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An Augmented Reality-based Telerehabilitation Architecture for Supporting the Training of Powered Wheelchair Users

Daniel Stefany Duarte Caetano

Uberlândia

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An Augmented Reality-based Telerehabilitation Architecture for Supporting the Training of Powered Wheelchair Users

Thesis submitted in partial fulfillment of the requirements for the degree of Doctor of Science to the Post-Graduate Program of the Faculty of Electrical Engineering at the Federal University of Uberlândia.

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“Everything begins with choice!
Matrix Reloaded - 2003”

Abstract

Many people worldwide have been experimenting a decrease in their mobility as a result of aging, accidents and degenerative diseases. In many cases, a Powered Wheelchair (PW) is an alternative help. Currently, in Brazil, patients can receive a PW from the Unified Health System, following prescription criteria. However, they do not have an appropriate previous training for driving the PW. Consequently, users might suffer accidents since a customized training protocol is not available. Nevertheless, due to financial and/or health limitations, many users are unable to attend a rehabilitation center. To overcome these limitations, we developed an Augmented Reality (AR) Telerehabilitation System Architecture based on the Power Mobility Road Test (PMRT), for supporting PW user's training. In this system, the therapists can remotely customize and evaluate training tasks and the user can perform the training in safer conditions. Video stream and data transfer between each environment were made possible through UDP (User Datagram Protocol). To evaluate and present the system architecture potential, a preliminary test was conducted with 3 spinal cord injury participants. They performed 3 basic training protocols defined by a therapist. The following metrics were adopted for evaluation: number of control commands; elapsed time; number of collisions; biosignals and a questionary was used to evaluate system features by participants. Results demonstrate the specific needs of individuals using a PW, thanks to adopted (qualitative and emotional) metrics. Also, the results have shown the potential of the training system with customizable protocols to fulfill these needs. User's evaluation demonstrates that the combination of AR techniques with PMRT adaptations, increases user's well-being after training sessions. Furthermore, a training experience helps users to overcome their displacement problems, as well as for appointing challenges before large scale use. The proposed system architecture allows further studies on telerehabilitation of PW users.

Keywords

Powered Wheelchair Training, Augmented Reality, Telerehabilitation, Power Mobility Road Test, Biosignals.

Resumo

Muitas pessoas em todo o mundo estão vivenciando uma diminuição de sua mobilidade como resultado de envelhecimento, acidentes e doenças degenerativas. Em muitos casos, uma cadeira de rodas motorizada (CRM) é uma ajuda alternativa. Atualmente, no Brasil, os pacientes podem receber uma CRM do Sistema Único de Saúde, seguindo os critérios de prescrição. No entanto, eles não têm um treinamento prévio apropriado para dirigir a CRM. Conseqüentemente, os usuários podem sofrer acidentes, pois um protocolo de treinamento personalizado não está disponível. Além disto, devido a limitações financeiras e / ou de saúde, muitos usuários não podem comparecer a um centro de reabilitação. Para superar essas limitações, desenvolvemos uma arquitetura de sistema de telereabilitação com Realidade Aumentada (RA) baseado no PMRT (Power Mobility Road Test), para apoiar o treinamento de usuários de CRM. Nesse sistema, os terapeutas podem personalizar e avaliar remotamente as tarefas de treinamento e o usuário pode realizar o treinamento em condições mais seguras. O fluxo de vídeo e a transferência de dados entre cada ambiente foram possíveis através do UDP (User Datagram Protocol). Para avaliar e apresentar o potencial da arquitetura do sistema, foi realizado um teste preliminar de três participantes com lesão medular. Eles realizaram três protocolos básicos de treinamento definidos por um terapeuta. As seguintes métricas adotadas para avaliação foram: número de comandos de controle; tempo decorrido; número de colisões e biossinais. Além disso, um questionário foi usado para avaliar os recursos do sistema. Os resultados demonstram as necessidades específicas dos indivíduos que usam uma CRM, graças às métricas adotadas (qualitativas e emocionais). Além disso, os resultados mostraram o potencial do sistema de treinamento com protocolos personalizáveis para atender a essas necessidades. A avaliação do usuário demonstra que a combinação de técnicas de RA com adaptações PMRT aumenta o bem-estar do usuário após as sessões de treinamento. Além disso, esta experiência de treinamento ajuda os usuários a superar seus problemas de deslocamento, bem como a apontar desafios antes do uso em larga escala. A arquitetura de sistema proposta, permite estudos adicionais sobre a telerreabilitação de usuários de CRM.

Palavras Chave

Treinamento em Cadeira de Rodas Motorizada, Realidade Aumentada, Telerreabilitação, Power Mobility Road Test, Biosinais.

Publications

The following are publications resulted by this work:

1. Caetano, D.S.D.; Valentini, Caroline; Mattioli, Fernando; Camargos, Paulo; Sá, Thiago; Cardoso, Alexandre; Lamounier, Edgard; Naves, Eduardo. **Proposal of an Augmented Reality Telerehabilitation System for Powered Wheelchair User's Training**. In: Journal of Communication and Information System, v. 35, p. 51-60, 2020.

2. Mattioli, Fernando; Caetano, D.S.D.; Cardoso, Alexandre; Naves, Eduardo; Lamounier, Edgard. **An Experiment on the Use of Genetic Algorithms for Topology Selection in Deep Learning**. In: Journal of Electrical and Computer Engineering, v. 2019, p. 1-12, 2019.

3. Caetano, D.S.D.; Mattioli, Fernando; Lamounier, Edgard; Cardoso, Alexandre; Naves, Eduardo. **Adaptação de uma Interface USB para Joystick VR2 aplicada ao Treinamento de Usuários de Cadeiras de Rodas**. In: Tecnologia Assistiva Desenvolvimento e Aplicação: Canal 6 - Bauru, Ed. 1, p. 267-273, 2018.

4. Caetano, D.S.D.; Mattioli, Fernando; Lamounier, Edgard; Barbosa, A. S. **O Uso de Realidade Aumentada em Treinamento de Cadeirantes por Telereabilitação**. In: Tendências e Técnicas em Realidade Virtual e Aumentada. Tendências e Técnicas em Realidade Virtual e Aumentada, v. 5, p. 102-120, 2015.

5. Caetano, D.S.D.; Mattioli, Fernando; Cardoso, Alexandre; Lamounier, Edgard. **[DEMO] On the use of augmented reality techniques in a telerehabilitation environment for wheelchair users' training**. In: 2014 IEEE International Symposium on Mixed and Augmented Reality (ISMAR), 2014, Munich, p. 329.

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List of abbreviations and acronyms

ADL	Activities of Daily Living
ALS	Amyotrophic Lateral Sclerosis
ANOVA	Analysis Of Variance
AP	Access Point
AR	Augmented Reality
ARSAWP	Augmented Reality System for the Assistance of Wheelchair People
ARTESH	Augmented Reality Based Telerehabilitation System With Haptics
AT	Assistive Technology
ATDs	Assistive Technology Devices
BVP	Blood Volume Pulse
CDA	Continuous Decomposition Analysis
EDA	Electrodermal Activity
ES	Embedded Systems
GLTF	GL Transmission Format
GPS	Global Positioning System
GSM	Global System for Mobile
GPRS	General Packet Radio Service
IADL	Instrumental Activities of Daily Life
IBI	Inter Beat Interval
ISCR	Integrated Skin Conductance Response
ICC	Intraclass Correlation Coefficient
IoT	Internet of Things
IP	Internet Protocol Address

HDMI	High-Definition Multimedia Interface
HMD	Head-Mounted Display
HMI	Human Machine Interface
HRV	Heart Rate Variability
HTML	HyperText Markup Language
HTTP	Hypertext Transfer Protocol
MVC	Model-View-Controller
NASA-TLX	Task Load Index developed by the National Aeronautics and Space Administration
OT	Occupational Therapists
PerMMA	Personal Mobility and Manipulation Appliance
PCDA	Power Mobility Community Driving Assessment
PIDA	Power Mobility Indoor Driving Assessment
PMRT	Power Mobility Road Test
PW	Powered Wheelchair
PWS	Powered Wheelchair Simulator
RT	Real-time
RT-WiFi	Real Time WiFi
RSI	Robot Service Initiative
RSNP	Robot Service Network Protocol
SCR	Skin Conductance Response
SD	Sequence Diagram
SI	Stress Index
SPR	Skin Potential Response
SSQ	Simulator Sickness Questionnaire
UDP	User Datagram Protocol

UML	Unified Modeling Language
USB	Universal Serial Bus
URL	Uniform Resource Locator
VE	Virtual Environment
VR	Virtual Reality
VRE	Virtual Reality Environment
VRSIM-2	Virtual Reality-Based Simulator-2
WebGL	Web Graphics Library
WebRTC	Web Real-Time Communication
WLAN	Wireless Local Area Network
WSTP	Wheelchair Skills Training Program

1 Introduction

1.1 Motivation

In Brazil, more than 45 million people have some motor limitation. Among these, 2.33 percent (1 million people) have a severe motor disability, according to the 2010 census (CARTILHA, 2012). Mostly are elderly people whose autonomy is seriously affected by a decline in their motor function and cognitive performance. Also, it includes individuals who have suffered a stroke or injury (ARLATI et al., 2019; CARO; COSTA; CRUZ, 2018; SCHERER; FEDERICI, 2015). According to the Census of England and Wales, carried out in 2011, 1.9 percent of the population use a wheelchair, an estimated 1.2 million people (JOHN et al., 2018). Other countries will have, proportionally, similar numbers within their population.

In this context, a Powered Wheelchair (PW) is one of the most important Assistive Technology Devices (ATDs) to aid in recovering their autonomy in performing Activities of Daily Living (ADL) and Instrumental Activities of Daily Life (AIVD) (MACGILLIVRAY et al., 2018; SCHERER; FEDERICI, 2015). However, not everybody has conditions to acquire such device (ARLATI et al., 2019; VAILLAND et al., 2019; CARO; COSTA; CRUZ, 2018).

The Unified Health System in Brazil is responsible for providing a PW for users, attending criteria established by Brazilian Health Ministry Ordinance n. 1272 through rehabilitation centers in Brazil (BRAZIL, 2013a; BRAZIL, 2013b). Although users get a simple training on the PW, it is not enough to prepare them, which leads to misuse, eventual accidents and also leads to ATDs abandon (PETTERSSON et al., 2014; BRAZIL, 2013a; BRAZIL, 2013b). Furthermore, many users face different problems to overcome their displacement of rehabilitation center like financial resources, time available and others (MITSUMURA et al., 2014).

In recent years, authors have been exploring Virtual Reality (VR) in many protocols and several safely situations(VAILLAND et al., 2019; JOHN et al., 2018; KAMARAJ et al., 2016; MAHAJAN et al., 2013). A Virtual Reality Environment (VRE) for PW driving training, which is focused only on indoor challenges are shown by John et al.(JOHN et al., 2018), Kamaraj et al. (KAMARAJ et al., 2016) and Mahajan et al. (MAHAJAN et al., 2013). A VRE with indoor and outdoor scenarios, but not yet focused in training is shown by Vailland et al.(VAILLAND et al., 2019). An important feature for these VRE's, that increase user training adherence, is the immersion level. Usually, it is related to the quality of 3D models, the number of senses transferred to the VRE, e.g., a head-mounted display

(HMD) or desktop monitor, used to preview the VRE. Although it can lead the user to have cybersickness (VAILLAND et al., 2019; JOHN et al., 2018; KAMARAJ et al., 2016). Notwithstanding, these VRE's have some limitations such as tested only with healthy users, poor quality of VR immersion, some real-world situations are not easy to reproduce, and the existence of hidden objects in some cases. When eligible users are involved, there are many causes of limitations and not every user is able to wear an HMD. Thus, an adaptive and flexible environment, that allows the therapist to set up individualized protocols and to assess users distinctly, caring about their impairments in Real-Time (RT) is needed (MACGILLIVRAY et al., 2018).

Driving performance was assessed in many different ways in presented simulators. A non-standard statistic method to asses comparative metrics among the users from each group was used by John et al. (JOHN et al., 2018). The PMRT was chosen by Kamaraj et al.(KAMARAJ et al., 2016), Mahajan et al. (MAHAJAN et al., 2013) and Massengale et al. (MASSENGALE et al., 2005) as a standard and reliable methodology (training protocol and assessment) applied for each user distinctly. Moreover, user's emotional state associated with a training session was not evaluated. Biosignals data processing allows looking for clues related to poor driving performance connected to that emotional state (AFFANNI et al., 2018; LANATÀ et al., 2014; HERNANDEZ et al., 2014; HEALEY; PICARD, 2005).

On the other hand, Augmented Reality (AR) can provide user interaction in a more realistic and intuitive way and safely (MANRING et al., 2020; BORRESEN et al., 2019; ABDALLAH et al., 2019; WIEDERHOLD, 2019; ECKERT; VOLMERG; FRIEDRICH, 2019; ZOLOTAS; ELSDON; DEMIRIS, 2018; MAULE et al., 2017; CAETANO et al., 2014). In doing so, the system augments the real world with digital information (e.g., pictures, videos, instructions, clinical data) enhancing the user's experience (BORRESEN et al., 2019). AR systems can allow a health professional to monitor users' performance visually. For example, haptic machines and wearable sensors can record quantitative information while users exercise (BORRESEN et al., 2019).

The user displacement challenge to address to the rehabilitation center has been overcome due to the advances in computer network technology, a new technique has brought the possibility of delivering rehabilitation services to users far from the rehabilitation centers. This technique — known as telerehabilitation (BARRIGA et al., 2016) has among others, the goal of extending and improving user care (LIN; SONG; MENG, 2016; BARRIGA et al., 2016). However, none work has been found in the literature, where integration of telerehabilitation and AR techniques are associated for PW user training.

Therefore, this work presents an AR-based telerehabilitation architecture developed to be used as a complementary tool for PW users training, based on the PMRT (KAMARAJ et al., 2016; MASSENGALE et al., 2005). This architecture allows a remote support by the therapist to assess, to track and to define customized protocols using virtual (static and animated) objects to be rendered in different markers. During the entire training session, user's biosignals (Electrodermal Activity - EDA and Blood Volume Pulse — BVP) were collected to assess the impacts of the different protocols on each user and provide clues related to performance improvements (AFFANNI et al., 2018; LANATÀ et al., 2014; HERNANDEZ et al., 2014; HEALEY; PICARD, 2005).

1.2 Objectives and Goals

The objective of this research is to evaluate the viability of a telerehabilitation environment with augmented reality techniques for the training of PW driving skills. To achieve this, the following goals were defined:

- To condute a literature review;
- To elucidate the main components of computer assisted rehabilitation systems, applied to PW training;
- To propose the main components to be used in each environment;
- To develop a web-server responsible for handling, measuring and saving information generated within the environments;
- To perform tests to assess the main application;
- To evaluate the solution with potential users; and
- To evaluate qualitative and emotional PW users training experience.

1.3 Thesis organization

The present thesis is composed of seven chapters, described as follows.

- Chapter 1 describes the motivation, aim, and objectives of this work;
- Chapter 2 introduces the background of the concepts used in the Presented solution;
- Chapter 3 presents related work;
- In Chapter 4 and 5 present, materials/methods, and implementation details;
- In Chapter 6, the preliminary results obtained in this research are discussed and;
- Finally, Chapter 7 presents the conclusions and future developments of this research.

2 Fundamentals

2.1 Introduction

Since 1995, many different areas of research have been cooperating with each other to define strategies, resources and services that can be developed, while reducing the problems faced by individuals who have some kind of limitation or disability (LUDY; BLUNT, 1995). Today, Assistive Technology (AT) is not only applied in local rehabilitation, but also, in the telerehabilitation process due to technology improvements (BARRIGA et al., 2016). This chapter presents the main fundamentals related to this thesis. They include: PWs, VR/AR techniques, training assessments, telerehabilitation, web server applications and embedded software.

2.2 Control of Powered Wheelchairs (PWs)

PWs are widely used all over the world by individuals with limitations. Normally, an user controls a PW with a joystick in order to move over long periods (FATTOUH; SAHNOUN; BOURHIS, 2004). For users with only lower limb limitations, joystick is presented as the basic control interface. An example of such joystick is presented in Figure 1. To define the joystick position, speed and direction values are used. Using an appropriate algorithm it is possible to define basics directions as right, left, front and back, according to Figure 2.

Figure 1 – JoystickVR2 - JSM (PGVR2, 2020)

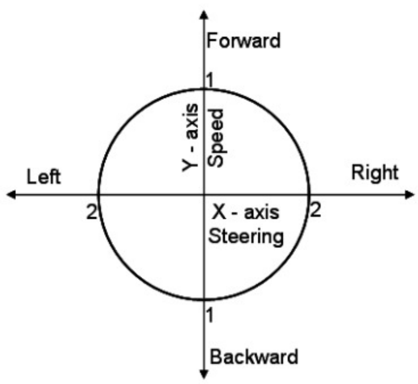

Figure 2 – Joystick axis interpretation (FATTOUH; SAHNOUN; BOURHIS, 2004)

A joystick control interface cannot fully meet the needs of the disabled and elderly person whose autonomies are seriously affected by a decline in their motor function and cognitive performance (RECHY-RAMIREZ; HU; MCDONALD-MAIER, 2012). AT, like plug-in devices (Figures 3 and 4), have been developed over the years to facilitate joystick handling by users during the training sessions or in their Activities of Daily Living (ADL) and Instrumental Activities of Daily Life (IADL)(ASSOCIATION et al., 2014; ASSOCIATION et al., 2008).

However, there is a gap in Ordinance n. 1272 defined by the Unified Health System in Brazil that describes the mandatory training, monitoring and maintenance of use, maintaining the absence of systematized protocols and standardized norms and it might expose the users to further injuries (VALENTINI et al., 2019; BRAZIL, 2013a; BRAZIL, 2013b).

Figure 3 – U-shaped joystick handle (SYP, 2020)

Figure 4 – Yellow joystick knob foam ball (PMS, 2020)

2.3 Virtual and Augmented Reality

VR and AR have been used in different situations to provide safe conditions to the user's training or adaptation phase, with different devices and control interfaces.

VR is an advanced user interface having, as main features, the ability for 3D visualization, spatial navigation and interaction in a 3D synthetic environment (CARDOSO; LAMOUNIER, 2006). In many situations, access to a physical training environment can be restricted by some constraints such as time and space. The user still can not have a caregiver to take them to a therapist center or it may be expensive to move close by (MITSUMURA et al., 2014). When such limitations are faced, VR can be used to extend availability of training environments, also bringing the training exercises to the user. The use of technology to support rehabilitation is not a new phenomenon, improvements in hardware and cost reduction increased the interest in the use of VR (WIEDERHOLD, 2019; POWELL; POWELL; SIMMONDS, 2014).

