11. Robot interaction adaptation for healthcare assistance

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Working paper

Assitive robotics is one of the big players in the technological revolution we are living in. Expectations are extremely high but the reality is a bit more modest. We present here two realistic initiatives towards the introduction of assistive robots in real care facilities and homes. First, a cognitive training robot for mild dementia patients, able to play board games following caregiver instructions and adapting to patient's needs. Second, we present the Robotic MOVit, a novel exercise-enabling control interface for powered wheelchair users. Instead of using a joystick the user controls the direction and speed of the powered wheelchair by cyclically moving his arms. Both robotic devices can adapt the interaction to the needs of the user and provide insightful information to researchers and clinicians.

Keywords: Hri, Socially assistive robotics, Cognitive training, Physical training, Human-robot interaction.

1. Introduction

Nowadays demanding for robotics is increasingly widespread. According to the forecast of Boston Consulting Group (Woldgang, 2017) the global market for robotics is projected to reach $87 billion by 2025. New capabilities and applications are driving the convergence to robotics. With the progress in machine learning and computer vision, robots are able to process information, learn and adapt to different contexts. Moreover, the development of more advanced hardware (from sensors to smart processors) provide them with the ability to interact with the surrounding environment. Despite the technology progress, what makes the real difference is that now they are smaller more perceptive and more collaborative than their predecessors. Another important fact, that deserves to be mentioned, is that the venture capital investment tripled between 2016 and 2017, from $402 million to $1.2 billion (Dang, 2018).

Although the exponential growth and the great interest in companies for this technology, robotics compared to other AI technologies, struggle to leave research laboratories. Although there are several robotic platforms that mechanically are ready to everyday use, the artificial intelligence that should drive these platforms is not ready. Developing robots for real scenarios is still a challenge due to the unpredictability of the environment. Most of the robots are tested and validated in controlled environments where, despite the efforts to be robust enough to face unexpected events, is quite impossible to recreate what can happen in reality. This problem becomes even more evident when the robot interacts with people where their unexpected human behaviour can lead the robot to a state that does not know how to manage.

The cost of building robots and developing new forms of artificial intelligence is still prohibitive. The fact that practical robots are designed to cover a few tasks, combined with relatively high costs, makes robots as a consumer product still a promise.

One should not forget the ethical issues arising when using robots in contact with humans, and even more so when dealing with patients. Recently, the robotics community has tackled this problem and these questions are receiving increasing attention (Torras, 2018).

In this working progress paper, we show two robotic applications that aim at introducing robotics in health-care facilities and homes. The first robotic application is an assistive robot designed to administer cognitive training exercises to patients. The robot through speech and gestures can support the patient and provide encouragement and motivation to successfully complete a game. The main goal is to provide the doctor with intelligent tools to facilitate the diagnostic and treatment using physical amusing games.

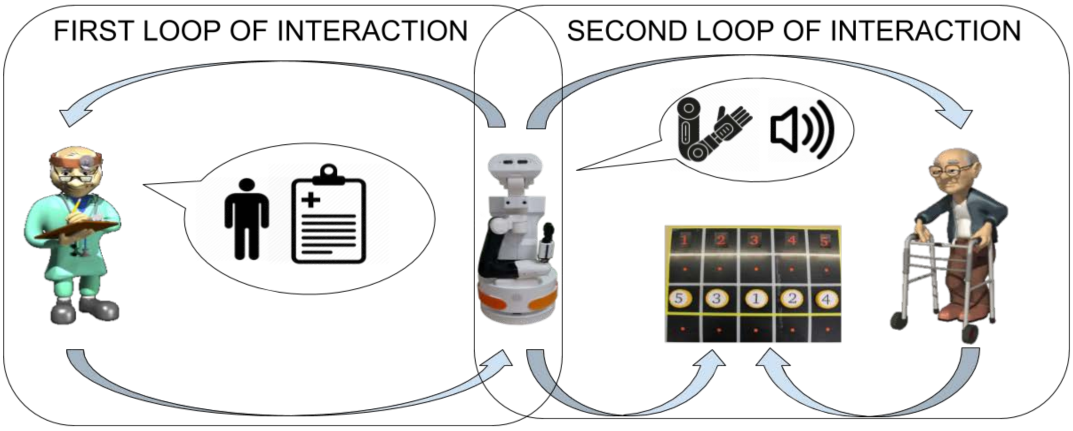
The second robotic application focuses on providing integrated daily exercise to powered wheelchair users with a novel robotic control interface that requires the user to perform a cyclical arm motion to control the speed and direction of the wheelchair. The robotic device is able to modulate the exercise intensity to the needs of the user. The main goal is to continuously provide opportunities for controlled exercise during daily life.

