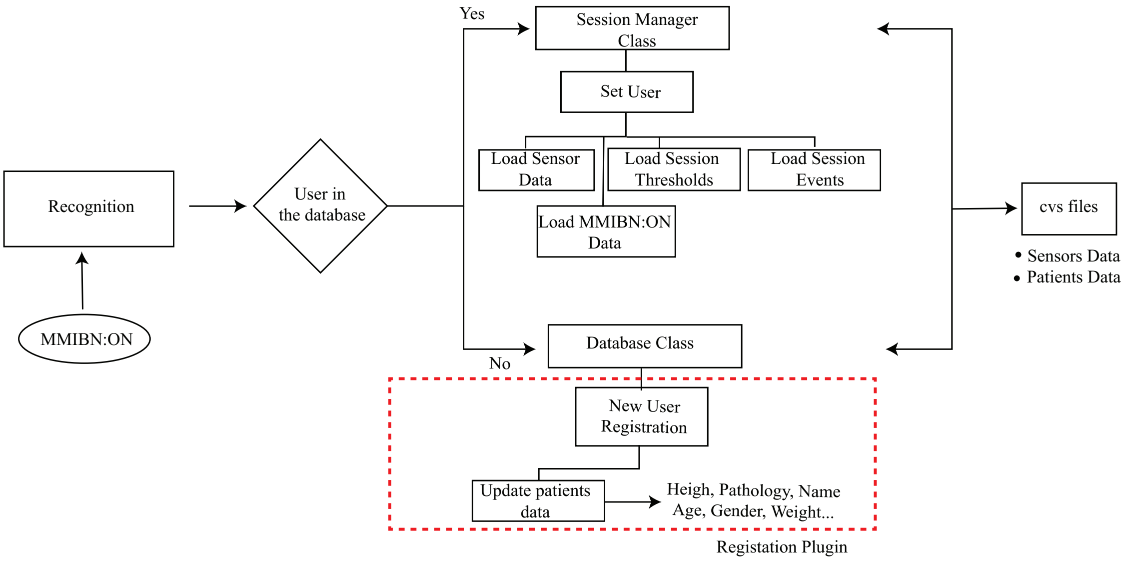


Figure 5: Database Model for the Recognition Plugin

the NAO robot and the Coreographe tool. Some example of behaviors and models are explained in this appendix.