Many researches in cognitive rehabilitation have been investigating the use of VR techniques (VAILLAND et al., 2019; JOHN et al., 2018; KAMARAJ et al., 2016; MAHAJAN et al., 2013). Among the main characteristics of these environments, there is the preservation of physical integrity of the user and training assessments. However, some users notice some difficult when using these systems. They face some limitations concerning the immersion that these environments offer.

AR optimizes the user experience since it creates an altered reality without losing the benefits of the physical setting (WIEDERHOLD, 2019). In the study conducted by Ines (2011), the use of AR techniques has proven to enhance user motivation and acceptance in many different situations (INES; ABDELKADER, 2011).

For instance, in work presented by Manring et al. (MANRING et al., 2020), an augmented training environment was created using Microsoft Hololens for controlling an interactive robot. Robots intervention is considered a high-risk task where practiced remotely by technicians or doctors. Robots are force-feedback devices that are not easy to operate, require high control accuracy, and also require extensive training by operators. For this reason, AR techniques were implemented to reduce the amount of training and increase the user skill to control the robot. Among the control, methods are: manual and automatic. The user can move the end effector of the holographic robot, and the physical robot will respond immediately, in manual control. Otherwise, the user can move the end effector of the holographic robot to the desired location, view a holographic preview of the motion, and select execute if the motion plan is satisfactory, using automatic control. Figure 5 illustrates on *left* side: “The physical robotic arm has just moved to the position of the holographic arm” and on *right* side: “Previewing motion operation”. It is possible to customize the AR rendering using fiducial AR markers or not.

Figure 5 – *Left*: “Automatic” - *Right*: “Manual” modes by (MANRING et al., 2020)

Silva (2011) developed a distributed environment using AR techniques (SILVA, 2011). A shared AR environment is an exciting feature to be used in telerehabilitation situations. Thus, the user and therapist can interact at the same time with the environment making the user evolves more effectively.

2.4 PMRT training assessments

In any rehabilitation/training process locally or remotely, to assess user performance is essential to be related to driver skills improvement (MACGILLIVRAY et al., 2018). This evaluation process can be either carried out automatically or not (JOHN et al., 2018; MASSENGALE et al., 2005). In the automatic method, a (statistical) calculation is performed based on the process metrics, without the intervention of the health professional(JOHN et al., 2018). Or in non-automatic method, the health professional who holds the user's clinical information assigns a score, based on standard parameters (MASSENGALE et al., 2005).

Another important aspect in the evaluation process is to verify if it is performed in an interpersonal or intrapersonal way. The PMRT defined by Massengale et al. (MASSENGALE et al., 2005) is a standard and reliable methodology (training and evaluation protocols) applied to each user (intrapersonal way) in a different way. The PMRT consists of 2 groups of tasks: structured and unstructured. The 12 structured tasks are predictable. The 4 unstructured / dynamic tasks are unpredictable and require the user to make decisions about interacting with the environment, such as avoiding a person walking down the corridor or avoiding a therapy ball on the way (MASSENGALE et al., 2005). The user is considered approved in a training protocol when he/she reaches a score higher than or equal to 95%. All tasks assessed in the PMRT are based on visual perception of the professional in charge. Before attribute a task score, the health professional has to be aware of the following rules:

- 4 - Completely independent: optimal performance: able to perform task in one attempt smoothly and safely;
- 3 - Completes task hesitantly, requires several tries, requires speed restriction, and/or bumps wall, objects, etc. lightly (without causing harm);
- 2 - Bumps objects and people in a way that causes harm or could cause harm to driver, other persons or to objects;
- 1 - Unable to complete task: reason: For example, may require verbal and/or visual cues or physical assistance.

2.5 Telerehabilitation

As defined in (DEUTSCH; LEWIS; BURDEA, 2007), "telerehabilitation is the provision of rehabilitation services (evaluations and interventions) at a distance by therapists at a remote location". Over recent years, telerehabilitation technology has been developed seeking to address some issues related to classical in-clinic treatment (PANI et al., 2014;

POSTOLACHE et al., 2011). Among these issues, one can highlight the one presented in Figure 6, which is the availability of the physical environment (and equipment) and the time and expenses associated to users and therapists displacement (BRENNAN et al., 2011; HOLDEN; DYAR; DAYAN, 2007; DHURJATY, 2004).

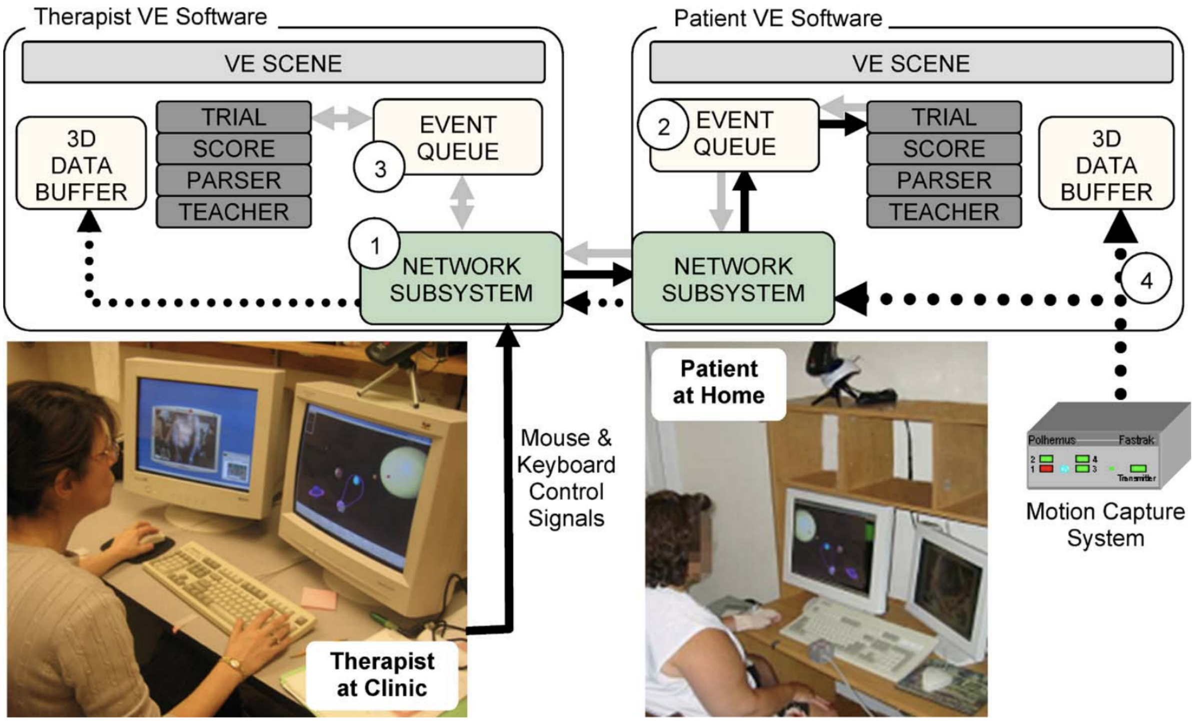

Figure 6 – Virtual telerehabilitation system (HOLDEN; DYAR; DAYAN, 2007)

Telerehabilitation technology can be used to improve existing rehabilitation protocols. Since many standard treatments include a high number of repetitive exercises, users are required to perform additional exercises at home, without the supervision of a therapist (ORTIZ-CATALAN et al., 2014). In these cases, telerehabilitation software can be used to provide the therapist with valuable feedback. As stated by (ORTIZ-CATALAN et al., 2014), “the monitoring of quality and quantity of home-based rehabilitation interventions can potentially have a large positive impact on the quality and adherence to long-term treatments and rehabilitation outcomes” (PONS; TORRICELLI, 2014). Finally, it is important to mention that telerehabilitation applications run over pure network (UDP or HTTP – Hypertext Transfer Protocol) protocol sockets (LEUNG et al., 2007).

2.6 Web server applications

Currently, with the intensive use of Internet, fast development of web technologies and high-performance computer hardware, building web sites and constructing software systems on the web are dominant trends in the e-commerce industry (ATTITALLA; CHOKSI; POTDAR, 2016; ZAMBONELLI, 2016; LAINE et al., 2011; STROULIA, 2001).

Web server-based approaches allow controlling devices and appliances remotely. Two methods are being used: one is to develop an embedded web server using dedicated hardware, and the other is to use Cloud-based services and develop the application on it, without the need for hardware, latency or network failure (ATTITALLA; CHOKSI; POTDAR, 2016).

Researchers (TILLEY; HUANG, 2001) classify web sites architectures in three categories, according to their level of complexity, interactivity and functionality:

- Static: plain HyperText Markup Language (HTML) web sites;
- Interactive (Front-end side): dynamic HTML plus some scripting programs (e.g., JavaScript); and
- Dynamic (back-end site): powerful server-side systems that can generate web contents dynamically.

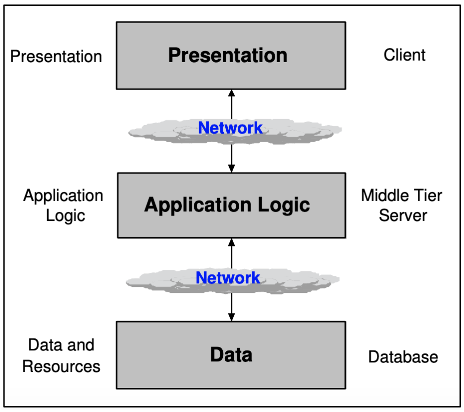

Figure 7 – A typical three-tire architecture (SUN; WONG; MOISE, 2003)

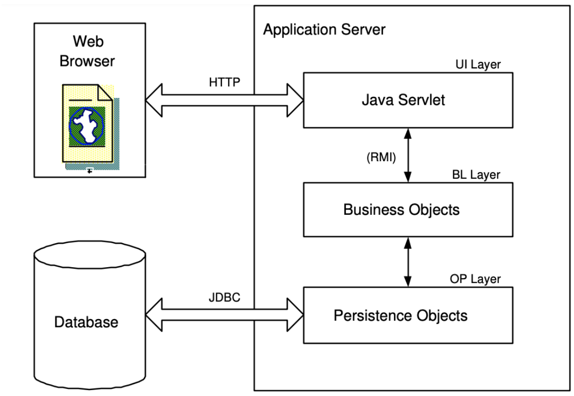

Figure 8 – The first version architecture (SUN; WONG; MOISE, 2003)

The dynamic web application architectures presented in Figures 7 and 8 allows one to:

- Manage image/videos streams in order to provide a powerful visual feedback from user;
- Establish different channels to receive/redirect all different kinds of data coming from different user control interfaces;
- Save all data generated during user experience allowing for the processing of this data creating indicator measurements across the acquired evolution and;

- Operating system and platform independence, as long as it is supported in the browser.

Throughout the web server features, it's possible to develop a cross platform application which can be accessed for everyone from different places in the world. Different modules can be implemented based in Java Servlets. Each kind of data from different devices all over Internet, can be handled for different modules. For instance, video stream manager to visualize different physical places, store different real time data to generate reports (ATTITALLA; CHOKSI; POTDAR, 2016; KOVATSCH; MAYER; OSTERMAIER, 2012; LORETO; ROMANO, 2012).

2.7 Embedded Systems (ES)

Until the late eighties, information processing was associated with large mainframe computers and huge tape drives (MARWEDEL, 2010). During the nineties, this shifted towards information processing being associated with personal computers. The trend towards miniaturization continues and the majority of information processing devices will be small portable computers integrated into larger products. These portable computers are called Micro-controllers.

A Microcontroller is a self-contained system with peripherals (input and output devices), memory, timers, externals interrupts, digital-analog conversions and a processor that can be used as an Embedded Systems as shown in Figure 9. Thus, Embedded Systems are information processing systems embedded into an enclosed product (MARWEDEL, 2018). Microcontrollers are present in many different products, such as, phones, peripherals, automobiles etc.

These features is strongly necessary in the AT area. For example, an important requirement is to allow for different protocols to establish communication between embedded devices and computers, such as wireless, Ethernet and Internet.

Nowadays, there exist many different kinds of Microcontrollers. Each has it own specific hardware definition, libraries and models, for example, Arduino CC[1] and Microchip[2].

2.8 Final remarks

This chapter covers essential concepts to this thesis development. It takes into account the necessary adaptations to the users' limitations, when dealing with the PW

[1] Arduino website: https://www.arduino.cc/
[2] Microchip website: http://www.microchip.com/

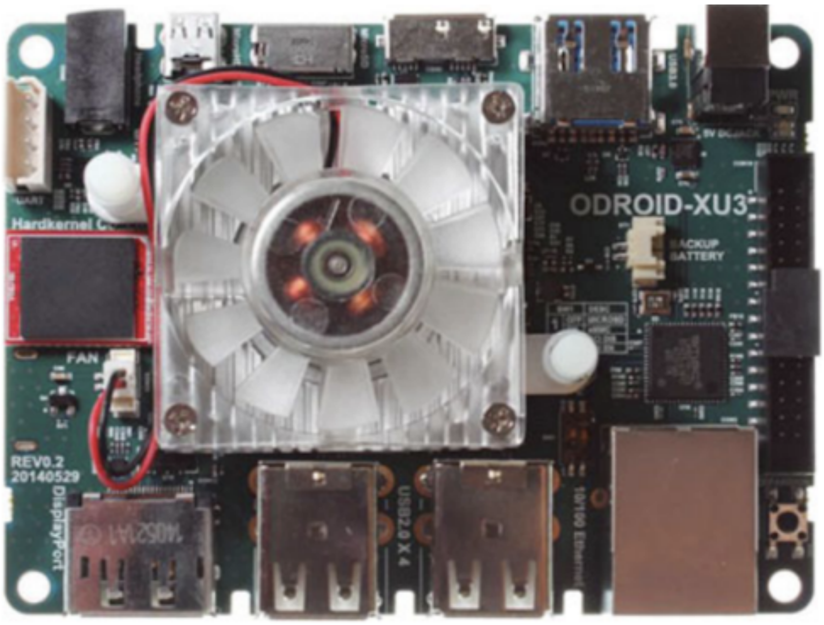

Figure 9 – Odroid XU3 ES - designed to space exploration (MARWEDEL, 2018)

control interfaces and also the lack of resources/difficulties to travel to the training centers. Presented technological subjects (software/hardware) helps to trigger the PW remotely and also, to collect and transmit control signals. In addition, it also discusses how to develop a safe and adaptative training environment using AR or VR techniques. Moreover, it has been pointed up the relevance to evaluate the user's performance during the sessions. These fundamentals give support to understand how to develop, integrate, and share the resources to be accessed by users from anywhere by needing only Internet access.

Next chapter presents related work considering Telerehabilitation applications and systems supported by VR and AR technology for the training of PW user

3 Related Work

3.1 Introduction

This chapter presents studies from the literature about telerehabilitation, PW training, assessment, real-time training and AR. The objective is to identify the state of art in this area, by evaluating the main features of each work.

At the end of this chapter, a related work comparative study is discussed in order to justify the proposed system.

3.2 Augmented Reality

3.2.1 Innovative Real-time Navigation Assistance to Wheelchair Users

The RT navigation assistance mobile application was developed by Abdalla et al. (ABDALLAH et al., 2019) to afford wheelchair users with motor disabilities mobility assistance, which consists of guiding them from a source point to a desired destination.

Based on the user needs, the authors developed the Augmented Reality System for the Assistance of Wheelchair People (ARSAWP), which gives an augmented touch to accessibility information as presented by Figure 10. It also allows for remote monitoring capabilities of such users.

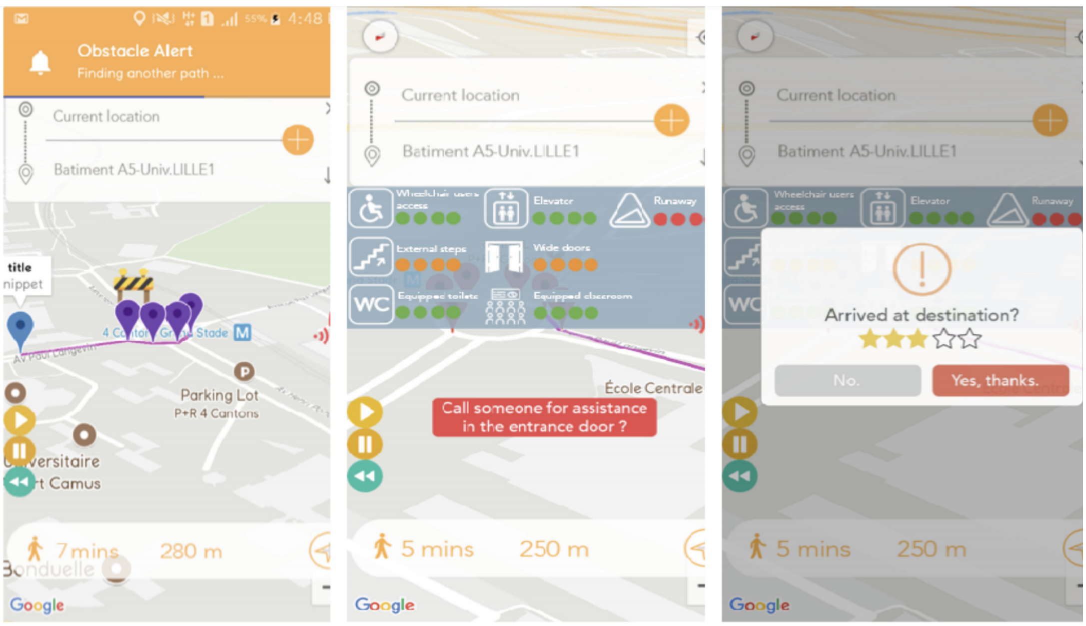

Figure 10 – Navigation system interfaces preview (ABDALLAH et al., 2019)

The ARSAWP gives them a glimpse of accessibility information concerning the desired destination whether it is accessible, accessible with assistance or not accessible at all, according to his current location. After the user has chosen their destination, the ARSAWP creates a RT accessibility graph based on the user's Global Positioning System (GPS) coordinates and the area cartography supported by an innovative Dijkstra algorithm. The ARSAWP notify the user when an obstacle is detected on the way. Then, the ARSAWP reroutes to another obstacle-free path. Obstacles already reported by other users are included in the obstacles management system to notify wheelchair users the presence of potential obstacles. ARSAWP handles a real-time display of obstacles and paths on a map using Google Maps Application Programming Interface (API).

In this case, it is observed that the AR techniques are useful by guiding the wheelchair user, improving the activities of daily living. This technique increases the user's traveling journey due to virtual information visualized. Features like these can be exciting in the process of training of PW users.