2. Robots for cognitive training of Alzheimer patients

Alzheimer's disease is a degenerative disease and the most common cause of dementia. Dementia progressively affects memory, language, and most of the cognitive skills, that will affect the personal day-life activities. It is estimated that around 50 million people worldwide are affected by Alzheimer's Disease (AD). Worldwide dementia care costs to the governments upwards of US$1 trillion. In the United States the total investment for health care, that includes long-term care and residential care is projected to increase from $290 billion in 2018 to more than $1.1 trillion in 2050 (Alzheimer's Association, 2019). One of the biggest public healthcare challenges is the lack of caregivers and therapists. This poses several impediments in the delivery of high-quality health and social care (Goldman, 2017).

Socially Assistive Robot (SAR) technology could assume new roles in health and social care to meet this higher demand and provide the opportunity by supplementing human care.

Tapus et al. 2009 show how SAR can be employed to engage patients and keep them interested during a cognitive task through motivations and encouragements. Tsiakas et al. 2017 present a SAR system for personalized and adaptive cognitive training. The task is a sequential learning task that can measure learning or behavioral disabilities in children. Moro et al. 2018 present a robot, Casper, able to learn personalized behaviours to provide effective assistance to users with cognitive abilities. Chan et al. 2012 develop a SAR with abilities to learn appropriate assistive behaviours based on task complexity and the user state. Their aim was to develop a robotic system that can engage and motivate people during cognitive training exercises



(a) (b)

Figure 1. Double loop of interaction: Caregiver-Robot (a) and Robot-Patient Interaction (b).

In this working paper, we present a cognitive robotic system that can be employed by a caregiver in order to administer cognitive training and evaluation to people affected by Mild Dementia (MD) and

AD. The goal is to provide personalized one-on-one cognitive training for MD and AD people who otherwise might not receive that care. The use of a physical game, opposed to a tablet or other electronic devices, is beneficial because causes additional activation in motor skills and mirror neurons (Rossi et al, 2018). In Section 2.1 we describe the proposed framework and in Section 2.2 we present the results of an experiment performed with able people to evaluate the effectiveness of the robot adaptability and finally in Section 3.3 we present the next steps to evaluate the robot in a more realist scenario.

2.1 Proposed solution

In our paper (Andriella et al. 2018) we present the cognitive exercise scenario and the way the three different actors, caregiver, robot and patient, interact. The objective of the exercise is to sort tokens in ascending order on the board with as few mistakes as possible minimizing the completion time.

We design a hri framework, embedded in a robotic system, able to adapt, learn and reason to the environment and the user's behaviour. The robot is able to provide him with encouragements and hints while he is playing a cognitive exercise.

We propose two main loops of interaction: a caregiver-robot interaction and a robot-patient interaction (see Figure 1). In the first loop, the caregiver interacts with the robot in order to set up the mental and physical impairment of the patient. Moreover, in this stage, the caregiver is able to define the preferred behaviour of the robot in term of interaction modalities (speech and gesture) and levels of assistance. In the second loop of interaction, the robot administers the test to the patient starting from the initial setup of the caregiver. During the test, the robot can adapt to the learned user behaviour and provides assistance based on his performance.

The framework consists of a robotic platform, in this case, a Tiago Robot[1] empowered with adaptive capabilities in order to interact with people through speech and gestures.