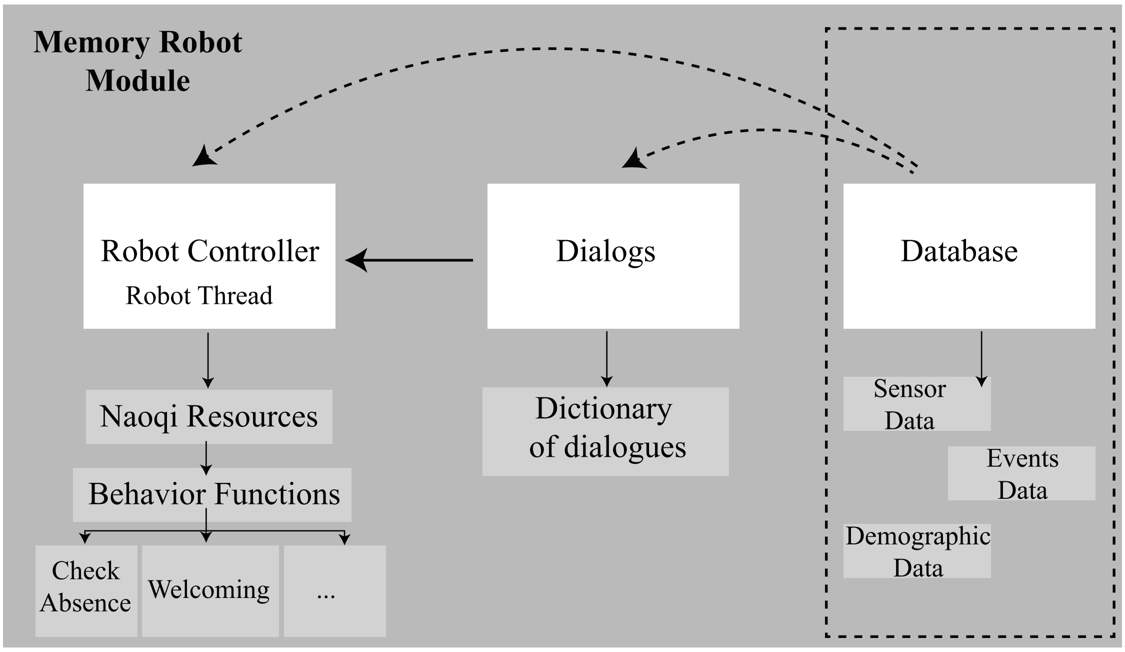


Figure 6: *Memory Robot Module* architecture for the patient-robot interface. The main part of this module can be seen: (i) *Robot controller*, (ii) *Dialogs library* and *Database library*.

Figure 7 present a general scheme of the robot module developed for the *Memory*

Robot Scenario. Several functions were implemented to fulfill the requirements of the CR scenario. Taking into account the data stored in the *Recognition Plugin* the robot could perform specific tasks during the session.

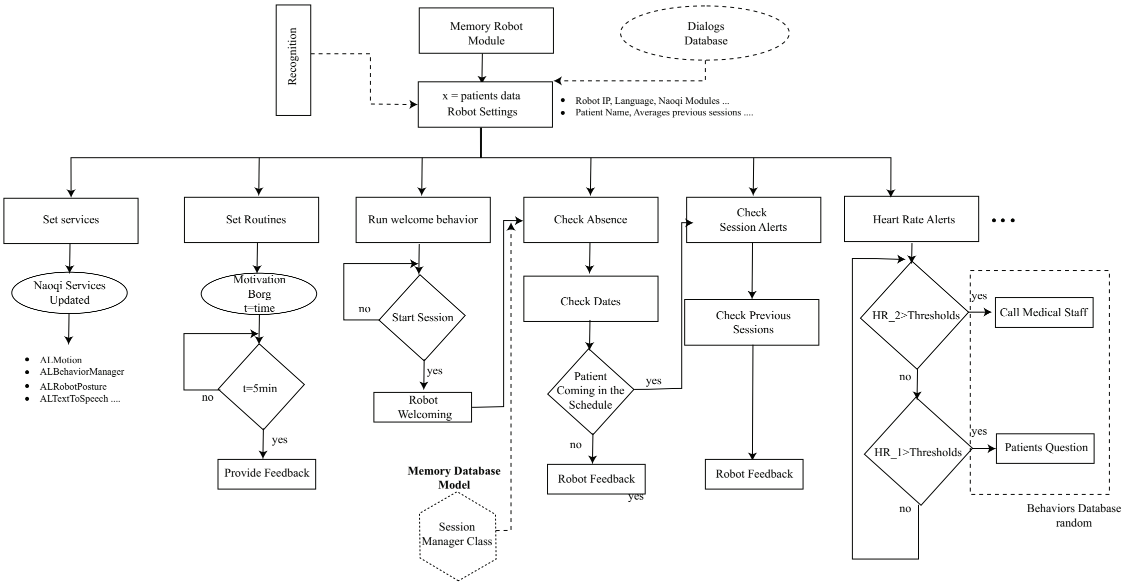


Figure 7: Memory Robot Module for the *Memory Scenario*

In this case, the main functions are *CheckAbsence*,*Check Sessions Alerts* and *Feedback Alerts* (i.e., heart rate and cervical posture feedback. Within this functions the robots tasks are developed considering the previous sessions. Furthermore, a database with dialogues and behaviors (body gestures) are created to promote the long-term interaction. For example, the heart rate behaviors were developed in the Coreographe, several animation were created with the *Timeline Tool* which enables the body gestures movements.