3.2.2 Head-Mounted for Explainable Robotic Wheelchair Assistance

Robotic wheelchairs controls have been improving with a wide range of unconventional input methods, such as brain-machine interfaces and head motion. Also, improvements in navigational assistance algorithms have contributed to bettering user technology integration for powered mobility, as opposed to traditional joystick control. The lack of sensorimotor capacity to steadily navigate an environment, using a standard joystick-controlled wheelchair, had shown up the necessity to engage shared control.

Although these features are added to ensure user safety, they may disorient or frustrate the user hindering user's ability to learn how to navigate a wheelchair and thus leading to their failure to acquire ownership of these mobility platforms. The AR HMDs have recently gained attention as training simulators for off-line learning of wheelchair control. However, AR HMDs can potentially serve as a more transparent mode of communicating assistance, but still have to be integrated into physical wheelchairs for on-line operation.

Based on the difficulty that severely disabled individuals present to build a mental model of their robotic wheelchairs behavior under different environmental conditions, Zolotas et al. (ZOLOTAS; ELSDON; DEMIRIS, 2018) proposed this work as shown in Figure 11.

Where:

1. Composite image of the visualisations rendered on the user's view through the AR headset;
2. The grey path shows the trajectory generated by the user's manual input;

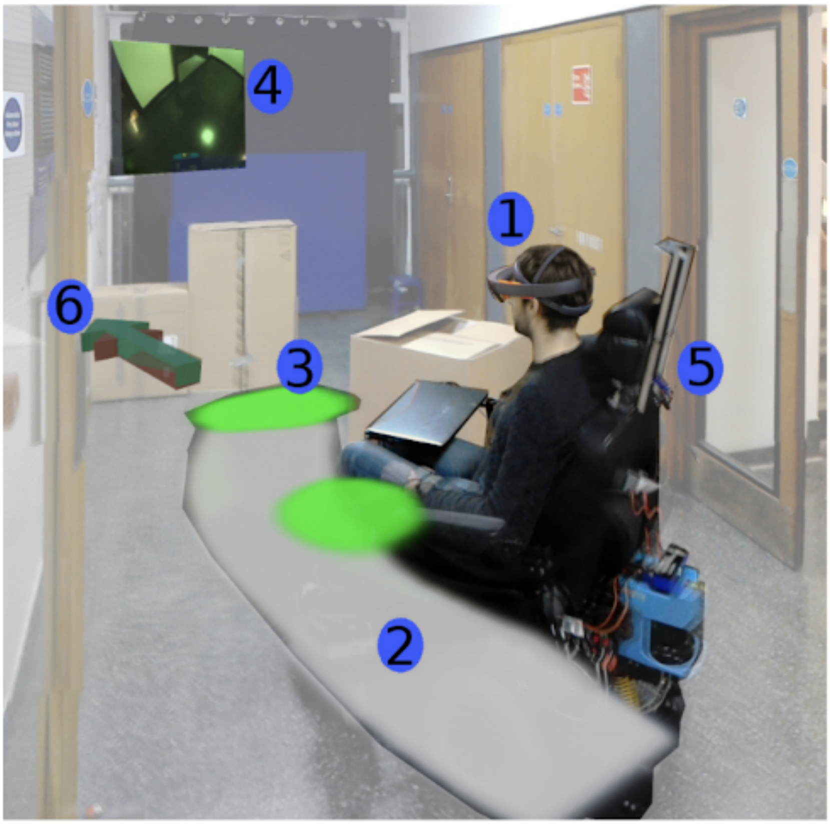

Figure 11 – Hololens AR system (ZOLOTAS; ELSDON; DEMIRIS, 2018)

3. The green patches highlight objects that pose as potential collisions;

4. The rear view display captures;

5. The camera image mounted on the back of the seat which includes overlaid graphics, such as the path and obstacle cues; and

6. The green and red directional arrows represent the user's raw input and the corrected output, respectively.

To explore the assistive effects of AR on wheelchair control, 16 non-disabled participants in where they were invited to complete a navigation route four times, in sequence. The author's findings show the integration of AR HMDs with robotic wheelchairs, brings benefits. For instance, the rear-view display yielded enthusiastic participant responses by presenting helpful information to users at a comfortable and non-intrusive viewing angle, as long as certain design choices are taken into account.

The Microsoft Hololens was used in this case as an immersive way to augment the user experience and to highlight the benefits of AR techniques into the wheelchair users ADL. Nevertheless, the Microsoft Hololens is only capable of enriching the 3D real environment where the user is and not a remote one. It might represent a constraint, once many users are not able to address to a rehabilitation center and need telerehabilitation to support them to achieve it.

3.2.3 Augmented Robotics for PW to Enhance Mobility

A robotic framework able to plan and control a part of the route according to a normal HMI based on AR is proposed by Maule et al. (MAULE et al., 2017).

Indeed, mobile robotics is an important discipline that provides autonomous systems from medicine to industrial applications to support humans' needs. AT like PW has a considerable impact on the quality of life of users affected in their mobility due to spinal cord injuries or degenerative diseases as Amyotrophic Lateral Sclerosis (ALS). Many of these users need a caregiver to help them in there ADL, but it doesn't improve their self-esteem. In order to improve their autonomy, different AT has been developed to reduce this feeling such as a joystick, keyboard, breath or eye tracker to control the PW. In most severe cases, as mention before, the users get very tired for being focused on the screen the whole time. Moreover, not all disabled people have the possibility to adapt their house increasing the challenges.

The semi-autonomous HMI developed with AR techniques to control the PW brings great benefits to relieve the user during difficult maneuvers. The proposed AR-based application presented in Figure 12, is able to recognize points of interest (POIs) presented and recognised by fiduciary AR markers from the Kinetic V2.0.

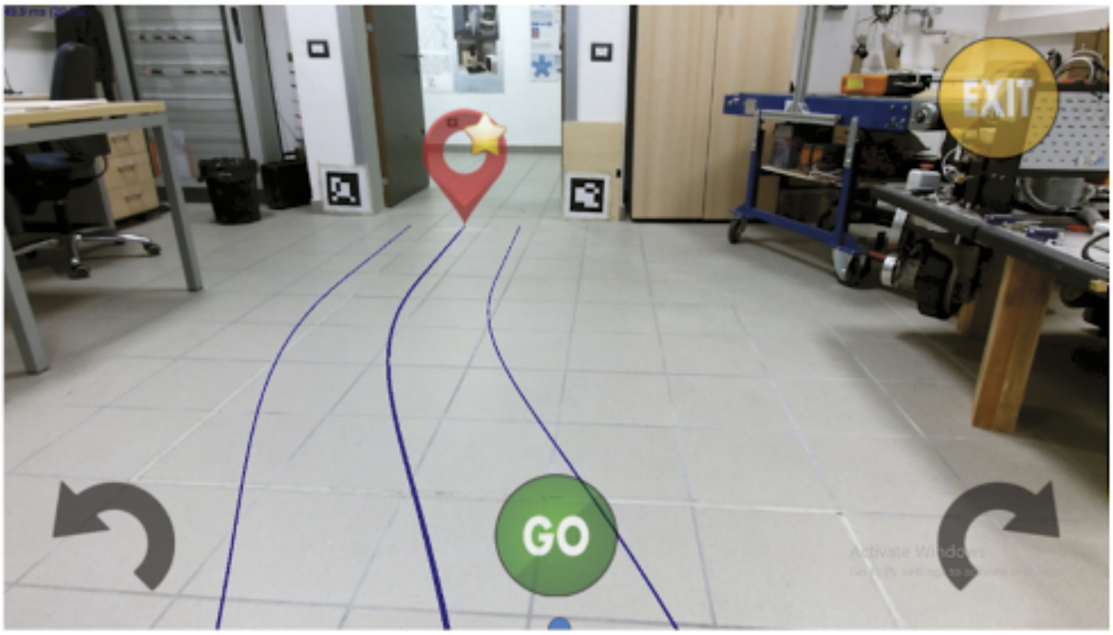

Figure 12 – HMI for the control of the wheelchair (MAULE et al., 2017)

When a POI enters in the field of view of the camera, the user can select it by his/her eye movement captured by TOBII EyeX (eye tracker). To start the semi-autonomous maneuver, the user must explicitly select the POI by gazing it for 3 seconds.

Based on the semi-autonomous system's main features, the authors realize some future issues to be implemented from the preliminaries tests. The AR techniques used to increase the user's experience during their activities doesn't present any failure based on Kinect V2.0 used as a camera. However, they realized the need to implement an on-line calibration process to Kinect before start using the system to reduce the position failures during the long periods of use.

Among the various characteristics, AR takes advantage of all the information in the real world and uses it to benefit the enrichment of the user experience. With the rendering of virtual objects on the fiducial markers, the user can interact with the existing POIs with their eyes. By activating the semi-automatic system to reduce their efforts or to control the PW through the options displayed on the screen. The HMI used in this work can in the future be incorporated into user training systems for PW and, with the use of telerehabilitation techniques, he can do distance training through a AR semi-immersive, using a monitor.

3.3 PW Training

3.3.1 Multisensory PW Simulator for Training and Rehabilitation

A multi-sensory PW Simulator (PWS) platform that provides visual, auditory and haptic feedback, as well as motion cues, is presented by Vailland et al. (VAILLAND et al., 2019). Adaptive features of the framework allow integration with HMD, immersive rooms, single screens and the integration of add-ons and configuration adjustments to meet the individual needs of users. The authors aim to provide a realistic wheelchair driving experience for training and skill transfer to real-life situations.

The framework requirements were defined based on challenges lived for people experiencing mobility in where the PW driving is a challenging task that requires good visual, cognitive and visuospatial abilities. Occupational Therapists (OT), physiotherapists and neurologists analyzed the suggestion form filled out by the users from the Pole Saint Helier Physical Medicine and Rehabilitation Center to better highlight the features (VAILLAND et al., 2019).

Two 3D scenes (outdoor and indoor) were respectively reproduced based on "Rennes Metropole"(Figure 13) and "Pole Saint Helier"(Figure 14) using the widespread 3D engine Unity3D to visually render 3D scenes. VR techniques were chosen to better fit with the motion platform used to truly reproduce the kinematics and the controllers increasing the Sense of Presence (SoP).

Figure 13 – Outdoor scene (VAILLAND et al., 2019)

Figure 14 – Indoor scene (VAILLAND et al., 2019)

The integration tests were performed and the authors considered the current issues to be addressed futurely, such as:

- Setup limitations regarding motion feedback to control all 4 DoF and to enhance the simulator kinematics in order to handle interactions with the environment such as bumps, vibrations and collisions; and
- The Virtual Environment (VE) to provide visual feedback and also to populate 3D scenes with dynamic entities such as avatars, vehicles, etc.

Further, the clinical assessment with PW users to evaluate the impact of the various feedback modalities provided by the simulator on SoP and cybersickness has to be assessed.

Although VR is widely used in simulators, it is not easy to adjust the platform implantation to increase the user SoP. On the other hand, in an augmented controlled room with real physical objects, static and animated virtual objects, a therapist can fit individuals protocols better. Thus, the user is able to have a natural and realistic training process and using telerehabilitation techniques he/she doesn't need to move to a rehabilitation center.

3.3.2 Protocol for driving a PW using RV

The Unified Health System and the centers are responsible for the concession and dispensing services of AT equipment, such as, for example, the PW.

For this, one must consider some eligibility criteria for PW prescription and training, in order to guarantee the safety and autonomy of the AT user, to avoid the abandonment of the equipment and their exposure to accidents during their ADL. In fact, during these activities, there are unforeseen situations that require specific maneuvers in the PW, limiting their social participation and the recovery of their independence.

VR its being used widely in many different situations in medicine areas for training purposes in past years (VAILLAND et al., 2019; JOHN et al., 2018; KAMARAJ et al., 2016; MAHAJAN et al., 2013). For this reason, Valentini et al. (VALENTINI et al., 2019) present a comparative study, split into two groups. One performs first in a VE (Figure 15) with audible warnings for each task accomplished and then the real protocols scenery (Figure 16). The other carries out a set of protocols in real scenery.

Figure 15 – VR intervention training (VALENTINI et al., 2019)

Figure 16 – Real intervention training (VALENTINI et al., 2019)

The study carried out brought up many considerations, such as:

- The users who underwent VR through intervention showed better development in the execution of the tasks in comparison to the real interventions;
- Users reported difficulties in using the simulator, as they felt lost during the performance of each set of tasks, despite the sound signals as the activities were completed;
- Others considered it strange to perform activities on a sports court;
- It was not possible to meet the needs of each user individually; and
- Users reported that the design of some scenarios should be improved, suggesting clues with better realism, with objects and obstacles better distributed.

Based on considerations made by users, it is noticeable that VR environments still have limitations, such as non-adaptive scenarios and ineffective realism. All of these limitations could easily be addressed using AR techniques. The protocols could be defined in real-time, through the previous selection of the animated or static virtual objects that would compose a series of tasks and also, use arrows to guide the user during the tasks.

Finally, the use of telerehabilitation techniques and distributed systems would make the user experience even easier, since he could remotely connect to the system by performing the actions proposed remotely by the therapist.

3.3.3 Virtual Environment for Training PW Manoeuvres

Learning the necessary driving skills can be a daunting task, particularly for individuals with severe, or multiple motor limitations (RODRIGUEZ, 2015).

Despite VR has been utilized in various training scenarios, previous research appoints that price and technology limitations have been a barrier to commercial adoption. In contrast, affordable, high fidelity interfaces for VR such as the Oculus Rift HMD are now becoming readily available.

Based on these facts, John et al. (JOHN et al., 2018) present a more intuitive, immersive VE for training users of PW that can easily be deployed and in which a new user of a PW can quickly learn how to operate it.

The authors do not attempt to reproduce reality, rather they use abstract tasks. Figure 17 present on the left: go through doorway and on right: traverse a circle and reach out to press a light switch. Figure 18 shown on the left: slalom and on the right: reverse parking. These components task helps to develop the same skills required and used during PW navigation.

Figure 17 – Task components (a) (JOHN et al., 2018)

Figure 18 – Task components (b) (JOHN et al., 2018)

For the first test, thirty-three able-bodied volunteers were randomly divided into three groups of eleven:

- A Control group who would receive no training;
- A group wearing the "HMD" (Figure 19) having an immersive experience with PW-VR application; and
- A "Desktop" group who also uses PW-VR, but just with a desktop monitor having a semi-immerse experience, as presented by Figure 19.

From the experiments performed the authors realizes:

- The learning acquired in the HMD-based VR environment was transferred to the physical world; and
- There is a benefit in using a VR-HMD simulator for training wheelchair users, in terms of navigation performance improvement.

However, results from the SSQ (Simulator Sickness Questionnaire) indicate that cybersickness, the mismatch between physical and virtual motion in PW-VR for the HMD group, is a problem, even with a relatively short training session (KENNEDY et al., 1993).

The main focus of this work is to assess whether driving a PW skill increasing through an VR environment, using a HMD. As reported by the authors, no real volunteers were invited and it was not yet the focus of the work to assess the real challenges experienced by users. However, depending on the level of limitation of eligible users, not everyone will be able to use HMD and there is also the cybersickness effect that can be solved using

Figure 19 – VR training environment (JOHN et al., 2018)

AR techniques. Adapting tasks in VR environments to the needs of real users is still a challenge. In addition, these users may have to go to a rehabilitation center. In this way, the use of telerehabilitation techniques may allow the sharing of the environment between therapists and users through the Internet, reducing this need.

3.4 Training assessment

3.4.1 Protocol for driving a PW using VR

Looking for best practices concerning training methodology and assessment tools, Valentini et al. (VALENTINI et al., 2019) studied the works proposed by (JOHN et al., 2018; MARTINS et al., 2017; NUNNERLEY et al., 2017; TORKIA et al., 2015; MAHAJAN et al., 2013).

John et al. cite john 2018 presents the statistical training results between each of the groups of healthy participants through a one-way Analysis Of Variance (ANOVA). Nunnerley et al. (NUNNERLEY et al., 2017) have developed an immersive VR training system to build driving skills to eligible participants. Among them are, clinicians and experts PW users with Spine Cord Injury (SCI). Only the VE features were assessed. Due to limitations found, such as nausea and lack of VE realism that leads to minor training adherence, participants' training evolution was not performed. Martins et al. (MARTINS et al., 2017) and Mahajan et al. (MAHAJAN et al., 2013) used the PMRT to assess users' performance as shown in Figure 20. Torkia et al. (TORKIA et al., 2015) brings up qualitative information about PW users' perspective, which is very important when it is decided to developed some technological solution to these users.

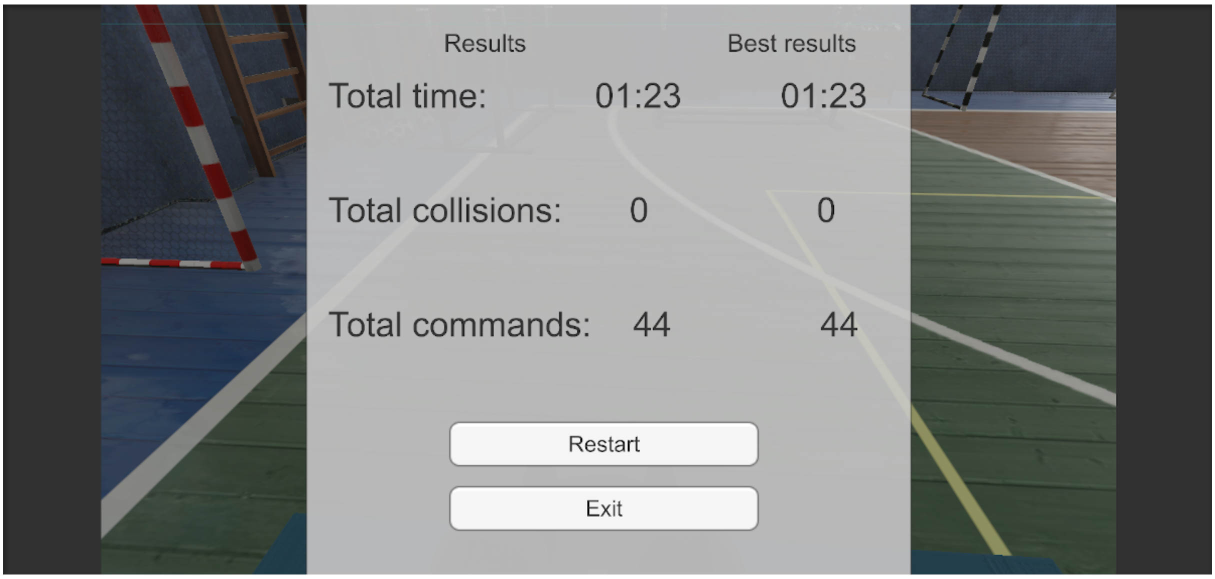

Figure 20 – Results screen presented to the user (MARTINS et al., 2017)

Based on these previous work fundamentals, the authors have decided to use the PMRT, Power Mobility IndoorDriving Assessment (PIDA) and the Power Mobility Community Driving Assessment (PCDA) to cover critical aspects of evaluation and activities present to the users (DAWSON; CHAN; KAISERMAN, 1994). Some important feedback come from (VALENTINI et al., 2019) research, like:

- Many felt tired after the continuous execution of 12 of the 16 PMRT activities; and
- The activities set was not individually fit to the participants.