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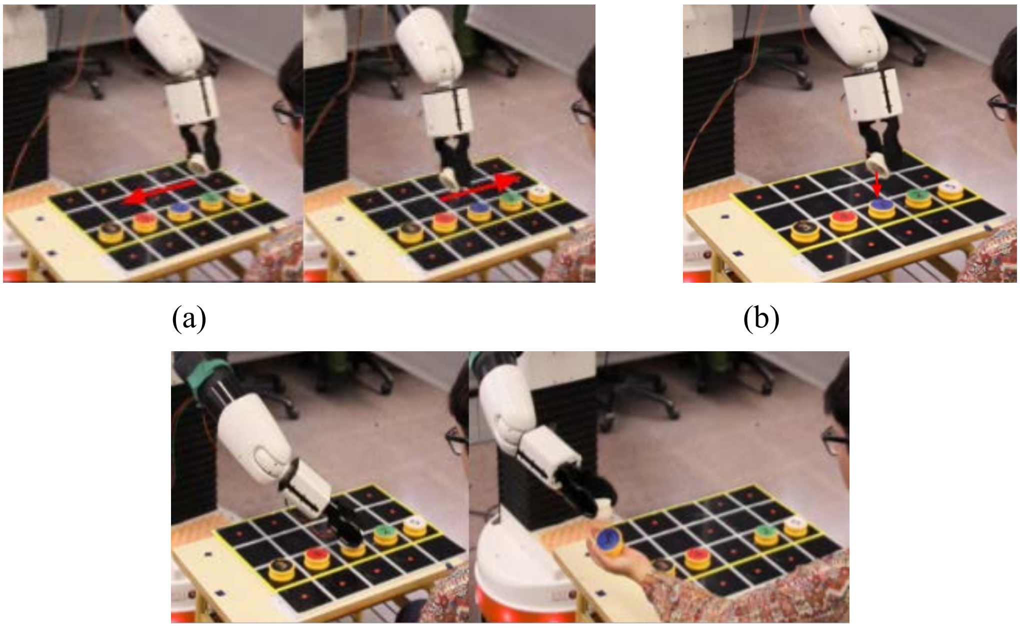
[1] http://tiago.pal-robotics.com/



(a) (b)

(c)

Figure 2. Example of levels of assistance. (a), the robot shows the user a subset of possible solutions. (b), the robot points to the user the right token. (c), the robot picks the right token and offers it to the user.

The robot is able to perceive the world, in our case the board and the person, through a camera mounted in its head. The robot provides assistance to the patient combining speech and gestures, among 4 increasing levels of assistance:

- LEV 1 (Encouragement): the robot provides motivational sentences to encourage the user. It is the only level of assistance where the interaction is only through speech.
- LEV 2 (Provide hints): the robot suggests a subset of possible solutions combining speech and gestures. It moves horizontally its arm on the board pointing on three different tokens (see Figure 2a)
- LEV 3 (Provide solution): the robot suggests the solution combining speech and gestures. It points with its arm in the direction of the right token (see Figure 2b).
- LEV 4 (Offer right token): the robot picks the right token and offers it to the user (see Figure 2c).

Every time the user makes a mistake, the robot picks the token and move it back in its initial location. The robot behaviour is set up in order to guarantee a full cognitive stimulation of the user. For this reason, the robot never performs by itself the right move but always pretends that is the user to complete the task. Only after 4 consecutive mistakes, the robot shows the user the right movement.

During the test, the robot provides assistance based on the user performance in term of the number of mistakes, assistance provided so far, reaction time and state of the game.