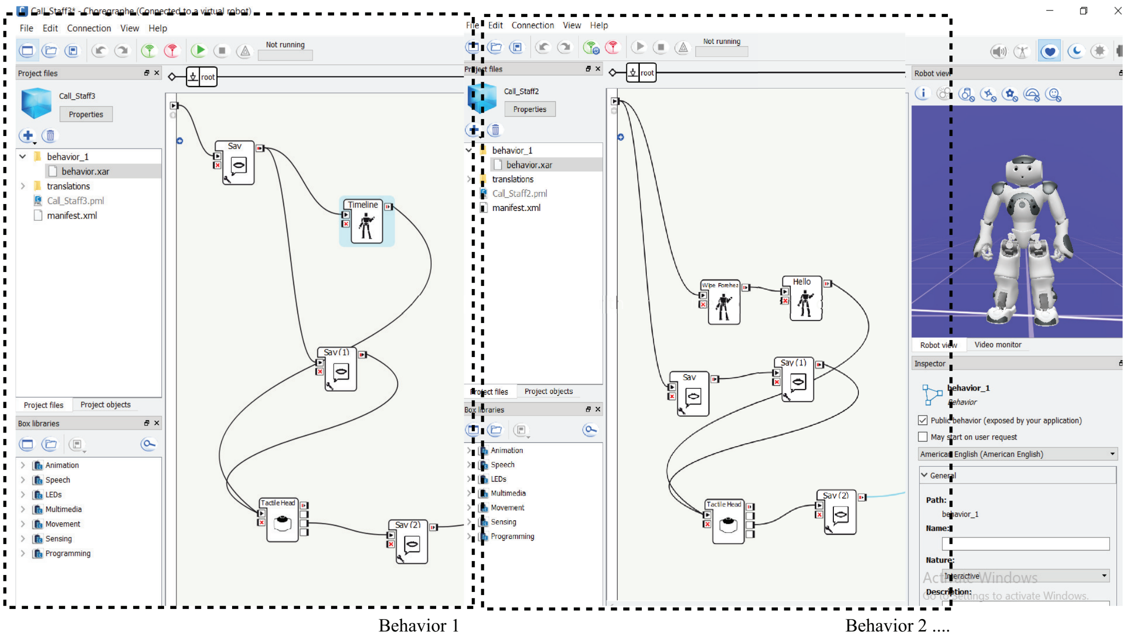


Figure 8: Example of robot *Memory Module* behavior developed in the Coreographe.

Table 1: UTAUT Questionnaire implemented to evaluate robot's perception for the patients group

Construct	No.	Questions
U	1	I consider that using robots it's a good tool to assist cardiac rehabilitation therapies.
	2	I consider that my interaction with the robot was comfortable.
	3	I enjoyed when the robot gave me verbal encouragement when I did a good job.
	4	I'm satisfied with the work the robot did.
	5	I consider that the robot adapts to my needs.
PU	1	I consider that the interaction with the robot was beneficial for my recovery.
	2	I consider that the rol of the robot was important for the therapy development.
	3	I think that the use of the robot helps me to compromise me to do a good job.
S	1	I feel safe at the therapies working with the robot.
	2	I consider it was easy to give information to the robot.
EU	1	I consider that the robot is ease to use.
	2	I consider that using the robot didn't affect the time of therapy sessions.
	3	I consider that the robot's instructions were clear.
PT	1	The robot made me confident.
	2	I did instruction the robot told me because I trusted him.
	3	I like using the robot during the therapies.
	4	It gave me confidence that the robot guides my therapy.
PS	1	I consider the robot a pleasant conversational partner.
	2	I find the robot pleasant to interact with.
	3	I feel the robot understands me.
	4	I think the robot is nice.
SP	1	When interacting with the robot I felt like I'm talking to a real person.
	2	It sometimes felt as if the robot was really looking at me.
	3	I can imagine the robot to be a living creature.
	4	I often think the robot is not a real person.
	5	Sometimes the robot seems to have real feelings.
Open Questions	1	Would you recommend the use of the robot to other patients who participate in Cardiac Rehabilitation?.
	2	In your experience. How could we improve therapy with the robot?
	3	Do you have any additional comment or suggestion over the robot and the interaction?