Even applying an adaptation on PMRT, the users felt tired after the trials, and it was recognized, based on eligible participants, that not all of then were prepared to face some challenges established by PMRT. These observations have to be considered into the development of future training systems taking advantage of professionals' expertise to better fit individually training tasks and evaluate users' performance. Finally, Figure 20 presents a metrics summary of the user performance at the trial moment. Nevertheless, the system offers the therapist an overall graphic of user metrics evolutions, which is very important to have an user evolution reading, across the trials.

3.4.2 Virtual Environment for Training PW Manoeuvres

John et al. (JOHN et al., 2018) present a more intuitive, immersive VR environment for training PW users, where the main focus is to prove that VR training intervention affords before real PW use.

ANOVA is applied to verify how significant the variance among the number of samples is. So, applying it on a data set, it's possible to check which are the relevant training metrics, according to the participants' skills.

The user evolution evaluation was obtained through the difference between each of the related metrics during each protocol performed. Such assessments come from the post-processing of the data collected. However, for an individual assessment, it's not desired and can not be accessed instantly using bar charts, that highlighting the participant's growth history. Comparative statistical analysis is essential for the scientific community, because it allows general analysis and cross-checking of information, but not from a single individual in a real-time telerehabilitation system.

3.4.3 Improving individualized PW skills training satisfaction

The World Health Organization identified that "user training" is a key requirement in the service delivery model of wheelchair provision (ORGANIZATION, 2020).

As a result, a lack of appropriate instruction leads to an ineffective use or even abandonment of wheelchairs and doesn't help the PW user who may struggle to use their mobile devices independently (PETTERSSON et al., 2014). Tips and falls are the leading cause of injuries among PW users and it emphasizes the need for improved training opportunities to ensure that PW is used safely to their full capacity (GAAL et al., 1997; XIANG; CHANY; SMITH, 2006).

MacGillivray et al. (MACGILLIVRAY et al., 2018) work aims to test the hypothesis that PW mobility-related goal satisfaction improves following five Wheelchair Skills Training Program (WSTP) training sessions and improvements are retained 3 months post-training.

Seventeen PW users were submitted to five 30-min individualized, one-on-one, WSTP sessions at a targeted frequency of 1–2 sessions/week. Training occurred at the participant's choice of location. Trainers helped participants to create PW mobility-related goals following WSTP (version 4.1) intervention and all goals set were required to have a mobility-related component (KIRBY, 2008). Goals strictly based on wheelchair maintenance would not have been accepted.

Approximately, 5–10 goals were created over the course of the training. Upon setting each goal, participants in the current study were asked to report their goal satisfaction –

“how would you rate your current satisfaction with your ability to perform that goal on a scale from 0 to 10 with 0 being ‘not satisfied at all’ and 10 being ‘extremely satisfied’?” (MORTENSON; MILLER; MILLER-POGAR, 2007). The one-way ANOVA was used to determine changes in the goal satisfaction scores.

The authors concluded that goal satisfaction following the WSTP improved years after initially learning how to operate a PW. The five training sessions were effective in improving goal satisfaction. A considered conclusion was that participants’ goal satisfaction scores were not significantly correlated with goal attainment scores recorded by the trainer, but mainly in meeting their needs.

It’s not only the lack of technology quality applied to define a toolkit for PW users training that reduces the user adherence of the training, which leads to injury risk and TA abandonment. But meeting the PW user needs is an essential target in practice. Based on the clinical information and interview rises, the therapist knows how better guide this user through the driving skill improvement, enriching their well being and independence to realized their ADL activities.

Thus, this study reinforces that to increase the adherence of any training process, to reduce AT abandon, it’s essential to care about user’s expectations, what they are prepared to do. For a telerehabilitation architecture that aims better-fit tasks by supporting PW user’s training, adaptative features are mandatory.

3.4.4 Driver’s stress detection using Skin Potential Response (SPR) signals

Car driving induced stress has a large impact on people’s wellness and can affect the way how they execute their activities. Being exposed to stress, can incurring car accidents (ZHENG et al., 2015). The problem of automatic detection of car drivers’ stress levels has become increasingly important, due to its impact on people security, and more generally on people’s health and well-being.

Two approaches have been developed in order to detect stress: the first is based on physical measurements and the second is based on physiological measurements (GREENE; THAPLIYAL; CABAN-HOLT, 2016). Among the various techniques proposed for stress detection, EDA monitoring is particularly interesting to gain information about the inner stress affecting a person, due to its correlation with the sympathetic nervous system response.

Affanni et al. (AFFANNI et al., 2018) propose a scheme based on EDA/SPR measurements show that, by appropriately processing EDA/SPR signals only, it is possible to efficiently locate stress events during driving. The authors propose an experimental setup, as shown in Figure 21 that allows defining a ground-truth for stress events recognition, and which confirms the validity of the proposed approach.

Figure 21 – A picture of the test setup (AFFANNI et al., 2018)

Tests were conducted in 15 subjects healthy conditions and with average driving experience. The experiments reveal it is effectively-identified stress triggers. The SPR signals can exhibit a complex behavior as noted by other authors, which can make it challenging to associate peaks with stressing events unambiguously.

Toward a PW training system, it is important to defined a reliable assessment methodology to better evaluate the user evolves during the trials. However, without a biologicals measure like stress level, the therapist can not track possible emotional reasons for the user is not evolving or performing well in some tasks. This approach brings a different look to the user's training towards their individualities, increasing the chances of success in enhancing their skills in driving the PW.

3.4.5 Interrater Reliability of the PMRT in the VR

The injuries and accidents rate of PW users has increased in recent years, because the number of PW users also increased (WOROBEY et al., 2012). This has intensified the need for better assessment and training programs for new PW users (KIRBY et al., 2015). The available driving assessment tools presented have clinicians with several obstacles, when assessing the ability to drive and train PW users to be time-intensive and non-standardized (CORFMAN et al., 2003). It's hoped that driving simulators may meet this need for better assessment and training (HOGAN; STERNAD, 2009).

A Version 2 of the Virtual Reality-based Simulator (VRSIM-2) is presented by

Kamaraj et at. (KAMARAJ et al., 2016) to provide a safe environment, where new users can improve their PW driving skills. The main objective of the VRSIM-2 is to be an effective PW simulator in administering the PMRT within a VE. In order to check this efficiency, a statistical analysis based on the clinician's or health professional score attributed to the PW user training tasks performed, called the Intraclass Correlation Coefficient (ICC), is used. The ICCs values is interpreted as: low (ICC<50%), moderate (50% - 75%), and high (75%).

To assess the ability of VRSIM-2 to achieve this goal, PMRT scores were used as a subjective measure of physicians' response and the Task Load Index developed by the National Aeronautics and Space Administration (NASA-TLX) was used as a subjective measure of users response as they interacted with different interfaces (RUBIO et al., 2004). Figures 22, 23, 22 represents the environments first-person viewpoint training condition. The HMI existent are the customised joystick (Figure 23), encoders on rollers (Figure 22) and PW joystick.

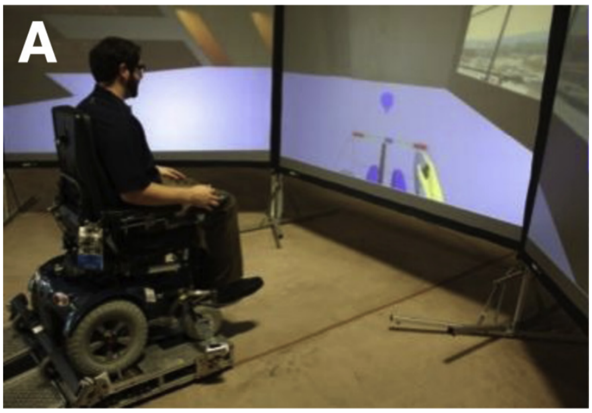

Figure 22 – VR display and rollers (KAMARAJ et al., 2016)

Figure 23 – Desktop VR screen and joystick interface (KAMARAJ et al., 2016)

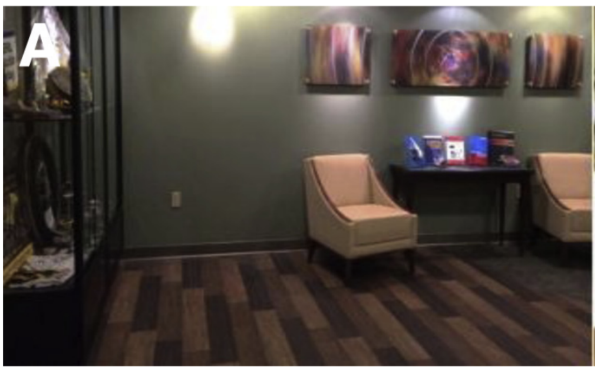

Figure 24 – Real-world office lounge (KAMARAJ et al., 2016)

Based on theses features, five different driving conditions were defined:

1. Desktop VR, rollers off and customised joystick interface controller;

2. Desktop VR, rollers on and encoders on rollers interface controller;
3. VR display, rollers off and customised joystick interface controller;
4. VR display, rollers on and encoders on rollers interface controller; and
5. Real-world scene, no rollers and PW joystick interface controller;

Experiments were conducted in 21 PW athletes recruited from the 31st National Veterans Wheelchair Games where each one perform all conditions. From a group of 5 clinicians, 2 rates were randomly select to evaluate each participant.

The authors' results show that the PMRT had high interrater reliability between the two raters in all five driving conditions. Also, PMRT had a high interrater reliability in conditions 1 and 4 and could be used to assess PW driving performance virtually in VRSIM-2.

Results present that the PMRT is a good methodology for the users' training assessment using a telerehabilitation system. Thus, different health professionals, even apart, may contribute equally with their results that can be used in the future for the scientific community based on a stable and reliable database.

3.5 Telerehabilitation

3.5.1 AR Based Telerehabilitation System With Haptics (ARTESH)

Borrosen et al. (BORRESEN et al., 2019) describes the features and utility of the system ARTESH which allows the sense of touch and direct physical musculoskeletal examination during a synchronous consultation. To reach an augmented experience presented by Figure 25, the authors equipped each site with two Xbox Kinect, one haptic controller, a 3D-capable TV, active 3D-glasses, and a computer. Thus, the 3D information collected by Xbox is rendered in real-time on 3D-glasses.

A pilot study with twenty volunteers evaluated the usability of the system (SCHUTTE et al., 2012). Among them, five healthy physicians and fifteen subjects referred to hospital-based PM&R clinic with a chief complaint of the arm and/or shoulder pain or weakness, were recruited for the study.

Results suggest that the system was effective at conveying audio-visual and touch data in real-time across 20.3 miles and warrants further development. However, the study's findings may not be generalizable to all locations, because it requires ultra-high-speed Internet with high bandwidth and speed requirements.

In this study, AR was chosen as the base technology for the development of the teleworking system to allow a realistic real-time interaction between clinicians and users

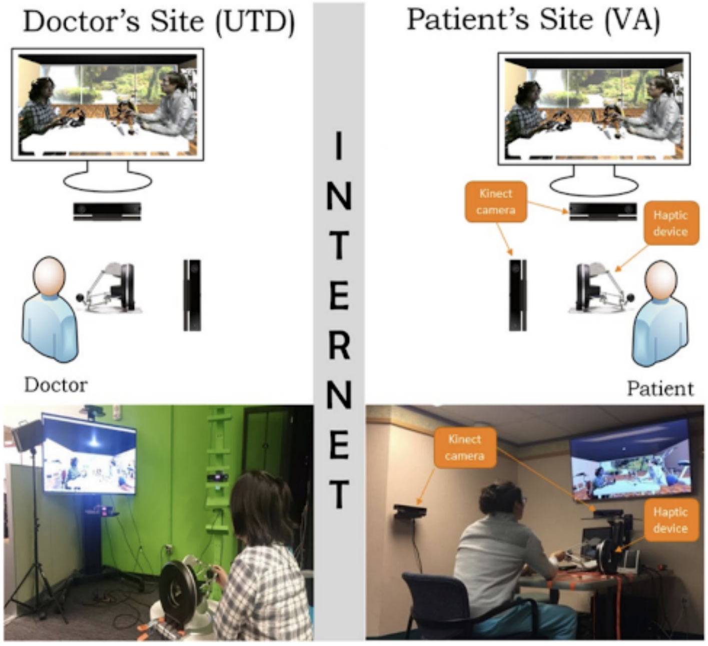

Figure 25 – Visual description of the setup at each site (BORRESEN et al., 2019)

in safe conditions. Although, as the results point out, despite being accepted by users due to the feeling of presence, there is still a limitation in the quality of experience concerning real-time usage due to Internet quality restrictions.

Borrosen et al. (BORRESEN et al., 2019) demonstrated in this work that is possible to merge a Telerehabilitation experience with AR techniques. However, the authors result highlight that the Internet quality can reduce user feeling experience and notice the importance to be aware of bandwidth restrictions for telerehabilitation systems.

3.5.2 Kinesiotherapy Device for Hands Rehabilitation

(PANI et al., 2014) present the development of a kinesiotherapy device applied to rheumatic users' rehabilitation. This device is presented in Figure 26 and allows for remote monitoring capabilities of such users. In order to help recover their abilities, users are requested to execute an exercise protocol, for which all performance data are stored. Two main operation modes are available as:

(a) Real-time control mode: In this mode, users execute the proposed exercises under local supervision of a therapist; and

(b) Deferred tele-monitoring mode: In this mode, the device guides the user through the execution of the exercises without local supervision. Performance data is sent to a remote server and will be available for further analysis by the therapist.

Figure 26 – Proposed telerehabilitation device (PANI et al., 2014)

On real-time control mode, the user executes a set of proposed exercises and a set of statistic data is sent to the therapists' computer, connected to the rehabilitation kit, via Bluetooth. On deferred tele-monitoring mode, after the proposed exercises' execution, statistic data is sent to a remote server, connected to the rehabilitation kit via Global System for Mobile (GSM)/ General Packet Radio Service (GPRS) (PANI et al., 2014). The therapist may then access this data on the remote server, using the Internet. Figure 27 presents the main components of the proposed solution.

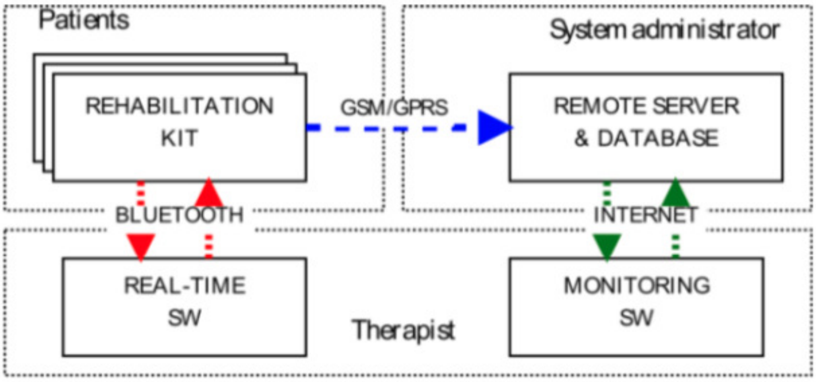

Figure 27 – Main components of the tele monitoring system (PANI et al., 2014)

The rehabilitation kit presented suggests an interesting approach when the assembly of specific hardware is needed and when there is no Internet to do data transfer. The use of an intermediate server to provide the therapist with access to offline statistical data can be extended to other applications, such as PW users rehabilitation. On the telemonitoring system, only statistical data (related to user's performance during exercise execution) is collected for the therapist.

In this telerehabilitation tool, the video streaming showing the execution of the exercises is also important, even with the network traffic overhead. Then, the therapist can assess if each set of exercises has been rightly performed by the user, increasing the efficiency of treatment.

3.5.3 Development of Remote Controllable Visiting Robot

Due to the depopulation and ageing across the location, the number of wheelchair users has raised. The family or caregiver cannot easily go to see him or her, because it takes a lot of time and is costly (MITSUMURA et al., 2014).

The work proposed by Mitsumura et al. (MITSUMURA et al., 2014) shows a remote-controlled wheelchair robot development, to be driven safely by a remote user with the function of telepresence and shared with family members or caregivers. The system functions and components are respectively represented in Figures 28 and 29.

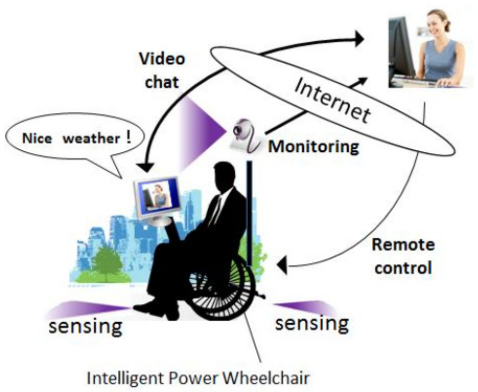

Figure 28 – Image of this robot system (MITSUMURA et al., 2014)

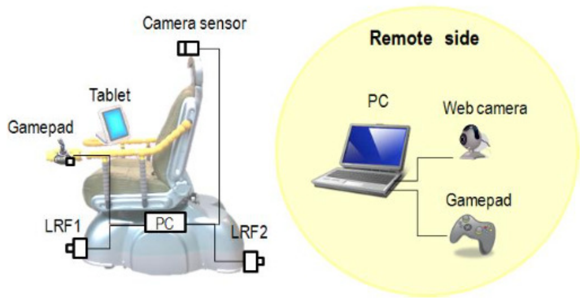

Figure 29 – System architecture components (MITSUMURA et al., 2014)

To establish visual communication between the environments, the Skype™ program was used. The Robot Service Network Protocol (RSNP) was also used to allow the remote control and the function of remote monitor on the base. RSNP is the communication protocol for robot service using Internet, which has been developed by Robot Service Initiative (RSI) (RSI, 2020). The communication infrastructure of RSNP is a web service one. RSNP provides communication function, multimedia function and robot service function as a module.