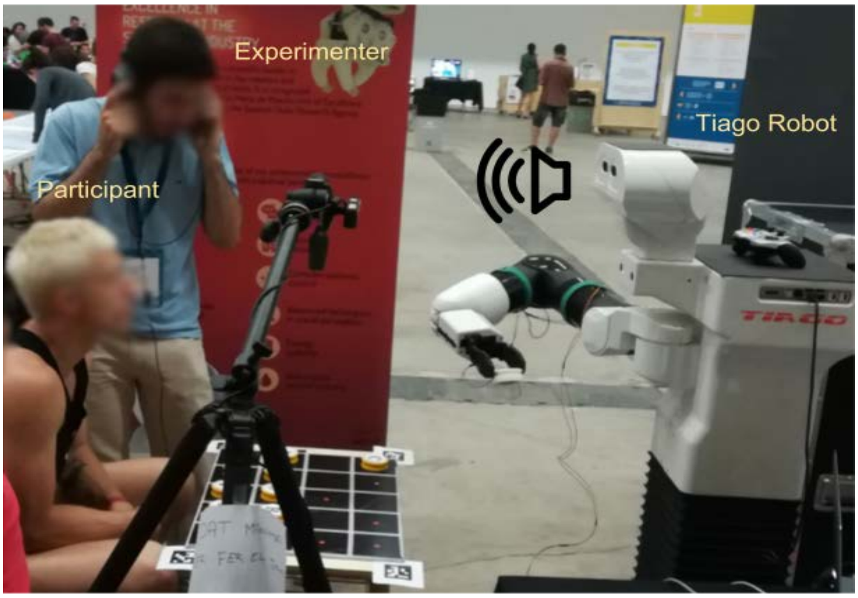


Figure 3. Experiment initial setup

An important aspect to tackle when providing adaptive assistance is the concept of flow that is defined as the state in which a person performing a task is fully focused and involved. The user is able to achieve that state if his skills match the difficulty of the task, in our case the cognitive exercise. If the exercise is too difficult, the user might feel anxious and thus can get demotivated. On the contrary, if the users' skills are enough to complete the test, interest disappears and boredom might show up. Our adaptive algorithm aims to provide enough assistance to accomplish the task according to the concept of flow. The expected behaviour is achieved, proving the robot with reward/penalty based on the success or failure of its action of assistance. In each state, the robot evaluates which is the most suited action with which engage the user for the next move in order for him to succeed.

2.2 Preliminary results

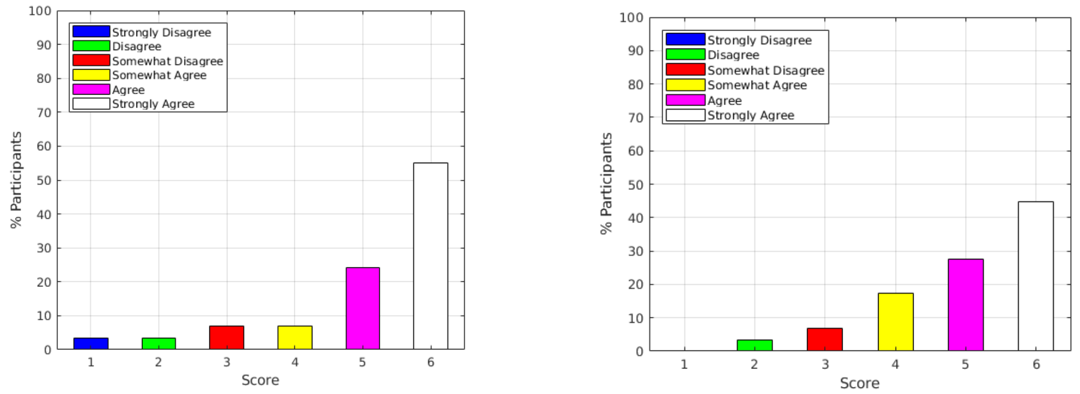
In this section, we present some preliminary results of our experiment at the MakerFaire of Barcelona 2018. The objective was to evaluate the robustness of the entire framework and the experience of non-trained and non-technical users during the game. Since the people were healthy without any physical and mental impairment we changed the game to a more difficult task. The proposed game was a puzzle game where we asked the user to compose the name of a Nobel's Prize using the tokens available on the board. The task had been chosen difficult enough, in order for the attendees to need assistance from the robot to complete it.

The robot played with more than 50 participants, between 18 and 65 years old. 29 participants were included in the evaluation for statistical analysis (see Figure 4).

Each user played once. Participants took an average of 210 seconds and 5 mistakes to complete the game.