Table 2: UTAUT Acceptance Questionnaire for Clinicians

Construct	No.	Questions
U/A	1	I consider that using robots is a good tool to measure the HR and the BP during CR sessions.
	2	I consider that using robots it's a good tool to alert me if there is an abnormal heart rate.
	3	I consider that it can be useful know the number of steps made by a patient during a session.
	4	I consider that using robots can help me carry out my tasks faster.
	5	I consider that the robot would not affect the time of cardiac rehabilitation sessions.
	6	I consider that the robot would not affect the time of cardiac rehabilitation sessions.
	7	I consider that using robots could improve my productivity during a therapy.
U	1	My interaction with the robot could be clear and understandable.
	2	I might find the system easy to use.
	3	Learning to use the robot could be easy for me.
PU	1	I consider that using robots can bring benefits for the patients.
	2	I consider that using robots could help me to make a more personalized therapy patient.
	3	I consider that using robots could aid me to evaluate better the therapy.
	4	I consider that using robots could make my work more interesting.
	5	I feel that the robot could replace me.
S	1	The robot would represent a risk to the patient's health.
PT	1	I would feel safe using the robot in the therapies.
	2	I could trust the work done by the robot in the sessions.
	3	I would like to use the robot during the therapies.
	4	I would trust the robot to help me guide the therapy.
	5	I would be afraid to use a robot in therapy..
PS	1	I consider that robots can be a pleasant conversationalist for the patient.
	2	I would like that the interaction between the patient and the robot can be pleasant.
	3	I would like the robot to understand the needs of the patient.
	4	I would like the robot to act as a friendly companion.
	5	I would like the robot to have an different modalities (monitoring, assistance and motivation).
	6	I would like to choose the program that the robot should perform during therapy.
SP	1	I consider that the interaction with the robot might feel like talking to a real person.
	2	I would consider good if the patient had the feeling that the robot will observe him in therapy.
	3	I consider it's good to imagine the robot as a living creature.
	4	I consider patients would usually think that the robot is not a real person.
	5	I consider the robot could have real emotions.

Table 3: WAI Questionnaire implemented to evaluate robot's perception for the patients in the *Memory Scenario*

Construct	No.	Questions
Bond	1	I feel uncomfortable with the robot.
	2	The robot and I understand each other.
	3	I believe that robot likes me.
	4	I believe the robot is genuinely concerned for my welfare.
	5	The robot and I respect each other.
	6	I am confident in the robot's ability to help me.
	7	I feel that the robot appreciates me.
	8	The robot and I trust each other.
	9	My relationship with the robot is very important to me.
	10	I have the the feeling that if i say or do the wrong things the robot will stop working with me.
	11	I feel the robot cares about me even when i do things that the robot doesn't understand me .
Task	1	The robot and I agree about the things I will need to do in therapy to help improve my situation.
	2	What I am doing with the robot in the therapy gives me new ways of looking at my problem.
	3	I find what i am doing in the therapy with the robot confusing.
	4	I believe the time robot and I are spending together is not spent efficiently.
	5	I am clear on what my responsibilities are in therapy with the robot.
	6	I find that the robot tasks during the therapy are unrelated to my concerns.
	7	I feel that the things I do in therapy will help me to accomplish the changes that i want.
	8	I am clear as to what the robot wants me to do in these sessions.
	9	The robot and I agree on what is important for me to work on.
	10	I am frustrated by the things I am doing in therapy.
	11	The things that robot is asking me to do don't make sense.
	12	I believe the way that the robot and i are working in my problem is correct.
Goal	1	I am worried about the outcome of these sessions with the robot.
	2	The robot perceives accurately what my goals are.
	3	I wish that the robot could configure the therapy according the purpose of our session.
	4	I disagree with the robot about what I ought to get out of therapy.
	5	The robot does not understand what I am trying to accomplish in therapy.
	6	The goals of these session assisted by the robot are important to me .
	7	The robot and I are working towards mutually agreed upon goals.
	8	As a result of the session with the robot I am clearer as to how i might be able to change.
	9	The robot and I have different ideas on what my limitations are.
	10	The robot and I collaborate on setting the goals for my therapy.
	11	The robot and I established a good understanding of the kind of changes that would be good for me .
	12	I don't know what to expect as the result of the therapy with the robot .

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