The robot system was developed based on the Buddy (wheelchair robot) and RT-Middleware, as shown in Figure 29.

In this work, a remote controllable wheelchair with telepresence function has been developed. However, experiments conducted on seven people controlling the wheelchair robot locally and remotely, as shown in Figures 30 and 31, report that five in seven people

Figure 30 – Local user control (MITSUMURA et al., 2014)

Figure 31 – Remote user control (MITSUMURA et al., 2014)

felt insecure, while being driven by a remote user than driving by one's own self. The reason was thought to be due to the fear of delay of the remote control and Skype. Indeed, there is a risk of disconnection from the network between remote side and local side. To solve this, a supervisor module was developed to stop the smart wheelchair automatically at the moment when the network seems to be disconnected.

From the Mitsumura et al. (MITSUMURA et al., 2014) work, some critical aspects have to be considered when the work boundary is telerehabilitation of PW users. First, the possibility of the therapist remotely intermediate, if were necessary, on the user training. Second, as the Internet link, during the training process, may fall or disconnected temporarily, an emergency stop has to be implemented to avoid a crash on remote PW.

3.5.4 A Mobile Gait Rehabilitation System

The mobile gait system is composed of network devices, computers, monitoring sensors, actuators, running embedded controls and decision making algorithms, as shown in Figure 32. The devices responsible for capturing the user's movements are linked to motion sensors and smart shoes. Mobile robots are used to provide assistive torque to the user's knee joint. The system also allows the therapist to remotely control user's exercises.

Real-Time WiFi (RT-WiFi) network protocol serves as the wireless communication subsystem between control application and the rehabilitation device for improved system mobility and telerehabilitation.

The RT-WiFi was designed to provide a real-time high-sampling-rate data transmission. The design of RT-WiFi is to provide enough freedom for supporting designers to choose their preferred communication behaviour. At the same time, the design of RT-WiFi should minimise the modification on the original Wi-Fi protocol. It must be transparent to both the upper layer software stack and underlying hardware. For instance, Figure 33 presents a system architecture plan to deploy three sensors and three actuators into this

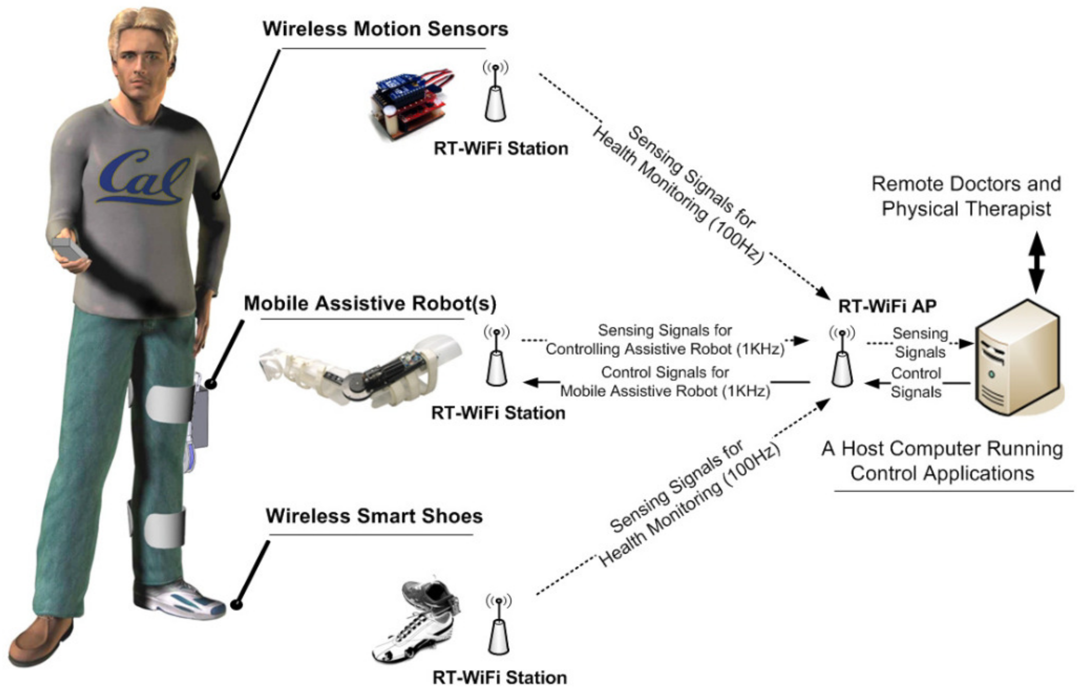

Figure 32 – Overview of the mobile gait rehabilitation system (WEI et al., 2013)

system. Depending of the physical proximity of each sensor/actuator, they are attached to different RT-WiFi stations. On a RT-WiFi network, a network manager and control application are running on top of the RT-WiFi Access Point (AP).

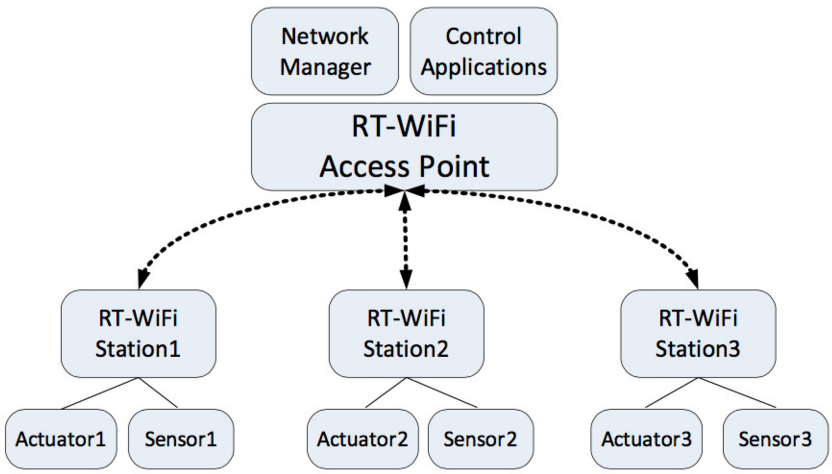

Figure 33 – RT-WiFi-based wireless control system (WEI et al., 2013)

Information time transfer (latency) into Internet applications is a highly important topic in the telerehabilitation and control systems. The presented RT-WiFi protocol is presented as a control paradigm that makes the control interface more efficient and reduces the latency on samples transferred during the process. So, this feature must be considered no matter the system, even for remote wheelchair training, by improving system performance and user experience at the same time.

3.5.5 PerMMA for wheelchair users

The first generation of a Personal Mobility and Manipulation Appliance (PerMMA) for wheelchair users is presented by Cooper et al. (COOPER, 2012). PerMMA is a mobile robot as presented in Figure 34, which has full power seat functions and a custom track system that interfaces with two robotic manipulators.

Figure 34 – PerMMA (COOPER, 2012)

Figure 35 – Remote operator station for PerMMA (COOPER, 2012)

The control of the PerMMA is maintained by the person in the chair, although control can be shared with a remote assistant at the same time, as presented in Figure 35. It allows a computer view data streaming from the PerMMA and to haptic robots mapped to the arm in the PerMMA. These features allow the user to complete tasks faster when they are not able to finish these task by himself.

The PerMMA is an example of how the knowledge base concerning wheelchair technology has grown. These improvements offer to wheelchair users a better quality of life. However, as stated by the authors, some issues still remain elusive, such as, optimization of wheelchair training and assessment tools. Despite this, the possibility to remotely assist the user during the training session visually and also interact with a PW become a relevant feature to a telerehabilitation system.

3.6 Final Considerations

The research projects that represent state of the art reveal elements and challenges that have to be considered in an augmented telerehabilitation system to support PW users' training. Telerehabilitation with remote assistance and real-time interaction is a standard feature, as well as, the latency challenge. Besides, media streaming technology is an essential issue for providing visual feedback to the user. And, combined with AR techniques, improves the user experience and also allows meet their needs individually. AR techniques also allow the therapist to customize the session objects. Finally, reliable and standard assessment methodologies are another important subject. All these elements will be further investigated in this research.

Table 1 – Comparative summary of related work

Related Work	**Telerehabilitation**	**PW training**	**Training assessment**	**AR**
(ABDALLAH et al., 2019)	✗	✗	✗	✓
(VAILLAND et al., 2019)	✗	✓	✗	✗
(VALENTINI et al., 2019)	✗	✓	✓	✗
(BORRESEN et al., 2019)	✓	✗	✗	✓
(ZOLOTAS; ELSDON; DEMIRIS, 2018)	✗	✗	✗	✓
(JOHN et al., 2018)	✗	✓	✓	✗
(MACGILLIVRAY et al., 2018)	✗	✓	✓	✗
(AFFANNI et al., 2018)	✗	✓	✓	✗
(MAULE et al., 2017)	✗	✗	✗	✓
(KAMARAJ et al., 2016)	✗	✓	✓	✗
(MITSUMURA et al., 2014)	✓	✗	✗	✗
(PANI et al., 2014)	✓	✗	✗	✗
(WEI et al., 2013)	✓	✗	✗	✗
(COOPER, 2012)	✓	✗	✗	✗

Table 1 presents a summary of the related work described in this chapter, considering the following features:

- *Telerehabilitation*: applications where users and therapists are located in different environments;
- *PW Training*: computer-assisted training of wheelchair users;

- *Training Assessment*: reliable and standard assessment methodology and procedures to be applied after training sessions; and
- *AR*: use of AR in health applications increase user experience with real world and also allows the therapist customize the training environment with different virtual objects and positions.

By analyzing Table 1, it is possible to note that until the present moment, a system with all features above, has not been found in the literature. It's believed that through these features, the user and therapist will be connected to a training environment and interacting in a more natural, secure, and efficient way. The idea is to have a user who, from any place with Internet and a computer, will issue commands necessary to control a PW and, at the same time, will receive visual augmented feedback in a traditional monitor device. Each user has different impairments and thus the therapist can set up a specific amount of tasks that will make part of the training protocol. Therefore, this research proposes the investigation of computer techniques that support the integration of all these features.

In the next chapter, the materials and methods used in this research will be detailed, as well as the proposed solution components.

4 Materials and Methods

4.1 Introduction

Relevant researches of wheelchair training, rehabilitation and telerehabilitation areas, as well as, their peculiarities, were presented in the last chapter. It has been observed that, to date, no AR system architecture allows the delivery of telerehabilitation services by therapists to PW users, as if it were performed at the rehabilitation center. It is important to allow the therapist to personalize, monitor, and evaluate the training of each user individually. In addition, the user can carry out this training based on their needs and potential, with a high level of realism and without leaving his house and compromising his safety.

This chapter gives details about materials and methods used to outline the project, such as system requirements and architecture, materials related to each architecture part, methodologies (training tasks and assessment), experimental training protocol and a web server application development methodology.

4.2 System requirements

It has been identified the need for designing a system architecture that allows the delivery of telerehabilitation services. With this, there is a demand for a physical space equipped adequately with assets that meet the needs of PW users. In an optimized way, it needs to be accessed and shared by therapists and PW users, at any time from any place. Also, technologies employed must allow the user experience to be enriched. The therapist can personalize the way the user will use the environment, and apply these changes instantly; that is, in real-time. Finally, they might interact and visualize the training experience in real-time as well.

Given these needs, it is possible to realize many advantages of this system architecture approach, such as:

- Physical space requirements:

    1. **Reduced physical space required:** Once the remote training environment is built, the user, being apart in a small room, equipped with a computer and auxiliary components. The visual feedback (PW movements and speed) came from their interaction using interface devices (keyboard, joystick and etc.) that

can be seen from a traditional monitor or an HMD. Also, an EDA wireless sensor might be used in order to collect biologicals signals; and

2. **Accessibility of the training space:** through the characteristics presented in the previous item, it is noticed that the training space can be more accessible to the users, even in their own residence if has Internet;

- Software requirements:

1. **Availability of the remote training environment:**this can be accessible 24 hours a day, being available to different users in different time zones;
2. **Customization of the remote training environment:** the AR techniques allow healthcare professionals to insert virtual objects into the environment for different purposes and different positions. Thus, according to individual user need, the therapist can define a different amount of tasks, that allows user evolves gradually in the accomplishment of their training. The physical components present in the environment might be upgraded;
3. **Training assessment:** an assessment methodology reliable has to be chosen to individually assess the PW user training, considering their capabilities;
4. **Training reports:** the system have to be connected to a database, allowing the storage of information regarding the training session. These data will be used to produce training reports and charts that can be accessed by the therapists accompanying the user in real-time; and
5. **Safety:** Although controlling a real PW, the user will be performing the exercises from a safe environment without being exposed to the risks that the actual training environment offers.

4.2.1 Non-functional and Functional requirements

In order to get an architecture that works properly, the following no-functional requirements were identified:

- System requirements:

1. **NF-R01:** To implement an AR module based on fiducial markers, responsible for rendering the virtual objects for each frame received at clients stations;
2. **NF-R02:** To implement an embedded system and hardware, responsible for controlling the PW and collecting its speed;
3. **NF-R03:** To implement a waiting routine, where all users and therapists may have the environment available either to start new training sessions or start those that are waiting.

- Telerehabilitation requirements:

    1. **NF-R04:** To implement a reliable video streaming that is necessary to collect visual information and provide visual feedback to the users. To ensure visual feedback to the users from the remote training environment, it is essential to guarantee at last a rate between 24 to 30 fps (CHOUITEN; DIDIER; MALLEM, 2012);
    2. **NF-R05:** To implement a data channel over the Internet to provide the data control streaming. The latency time for each control command transmitted from the user's to the remote training environment, should not be greater than 300 milliseconds (CHU; MOON; MUN, 2006); and
    3. **NF-R06:** To implement a software solution, which allows the use of different HMI, responsible to collect and transmit all control data and
    4. **NF-R07:** To offer real-time response.

The main functional raised requirements were:

- **F-R01:** To allow the user to login into the system, before starting the training session;
- **F-R02:** To allow the user to select a control interface in agreement with his possibilities;
- **F-R03:** To allow the user to issue commands to control a PW remotely;
- **F-R04:** To allow the user to preview and to hear, by distance, any change inferred on the remote training environment;
- **F-R05:** To allow the therapist to login into the system before starting his tasks;
- **F-R06:** To allow the therapist to register a new user in the system;
- **F-R07:** To allow the therapist to create a new training protocol to each PW user, using AR techniques;
- **F-R08:** To allow the therapist to set up, start and follow a training session PW users;
- **F-R09:** To allow the therapist to preview, interact with a PW and check the tasks accomplished by the PW user;
- **F-R10:** To allow the therapist to evaluate, take notes from the PW user training performed in real-time; and

- **F-R11:** To allow the therapist to track user training history using graphs.

The user is invited to select a local control interface, before to login in to the web system to do his/her training request. Figure 36 and 37 illustrate the actions to be performed by the user in different moments:

- **Local use case:** the user have to open a local application responsible to start data collection and to create the data channel link between the web server and his/her environment as shown in Figure 36. At the end, the user have to close application quitting and stopping data collection and data channel and;
- **Web use case:** the user have to connect to the system to select which control interface he will use and issue control commands as presented in Figure 37. At the end of his/her experience he/she has to fill out a survey.

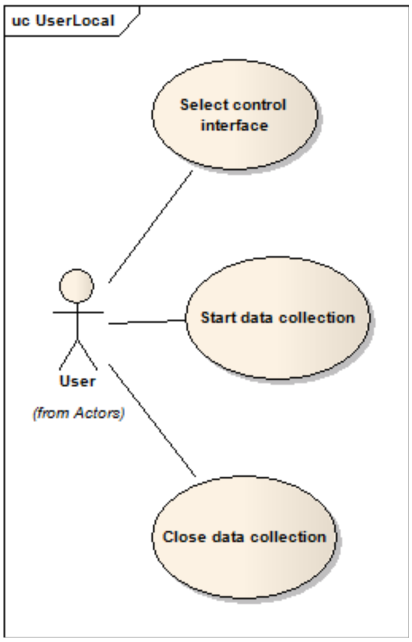

Figure 36 – User: Local use case

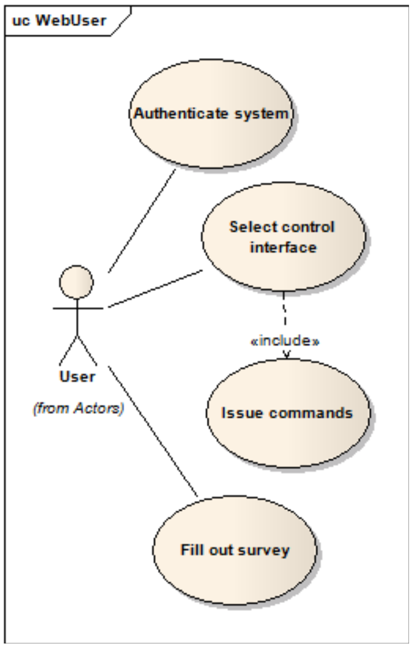

Figure 37 – User: Web use case

In order for the therapist to perform his duties through the process of rehabilitation of the PW user, the following actions were established described in Figure 38. Thus, the therapist is able to perform the following actions: to record his users' information in the system, create training protocols that meet the needs and capabilities of the individual user, define which protocols will be executed, initiate and monitor the training sessions and, if necessary, intervene in addition to evaluating, taking notes and track the history of training progress for each user.

In this way, the therapist can perform his activities as if he were inside the rehabilitation center.

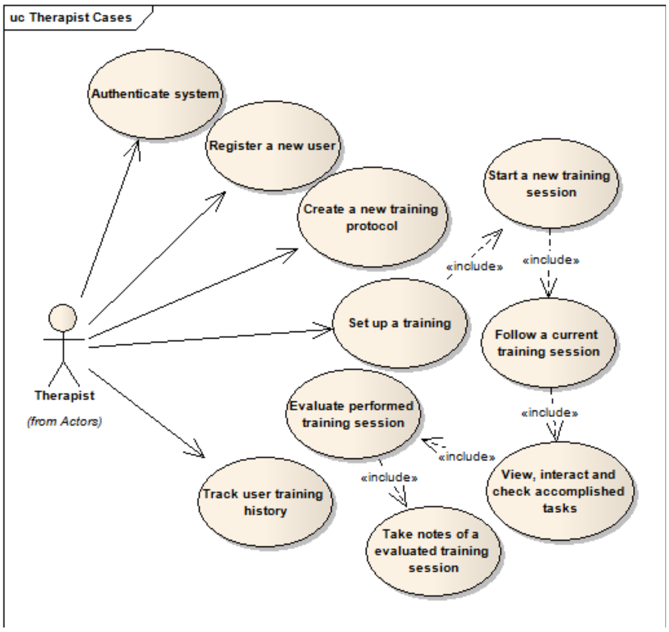

Figure 38 – Therapist use case

Based on the actions performed by users and therapists, some actions must be made by the system (Figure 39). These actions ensure that requests are correctly handled, as resources become available. Thus, they can receive the correct feedback of actions remotely performed through remote interactions with PW.