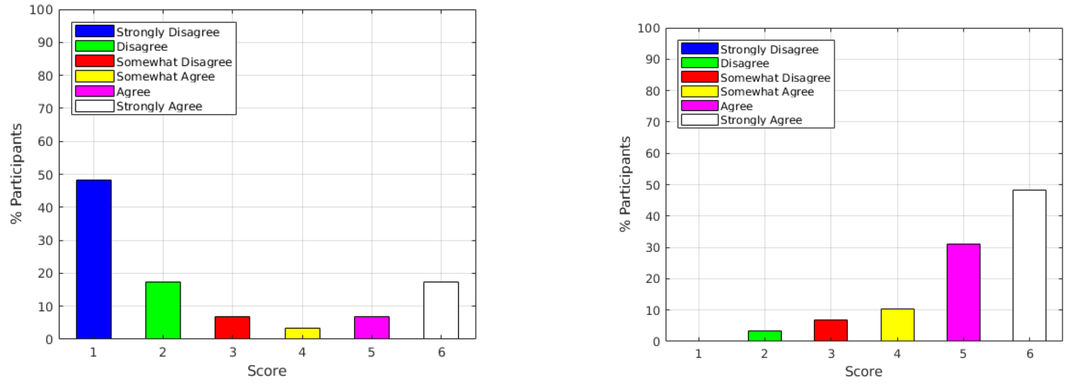
In order to evaluate the overall user experience, we asked the participants to fill a questionnaire about their experience interacting with the robot. The questionnaire contained the following questions:

1. Interacting with the robot in the game was likeable (Figure 4a)
2. Interacting with the robot in the game was comfortable (Figure 4b)
3. Interacting with the robot in the game was distractful (Figure 4c)
4. Interacting with the robot in the game was useful (Figure 4d)
5. Which modality have you preferred the most? (Figure 4e)



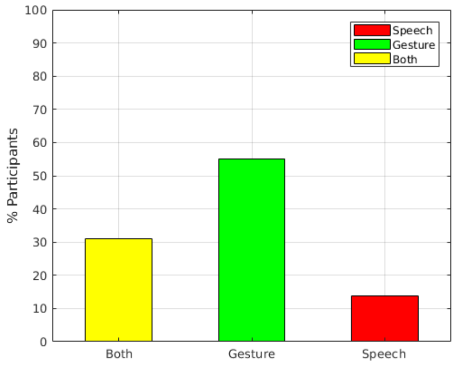
(a) likeability

(b) comfortable



(c) distractful

(d) useful



(e) prefered interaction modality

Figure 4. Results of the questionnaire.

As it is possible to notice all the users involved in the experiment had an overall positive experience interacting with the robot. A tiny note deserved the question regarding the interaction modalities. A very little amount of people preferred the speech (Figure 4c), that was manly because the voice system we were using was not thought to work in Catalan language and sometimes it pronounced worlds and letters in a way that was difficult to understand. Moreover, half of the participants played the game without using any external headset and since the environment was pretty noise they could not understand properly the instructions of the robot.

From this experiment the most relevant lesson learned are:

- speed up the interactions. The gestures of the robot (from level 2 to 4) were, from some users, perceived too slow. Moreover, the action of the robot that moves back the token was the one they were less willing to accept since as soon as they knew that the current move was not corrected, they wanted to move back the token by themselves and get another try. To this end, as next step, we will integrate into the robot the ability to detect whether if the user really needs assistance, since sometimes not providing any support might be the best choice.
- robustness to unexpected events. Sometimes participants did some actions that the robot was not prepared to face and its reaction was not the one the user was expecting. An effort in this direction is necessary since our final goal is to deploy the system in care facilities.

2.3 Future Work

In collaboration with Fundació ACE[2], we are preparing a longitudinal study to evaluate the cognitive training robot with patient affected by MD and AD. The final goal is to provide therapists and caregivers of a useful tool in order with the aim to reduce their burden and workload.

3. Robots for physical training of powered wheelchair users

The World Health Organization estimates that 1% of the world's population (i.e. just over 65 million people) need a wheelchair (WHO, 2013). In 2002, there were 2.7 million community wheelchair users in United States; approximately 30% use powered wheelchairs or scooters (Bauer et al., 2018). That same year, Medicare paid for 159,000 powered wheelchairs at a total cost of $1.2 billion. The use of powered wheelchairs is common among people with cervical spinal cord injury, amyotrophic lateral scoliosis, stroke, multiple sclerosis, Alzheimer disease, muscular dystrophy, and numerous other conditions (Kairy et al., 2014, Simpson et al., 2008). While power-wheelchairs are an essential technology to support mobility, their continuous use results in an increased level of sedentarism, which leads to secondary health problems such as obesity, diabetes and cardiovascular disease, as well as an increase in mental health problems.