Figure 40 demonstrates some administrative activities, which for the time being, must be defined before using the system, so that the environments are appropriately connected and to have control over the moment of information collection, from the experiences, carried out by users.

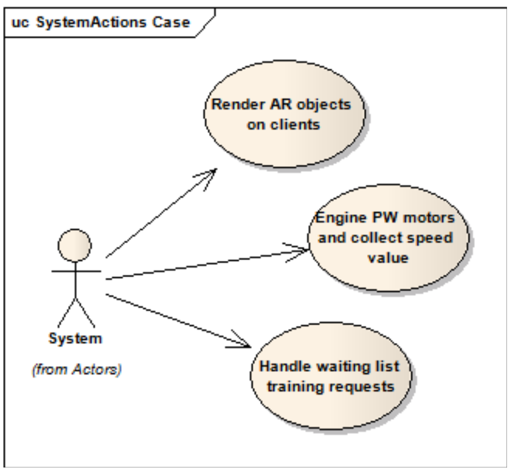

Figure 39 – System use case

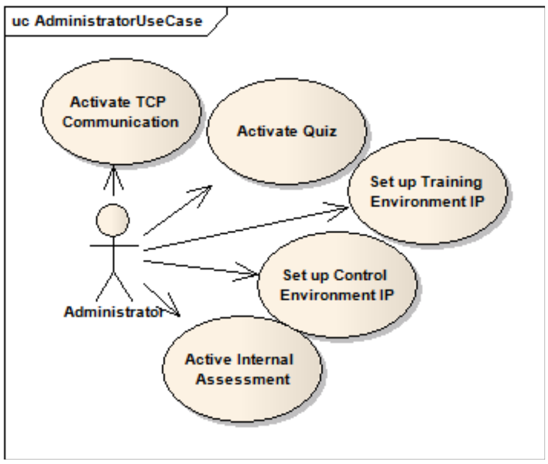

Figure 40 – Administrator use case

These requirements are fundamental for the environments in order to provide the user with a more realist environment. Thus, next session presents the proposed system architecture.

4.3 System architecture

A computational system used to train and evaluate users at a distance is, essentially, composed by three main modules, according to (BURDEA, 2004):

(a) Exercise software, running on the users station;

(b) Remote monitoring software, running on the therapist site; and

(c) A database and remote graphics capability, used for user's medical data.

Considering the main needed characteristics, based on previous related work and associating to the description provided by (BURDEA, 2004), the following software system architecture, shown in Figure 41 is proposed:

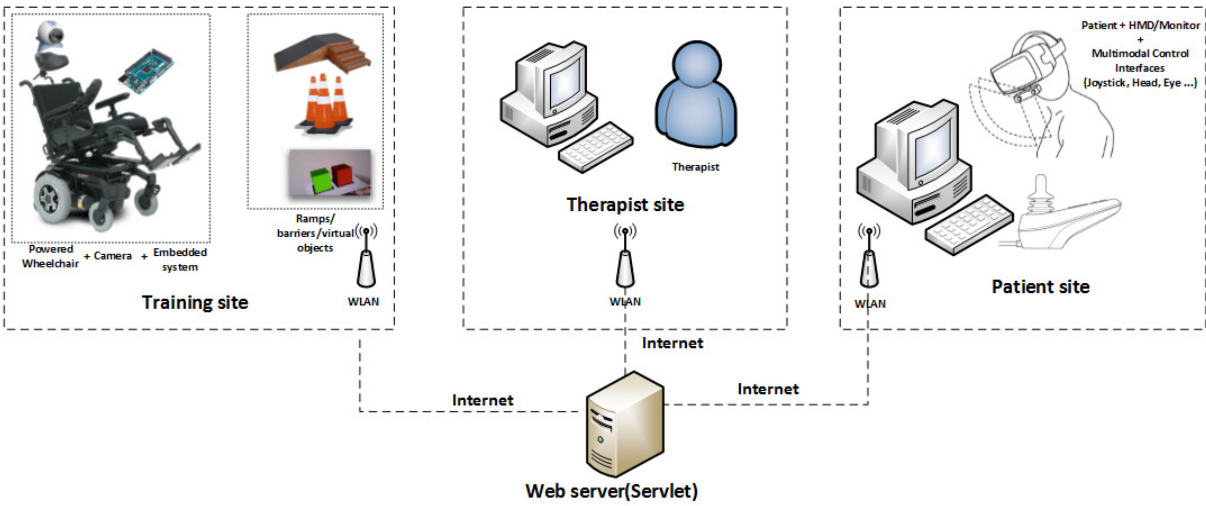

Figure 41 – AR Telerehabilitation System Architecture

1. A training site, in which the exercises protocol will be executed, is similar to the one proposed in item (a);

2. A patient site, from which the user remotely controls the PW, is similar to the one proposed in item (a); and

3. A therapist site is similar to those proposed in itens (b) and (c), in which a health professional can follow the exercises executed by the user and access performance data.

The following sections, explain the main details about each site.

4.4 System sites

4.4.1 Training site

This site is a controlled environment where each structural part was built based on 60 surveys form (Appendix I) filled out by PW users with different disabilities. The area presented in Figure 42 is $14.76\text{x}7.16\text{m}^2$ and is located in a classroom (-18.944766, -48.213257) at the Federal University of Uberlândia.

Figure 42 – Remote training site

The room is composed by an unmanned PW (Figure 43) without diagonal movements, physical objects such as curb and a high access ramp, uneven surface area, spine, portal and a set of AR markers, equally spaced a meter apart from each other.

Figure 43 – PW vehicle

The AR markers matrix has 14x7 positions. Additionally, virtual objects will be positioned over the AR markers, according to the configuration proposed by the therapist. From a Dlink DWR-922B 4G router modem (Figures 44 and 45), controlled through a connect to the Internet.

Figure 44 – Dlink DWR-922B - Front

Figure 45 – Dlink DWR-922B - Back

An interface controller box (Figure 46 and 47) are coupled to the PW (Figure 48 and 49) to trigger motor and collect the PW speed. The internal components of Figure 49 are: 1) Proprietary board under interface panel, 2) Input signals (Arduino) plug, 3) Processed control signals, 4) Internal power supply cables and 5) PW driver plug.

Figure 46 – HMI PW (Front): only Power On/Off interface panel option

Figure 47 – HMI PW (Back): PW and Arduino power supply plugs

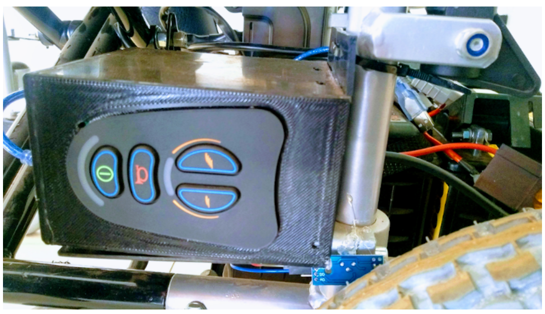

Figure 48 – Control box position at PW

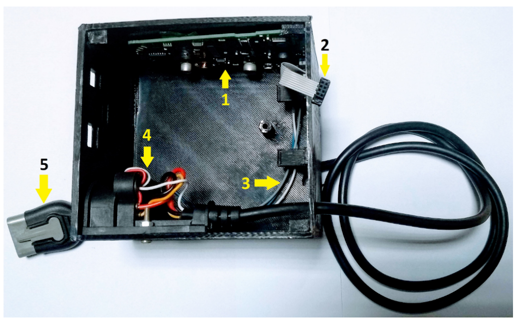

Figure 49 – Internal control box components*

A smartphone is integrated into the PW to provide remote clients (users and therapists) with visual feedback. These clients have, in their respective sites, a vision in the first-person of the augmented training session, which is more natural and realistic against the god view mode, which gives the user a top view of the whole environment. Also, the smartphone running the Android operating system, has a Team Viewer QuickSupport app installed to afford a remote connection.

4.4.1.1 PW control and Speed signal collection

A microcontroller board Arduino Mega 2560[1] (Figure 50) within a wifiShield[2] (Figure 51) is used to load the embedded system which receives all commands through the Wireless Local Area Network (WLAN) network.

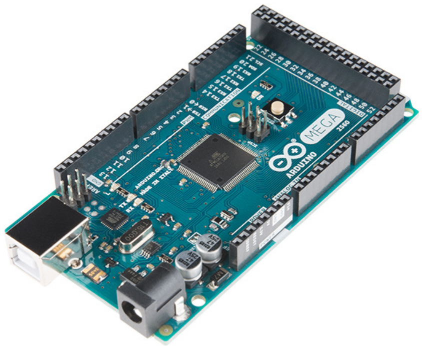

Figure 50 – Arduino Mega 2560

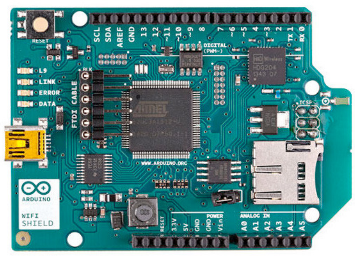

Figure 51 – WifiShield Arduino

A PWM shield (Figure 52) is used to transcript control signals, remotely received in different PWM pulses, which are recognised by proprietary board in Figure 49, responsible, in turn, to engine PW. The sensor (Figure 53) responsible for collecting the PW speed are coupled to it. The PW is controlled by an embedded system, which receives control signals from the remote server that is responsible for forwarding each signal received from the user. Control signals are received from the Internet and sent through a WLAN that returns the PW speed values to the remote server.

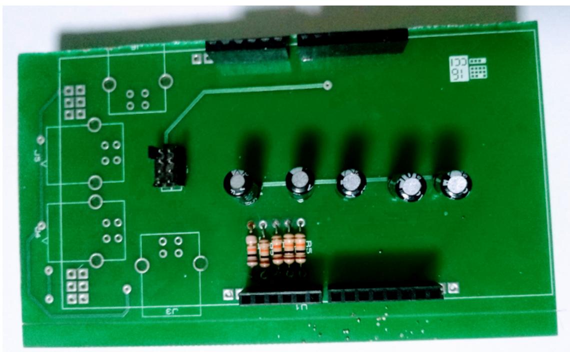

Figure 52 – PWM Shield converter

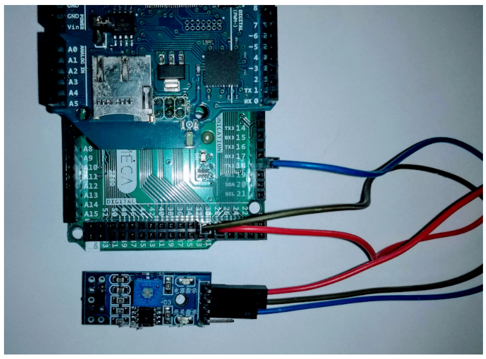

Figure 53 – Sensor follow infrared range IR Tcrt5000 Lm393

[1] https://www.arduino.cc/en/Main/arduinoBoardMega
[2] https://www.arduino.cc/en/Main/ArduinoWiFiShield

Through the WLAN, a data channel is established between patients and the training site. The command data streaming is released only after the user training request be authorized by the therapist. After that, an algorithm capable of recognizing each command and performing the respective PW movement is uploaded into the microcontroller. Nevertheless, for many reasons, sometimes, the control inputs can not be received because the data channel connection may fall or some package may be lost. For this reason, an emergency stop must be defined to avoid some possible PW crash (MITSUMURA et al., 2014). Figure 54 presents a Unified Modeling Language (UML) Activity Diagram of this process workflow.

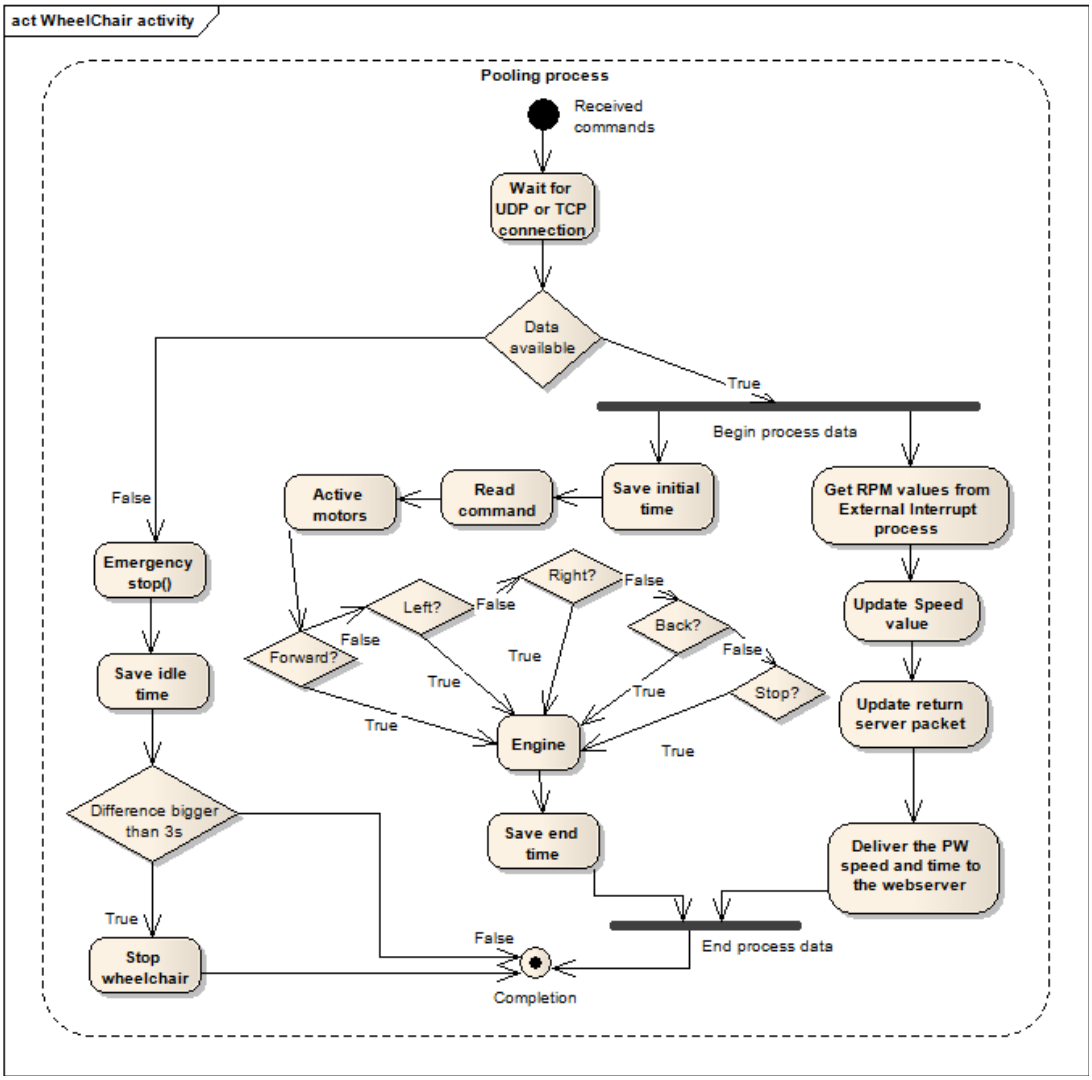

Figure 54 – Activity Diagram to PW data workflow

This Activity Diagram describes all actions related to data workflow into the embedded software. The microcontroller has the primary function of running all the time (pooling process) and also an interrupt process attached at the speed sensor, responsible for updating the PW Revolutions Per Minute (RPM). The first step is to recognize the client connection and if it has some data to be processed. Currently, this data is represented by a string value like (1, 2, 3, 4, or 5)(CAETANO et al., 2018). The PW, at this point, is only working with continuous speed. Further, the speed value can be changed in the agreement with PW user needs. The second step is, if it has data available, the initial time is updated and a general method accountable for activating the PW motors is triggered by performing the respective movement. Also, the RPM speed values are converted by Km/h values and buffered in a data packet. Otherwise, if it has no data available, the security function is called. Thus, the idle time is updated. After, the time difference between idle and initial is checked, and if it's bigger than 3 seconds, the general wheelchair method is called to stop the PW. In the end, a data packet containing microcontroller internal processing time information and the speed of the PW is returned to the server.

4.4.2 Patient site

In this site, the user is able to issue control commands to the remote PW, using the adapted joystick, as shown in Figure 55. Visual feedback is provided to the user.

Figure 55 – Adapted USB Joystick VR2 (CAETANO et al., 2018)

A desktop computer is used to provide communication with the user. Control commands are collected and further sent to the remote server, which is responsible to forward each command to the training site. Images from the training site are received through the Internet is augmented (AR techniques) and projected on the visual feedback device like a traditional monitor.

4.4.3 Therapist site

When dealing with telerehabilitation applications, it is desirable that therapists can follow the execution of the exercises (BURDEA, 2004). In the presented architecture, this requirement can be achieved in the therapist site. In this site, the therapist uses a desktop computer to follow the execution of the exercises by the user from an augmented (AR techniques) visual feedback rendered in his monitor. Also, the therapist would be able to configure the virtual objects to be rendered over the AR markers to customize the set of activities according to users' development in the training process. The therapist has to mark the tasks accomplished by the user during the trial. In the end, the therapist is redirected to an evaluation form to assess the training performed by the user. After the evaluation, the therapist is invited to take clinical notes about the user's experiment and then the evaluation process is finished. At any time, the therapist can access the graphical summary related to the protocols metrics, previously performed by the user.

4.5 PMRT methodology

4.5.1 Protocol tasks adaptation

The PMRT model, defined Section in Section 3.3, has being adopted as the standard protocol methodology in this research, due to its reliability. However, the PMRT has 16 tasks structured (predictable) and unstructured (unpredictable). As highlighted by Valentini et al. (VALENTINI et al., 2019) the users present themselves tired after accomplishing 12 tasks. Thus, an adaptation on PMRT is required to reduce user mental struggle and achieve his/her goal individually, ensuring his/her well being after the trials.

Data information collected during the trials is shown in Table 2.

Table 2 – Data collection information

N^o.	Description
1	Parameters like the number of input controls, elapsed time, collisions number are used to evaluate the users' trials performance;
2	A survey questionnaire is also used to provide qualitative information about the system from the users point of view as well as the therapist's comments about each activity performed and;
3	User biosignals are used to analyze protocols impacts during the trials.

4.5.2 Biosignal data acquisition and processing

Biosignal data acquisition is performed using the E4 wristband (Figure 56), manufactured by Empatica®. This instrument is an easy to wear wristband that can measure various biosignals, among them Electrodermal Activity (EDA) and Blood Volume Pulse (BVP).

Figure 56 – The E4 wristband for biosignal data acquisition

EDA data processing is conducted using Ledalab software (BENEDEK; KAERNBACH, 2016; E4; LEDALAB; KUBIOS, 2020) to decompose the signal in two components: phasic and tonic (as shown in Figure 57).

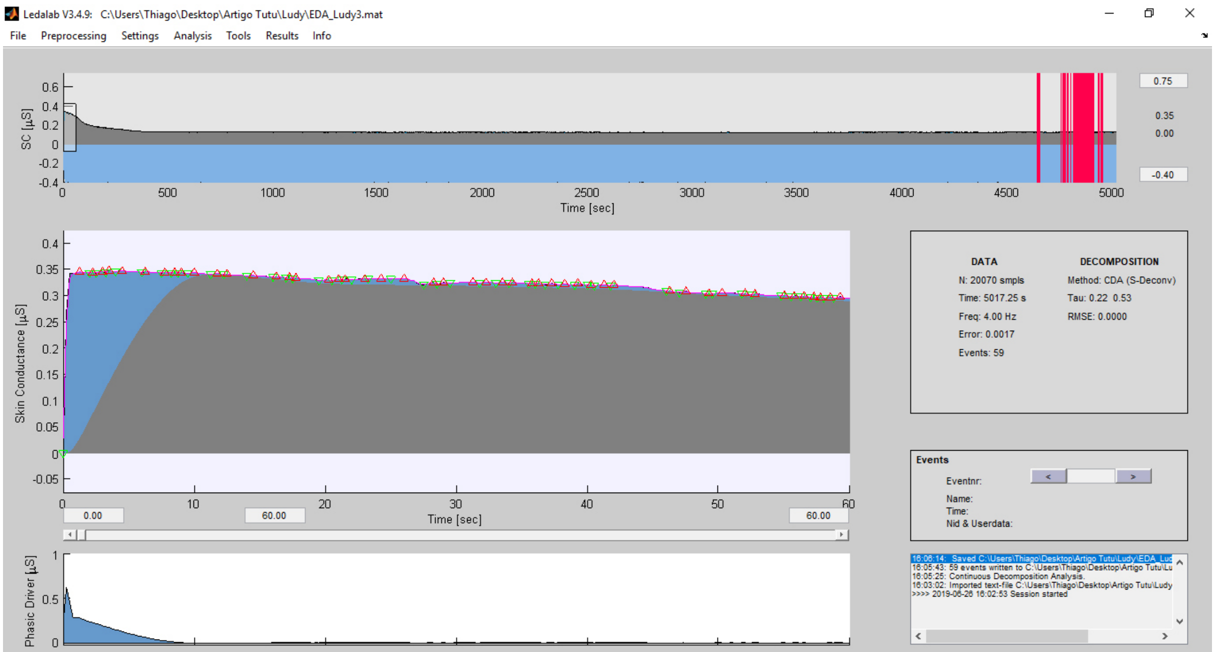

Figure 57 – Ledalab software used for EDA decomposition

For evaluation of the event related skin conductance responses (each command given by the users is considered an event in this preliminary study), the phasic component is used, considering an event response window starting 1s after each event and finishing 4s after this same event (KHALFA et al., 2002). The Continuous Decomposition Analysis

(CDA) method is used, given its robustness on decomposing EDA biosignals in continuous tonic and phasic data (BENEDEK; KAERNBACH, 2010).

Amongst output variables extracted from Ledalab to evaluate individuals responses, the Integrated Skin Conductance Response (ISCR) is used. This metric consists of the time integral of the phasic driver extracted by Ledalab within the response window (1s to 4s after event). This variable is chosen since it considers both magnitude and duration of responses (it's a time integral), while other available variables (count of SCRs, average SCR, sum of amplitudes of SCRs, SCR Phasic Max Response) take into account more unidimensional aspects of the responses. All data is standardized using z score shown in Equation (4.1) to reduce subject variability.

$$Z_i = \frac{X_i - \overline{X}}{S} \tag{4.1}$$

Data processing of BVP is performed using Kubios, as shown in Figure 58, a software used to analyze Heart Rate Variability (HRV)(HRV-SOFTWARE, 2017; E4; LEDALAB; KUBIOS, 2020). It utilizes Inter Beat Interval (IBI), extracted from BVP measured by the E4 wristband (E4, 2020) for each user on each protocol. It returns several output variables, among them the Stress Index (SI) calculated as the square root of Baevsky's stress index (BAEVSKY; BERSENEVA, 2008).

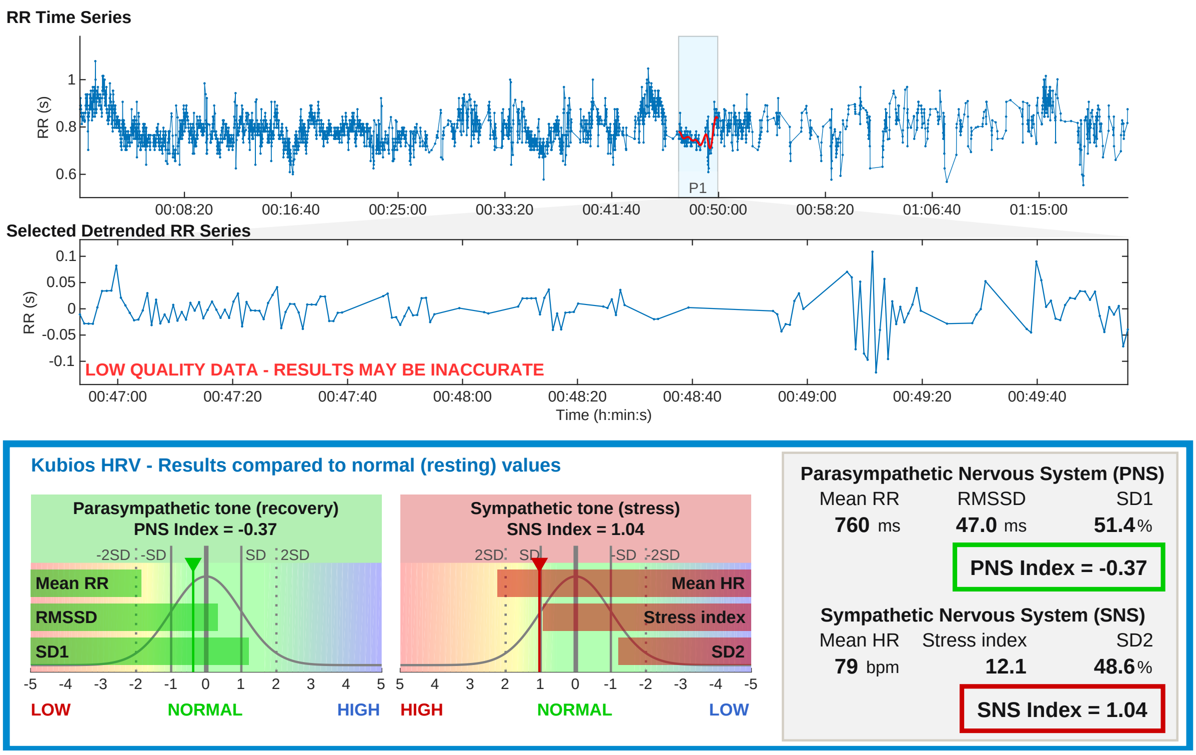

Figure 58 – A section of a report generated by the Kubios software for HRV

4.5.3 Assessment methodology

PMRT was chosen by having a higher ICC value as describe in Section 3.4.5 (KAMARAJ et al., 2016). Different metrics help to track users' evolution during the training protocols and can be used to better grade tasks values that's range (1-4) (MASSENGALE et al., 2005). Thus, parameters present on the first line of Table 2 are adopted as training metrics. Also, the biosignals on the third line in Table 2 are collected to give clues of the emotional state of the user during training protocol (AFFANNI et al., 2018).

Table 3 showns data analysis details coming from the user training experiment.

Table 3 – Data analysis information

N.o	Description
1	The PMRT Methodology is used for trials performance evaluation;
2	Bar charts shown the users questions evaluation and Word clouds (BLETZER, 2015) represent the most relevant reasons for the user's evaluations based on users and therapist's comments/notes and;
3	Protocols data analysis were divided in: 1. EDA Analysis, using ISCR as variable for statistical analysis between protocols. All statistical evaluations were made using the R-softwareŮ (JUREČKOVÁ; PICEK; SCHINDLER, 2019). The Shapiro-Wilk test is used, and the data distribution is found to be non-normal (ISLAM, 2019); 2. Stress Index Analysis, using the IBI time series (Inter-Beat Interval - Time between individual heart beats) is used to obtain the Stress Index for each protocol individually using the software Kubios (HRV, 2018).

4.6 Preliminary tests

General information about volunteers in this research is shown in Table 4.

Table 4 – Volunteers general information

No.	Description	Detail
1	Volunteers	Consist of 3 adults aged 22 to 57 years;
2	Gender	1 woman and 2 men with spinal cord injury (RIZZO; KOENIG; TALBOT, 2019; NUNNERLEY et al., 2017);
3	Location	Collection was made in a rehabilitation center 10 kilometers far from the training site;
4	Consent form	Volunteers were asked to fill a consent form (Appendix III);
5	Ethical Committee	The approval to conduct this research was obtained from the Federal University (377566140.0000.5152).

Clinical information about the volunteers in this research is detailed in Table 5.

Table 5 – Volunteers clinical information

N.o	Detail
1	He has 2 years of injury, has 18 months of experience in driving the Ottobock PW, drove a car previously, the user performance is satisfactory, the performance of ADL (feeding) / AIVD (change of posture, transport), has transportation (not adapted), house adapted to move around and needs joystick adaptation;
2	He has 5 year of injury, has 48 months of experience in driving the Ortobrás PW, drove a car previously, the user performance is satisfactory, the performance of ADL (Dress, undress, put on.) / AIVD is semi independent, has adapted transportation, house fully adapted and requested a joystick position adaptation;
3	She has 3 years of injury, has 6 months of experience in driving the Freedom PW, did not drive cars previously, the user performance is satisfactory but uses adaptation in the trachea, the ADL / AIVD performance is semi independent and semi independent, it does not have transport, have significant spasms that affect postural control and PW control performance. She is not well positioned in the PW. Required posture revision and joystick adjustment.

4.6.1 Procedure and process

The initial process steps followed for each volunteer every first time, instructed and supported by a therapist, is described in Tables 6 and 7.

Table 6 – Procedure and Processes - Part 01

Step	Procedure/Process
1	Ensure that the environment temperature is conditioned at 25°C for good quality of biosignals (LANATÀ et al., 2014);
2	Volunteers will be registered into the system by the therapist as a patient. Volunteers had the project explained again for purposes of clarification and for a chance to withdraw the study;
3	Volunteers will be instructed about how to log into the system;
4	Volunteers will be instructed about system functionalities and how to make the download of the application, responsible for transmitting the joystick commands to control the PW remotely;
5	The remote environment will be presented for the volunteers in 360° and explained how he/she must proceed to interact with it;
6	Volunteers will be instructed about how to request a training session;
7	Let the volunteer rest for 7 minutes before starting each training session to ensure a good emotional state and relax (LANATÀ et al., 2014);
8	Wearing the “E4 wristband” wearable device as shown in Figure 56;
9	Request the training sessions.

Table 7 – Procedure and Processes - Part 02

Step	Procedure/Process
10	While the therapist is selecting one of the preliminaries training protocols which are: drive straight forward (4.5 meters) in a narrow corridor without hitting the walls; turning right and left 90° and maneuver the chair by an access ramp, the volunteer reads all information about how to proceed in front of each virtual object;
11	At the end of each protocol, volunteers are invited to fill out a survey questionnaire with advantages, disadvantages and suggestions or observations about the protocol performed, while the therapist is evaluating the trial performed;
12	Volunteers have to rest for 5 minutes between each training session to ensure comfort and absence of side effects before another request (LANATÀ et al., 2014);
13	After the last protocol, volunteers are invited to fill out other questions related to his/her own individual profile and system requisites;
14	The study ended.

The survey questionnaires are shown in Tables 8 and 9. They were built based on the observations coming from Valentini et al. (VALENTINI et al., 2019), Borresen et al. (BORRESEN et al., 2019), Kamaraj et al. (KAMARAJ et al., 2016) which aboard users individual profiles and system requisites. In order for the volunteer can be able to better express the intensity of their perception for each question, we choose to use the Likert scale (LIKERT, 1932). The volunteer can express his opinion by indicating one of the options on a five-point scale. Normaly, the values vary from 1 to 5, or 5 to 1, or even from -2 to 2, but always representing five different intensities of agreement or disagreement.

Table 8 – Survey Questionaire - Part 01

N.o	Question Asked				
1	How was to learn about using the system?				
	5	4	3	2	1
	Very Easy	Easy	Relatively Easy	Difficult	Very Difficult
2	How do you evaluate the graphical interface of the system?				
	5	4	3	2	1
	Great	Very good	Good	Median	Bad
3	How was it to use the system?				
	5	4	3	2	1
	Very easy	Easy	Relatively easy	Difficult	Very difficult
4	Did the system meet the navigation needs?				
	5	4	3	2	1
	Excellent	Great	Good	Median	Bad

Table 9 – Survey Questionaire - Part 02

N.o	Question Asked				
5	How do you consider the quality of the image presented?				
	5	4	3	2	1
	Excelent	Great	Good	Median	Bad
6	Do you consider that the AR (virtual objects) help to carry out the training?				
	5	4	3	2	1
	Very	Moderate	Medium	Little	None
7	How was the processing time (response time)?				
	5	4	3	2	1
	Very fast	Fast	Moderate	Slow	Very slow
8	How much do you consider this tool assists in the development of driving skills?				
	5	4	3	2	1
	Intensily	Very	Moderately	Little	Nothing
9	How do you evaluate your well-being after training?				
	5	4	3	2	1
	Relaxed	Little tired	Tired	Very tired	Exhausted
10	Are you satisfied with the system features?				
	5	4	3	2	1
	Very Satisfied	Satisfied	Indifferent	Dissatisfied	Very dissatisfied
11	Does the system do what it was meant to do?				
	5	4	3	2	1
	Extremely well	Very well	Well	Relatively well	Nothing

The next section presents the web server application requirements in detail.

4.7 Web server application

The JavaŮ Servlet technology provides consistent mechanism that makes possible the development of an architecture with the following features: video streams, different channels to receive/redirect data, to generate data during user experience and system platform independency (SUN; WONG; MOISE, 2003). The Model-View-Controller (MVC) is an architectural pattern that separates an application into three main logical components: the model, the view, and the controller (BASHAM; SIERRA; BATES, 2008).

The web server application runs on client (patient and therapist) site, through the browser. Browsers such Google Chrome, Internet Explorer and Mozilla Firefox runs over a tightly controlled environment called sandbox (QUONG, 2020; TAIVALSAARI et al., 2008). A sandbox application can restrict piece of running code when, for instance, a javascript or a browser extension, try to access local resources[3] (QUONG, 2020). It is

[3] Universal Serial Bus (USB) and High-Definition Multimedia Interface (HDMI) devices or user data

only possible to access physical resources when the application is running locally. However, when the user needs to use the webcam for an example, he is requested to allow the use of this resource. It often happens, when is requested to establish a video stream connection using the WebRTC (Web Real-Time Communication) framework, implemented by the latest browsers affording multi-video-streaming channels between peers (HA et al., 2020; EDAN; MAHMOOD, 2020; GARCÍA et al., 2020).

Most of the times, it is not possible to access data from control devices such eye tracker, Rift HMD and others, without a run time installation. Also, it is not possible to install this into a browser. Therefore, it is necessary to have a local app running on the patient site computer, to establish a data channel between patient site and web server.

Figure 59 visualize all MVC components that come from the system architecture requirements and Use Cases (UC). The following sections, highlight the UML Sequence Diagram (UML-SD) that describes how each component's actions are connected.

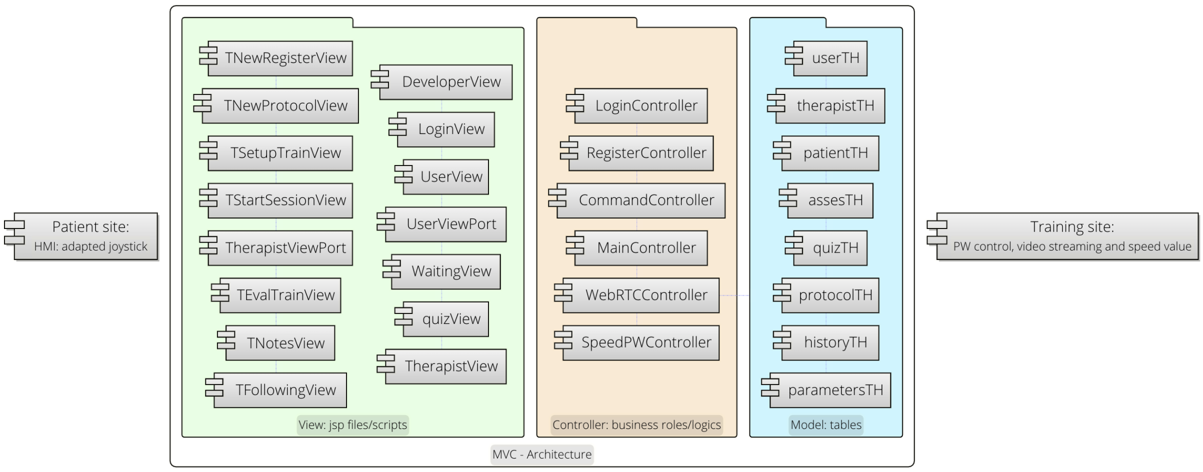

Figure 59 – MVC application components

4.7.1 Administrator: Parametrize system UML-SD

Based on the administrador UC actions, defined on Figure 40, the administrator UML-SD is presented in Figure 60.

These actions are essencial because some systemic internal actions depend on this parameters such as the Internet Protocol Address (IP) of training site, the protocol used between each site, the IP of patient site and if at the end of training session the user have to fill the survey.