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[2] http://www.fundacioace.com

Figure 5. Picture of the Robotic MOVit, which consists of two robotic arm supports with linear actuators that replace the armrests of the wheelchair.

Unfortunately, current exercise devices for power-wheelchair users, such as leg and arm cycles (Jansen et al., 2013), require the user to drive their wheelchair up to them, and then exercise during a fixed time period. In contrast, for people without disabilities, there are ample opportunities for integrated daily exercise (e.g. by biking to work, taking the stairs, achieving 10,000 steps etc.). It is well established that integrated daily exercise is one of the most effective ways of promoting health and well-being (Penedo et al., 2005). The goal of this project, therefore, is to provide similar access to integrated daily exercise for powered wheelchair users.

In Section 3.1 we describe the proposed solution and in Section 3.2 we present preliminary results of a pilot study with healthy subjects. Finally, in Section 3.3. we describe future work to evaluate the feasibility of using MOVit with people with Duchenne muscular dystrophy.

3.1 Proposed solution

In collaboration with the UCI BioRobotics Laboratory (University of California Irvine, USA) we have developed the Robotic MOVit, an arm exercise-enabling driving interface for powered wheelchair users. The Robotic MOVit is a powered version of our previous passive MOVit prototype (Lobo-Prat et al., 2018). The Robotic MOVit consists of two robotic arm supports that are mounted on the lateral sides of a powered wheelchair replacing the armrests (Figure 5). Compared to our previous passive MOVit prototype, the Robotic MOVit is capable of providing movement assistance and resistance with the linear actuators that are attached to the arm supports.

Instead of using a joystick to drive the wheelchair, the user moves the robotic arm supports with his arms through a cyclical motion to control the speed and direction of the wheelchair. The movement of the robotic arm supports can also be used as input signal for interfacing with external devices, such as computers or tablets, to play games (Figure 6).

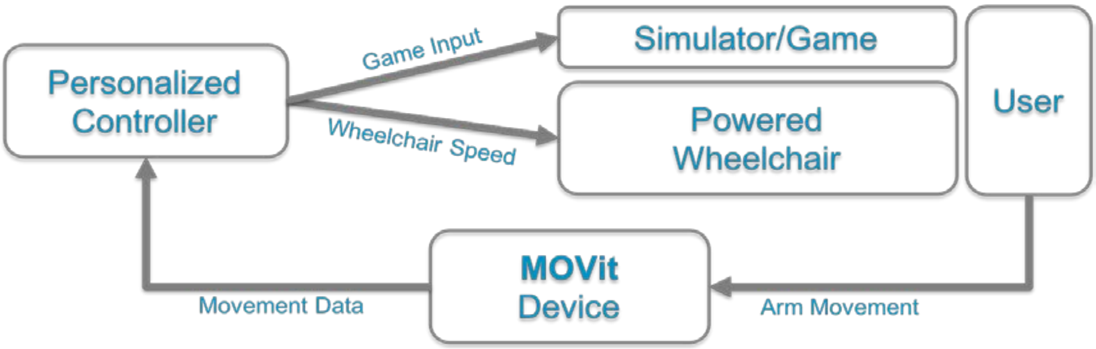

Figure 6. Control diagram of the Robotic MOVit.

The user moves the MOVit device with his arms and the personalized controller will use the measured movement data to control the speed and direction of the powered wheelchair, or the input signal for a videogame.

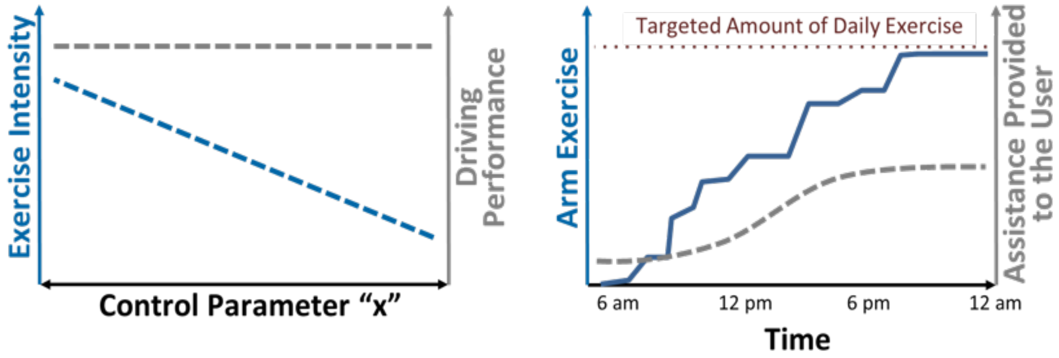

Figure 7. Right: MOVit will be able to sense the overall amount of arm exercise that has been achieved throughout the day and adaptively change the assistance provided depending on the user needs to reach a targeted amount of daily exercise. Left: MOVit will be capable of modulating the level of exercise by changing a control parameter (such as the force, amplitude or frequency of the arm movements required to drive the chair) while keeping an acceptable driving performance.

By using MOVit to sense the overall amount of arm exercise that has been achieved each day, and adaptively changing the arm range of motion/cycle speed required to drive the chair, we hypothesize that MOVit can intelligently provide an appropriate, long-term dose of dynamic physical training (Figure 7).

3.2 Preliminary results

We performed a pilot study with healthy subject to investigate the capabilities and limitations of the proposed solution. First, we quantified how oxygen consumption and heart rate were modulated by varying the frequency and amplitude of arm movement (N=8). Results indicated that increasing arm movement amplitude and frequency significantly increased heart-rate and oxygen consumption, reaching values that were comparable to a walking exercise. Then, we evaluated a novel control method for driving the wheelchair by moving the arm supports. Participants (N=24) were randomized to the MOVit group, or to the conventional joystick group, and performed driving tests over two days on a simulator and test course. After approximately 30 minutes of training, driving performance with the Robotic MOVit was comparable to using a conventional joystick, and produced a light level of exercise (Figure 8). These results showed for the first time the feasibility of exercising while driving a powered wheelchair.

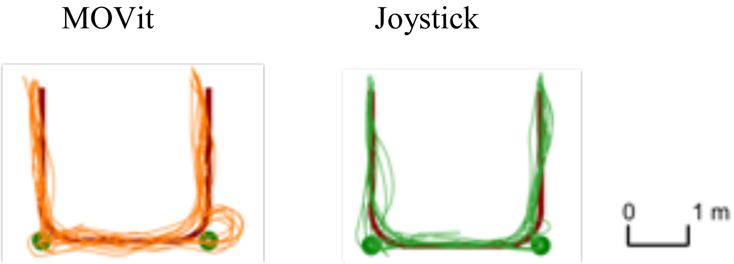

Figure 8. Example of six wheelchair paths from two participants driving with the MOVit device (orange) and with a standard Joystick (green).

3.3 Future Work

In collaboration with the Rehabilitation Department of the children hospital Sant Joan de Déu[3] (Barcelona, Spain) we will carry out a feasibility study with people with Duchenne muscular dystrophy to test the driving performance of MOVit and compare it to using a standard joystick. We will monitor heart-rate and muscle activity during the tests to investigate the exercise intensity when using MOVit.

4. Conclusions

This paper presented two implementations of robotic devices for health-care applications that have been developed to have and adaptive interaction with users. The first application aims to reduce the therapists' burden, providing caregivers with intelligent tools to facilitate the diagnostic and treatment using physical amusing games. The second application aims at providing opportunities of controlled exercise during daily life to people that is bounded to a powered wheelchair. Both applications share a common ground: they are designed as helpers to doctors and caregivers, and their aim is to adapt, up to some degree, to the user needs. Additionally, we envisage these two applications can become

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[3] http://www.fsjd.org/ca/

shortly real products. Both applications have been tested with healthy people and the preliminary results are promising. In collaboration with two healthcare partners, these robotic applications will be evaluated in short with real patients.

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