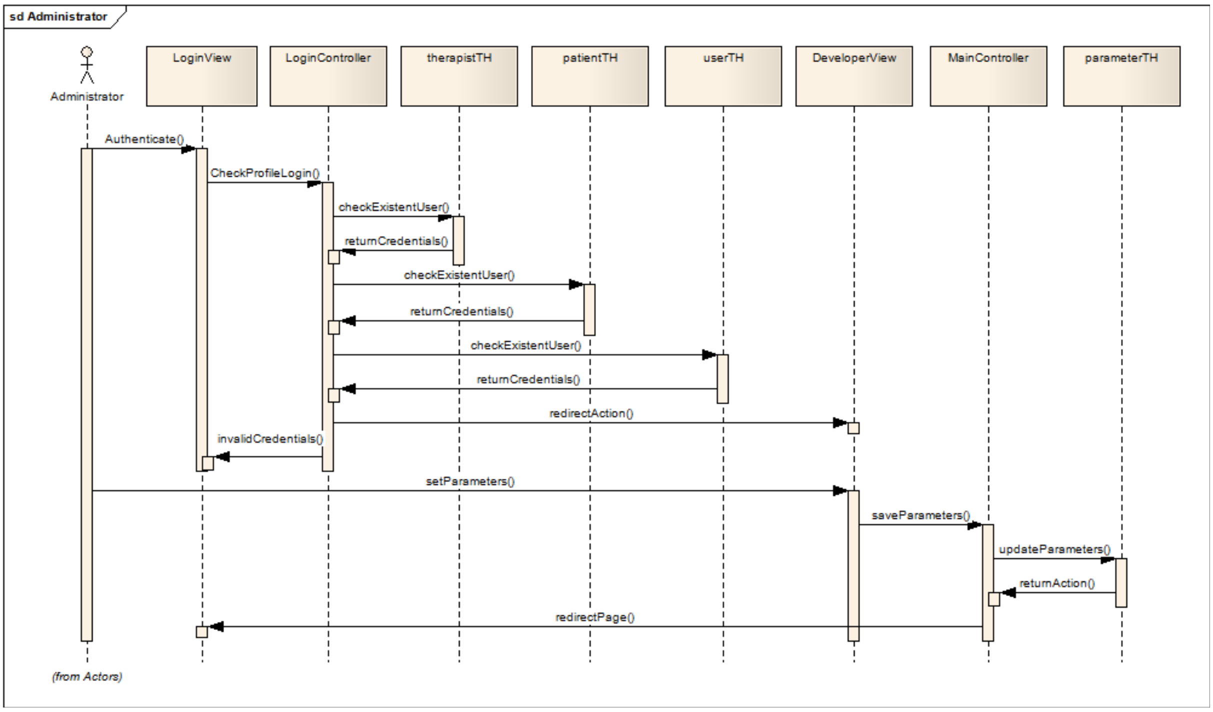

Figure 60 – Administrator: Parametrize system UML-SD

4.7.2 User actions UML-SD

4.7.2.1 User local use case UML-SD

Based on the user local UC actions, defined on Figure 36, the respective UML-SD is shown in Figure 61.

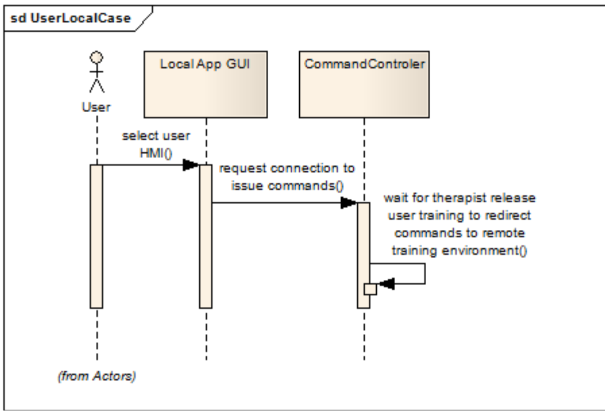

Figure 61 – Issuing commands locally - User UML-SD

As a browser is considered a sandbox (QUONG, 2020), it is necessary to take in count the need for a cross-platform runtime app to allow the user to transmit the control commands to the webserver. While the therapist has not finalized the training settings, to be performed by the requesting user, no commands will be computed or redirected to the training environment.

4.7.2.2 User Web use case UML-SD

As presented in Figure 62, the user have to proceed with the authentication in web application. Later, he/she is redirected to user "UserView". In this view, he/she must select the HMI to be used in agreement to his/her impairment and request his/her training. Until the therapist finish his tasks the user have to stay at "WaitingView".

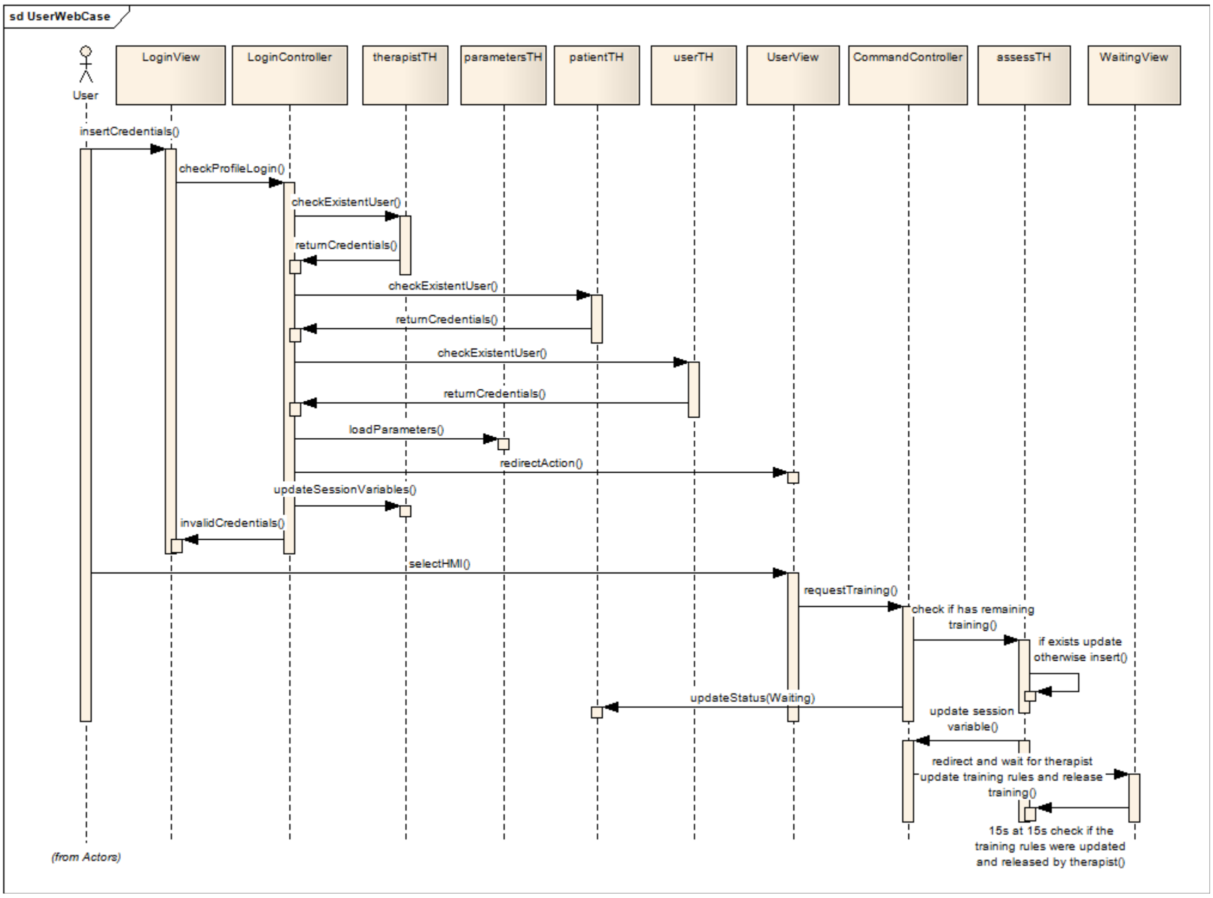

Figure 62 – Web authentication and request training part one - User UML-SD

Figure 63 continues with the UML-SD. After the therapist had setup the user training protocol and started a video streaming from mobile device at training environment, the respective data are update to the table and them the user is redirected to "UserViewPort". Where his/her command will be redirected to remote training site and preview augmented visual feedback. By finishing the training session, the user will be redirected to the survey page where he/she will invited to fill out all the information, presented in Table 7 line 11 and all questions from Tables 8 and 9.

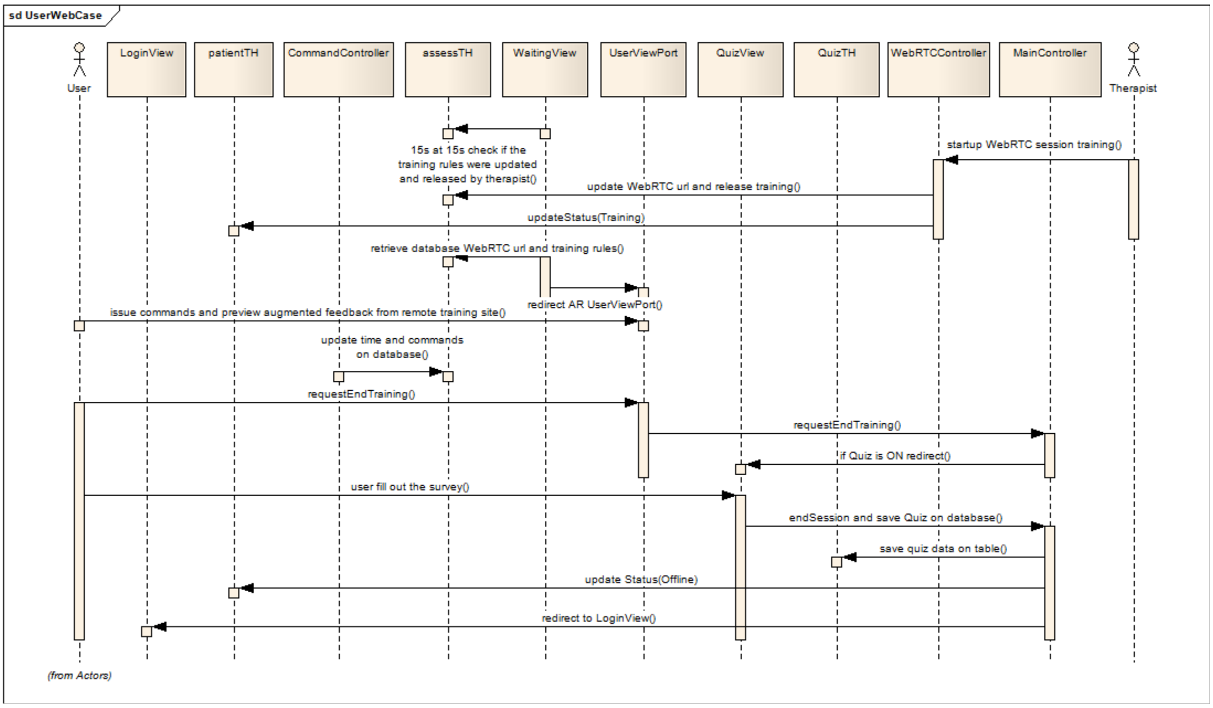

Figure 63 – Web perform training proposed and fill the quiz part two - User UML-SD

4.7.3 Therapist action use case diagrams

4.7.3.1 Therapist authentication Web use case UML-SD

As presented in Figure 64, the therapist have to proceed with the authentication in web application. Later, he is redirected to therapist “TherapistView”. In this view, therapist have access to all actions inherited on the UC shown in Figure 38.

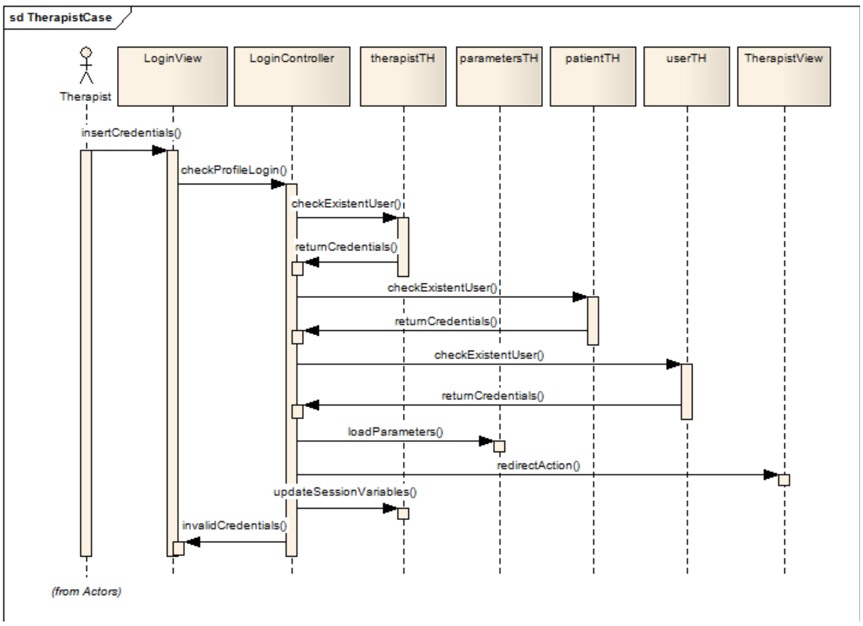

Figure 64 – Web authentication - Therapist UML-SD

4.7.3.2 Therapist register new user Web use case UML-SD

As presented in Figure 65, the therapist has to proceed with the new user registration, as stated in Figure 38. In the “TherapistView”, he can access the “TNewRegisterView” and he may insert a new user considering two profiles: Therapist or Patient.

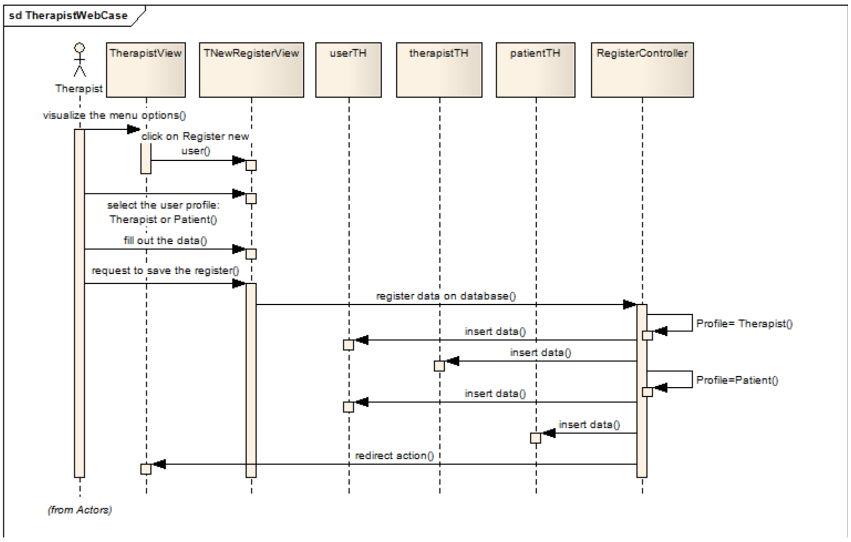

Figure 65 – Web register new user - Therapist UML-SD

4.7.3.3 Therapist new protocol Web use case UML-SD

As presented in Figure 66, the therapist has to proceed with the new protocol creation, as stated in Figure 38.

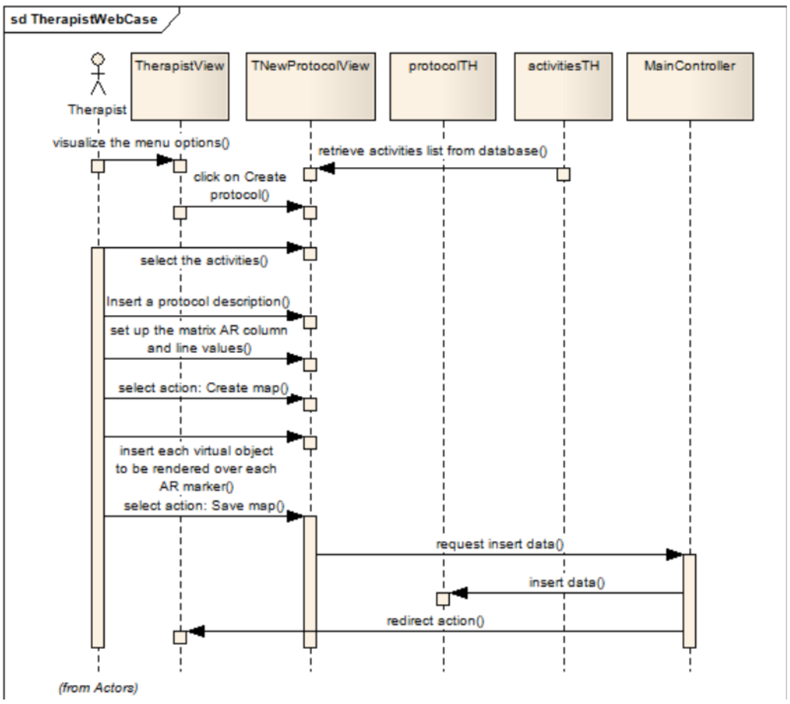

Figure 66 – Web create new protocol - Therapist UML-SD

In the “TherapistView”, he can access the “TNewProtocolView” and he may create a new protocol. The following actions may be performed in order to accomplish the protocol creation:

(a) Select the activity list that compounds the protocols’ tasks. Taking in count the adaptations highlighted in Section 4.5.1 and the 60 surveys filled out by the users, different activities of those that exist in PMRT might be used in the future;

(b) Define a brief description of the protocol, for example, “Protocol 01: detailed characteristics”. The special character “:” is used to split short name and protocol details;

(c) Define the column number and line number of AR matrix used to create a new protocol training;

(d) To created an empty AR map the “Create map” action was defined;

(e) Select the virtual objects, among them must have “static” and “animated” object to guarantee the two main classes of activities of PMRT. These object might be used as a guidance, avoidance or with specifics actions;

(f) To save the created protocol, the “Save protocol” action was defined;

(g) To clear the map created, the “Clear map” action was defined; and

(h) To end session, the “Close” action was defined.

4.7.3.4 Therapist define training use case UML-SD

As presented in Figure 67, the therapist has to define which action is performed for each training requisition. Among the action, until the user starts to train, are: “Define protocol”, “begin a session” and “follow the training”, shown in Figure 38. From the “TherapistView”, the menu option “TSetupTrainView” where the previous training requests can be previewed and accessed.

To apply one of these actions, the therapist always has to select one training requirement before, selecting the action. It is only possible to begin a session to some training request that already has his/her protocol defined. It is only possible to follow the training of a request made, which the session was already initiated.

When the “begin session” action is selected, the smartphone attached in PW, is remotely accessed to open a video streaming from the training site, where the AR markers and all physical components used to create a better training experience were placed. The pure video streaming (video and audio) is received in each site and augmented to the enrichment of the user experience.

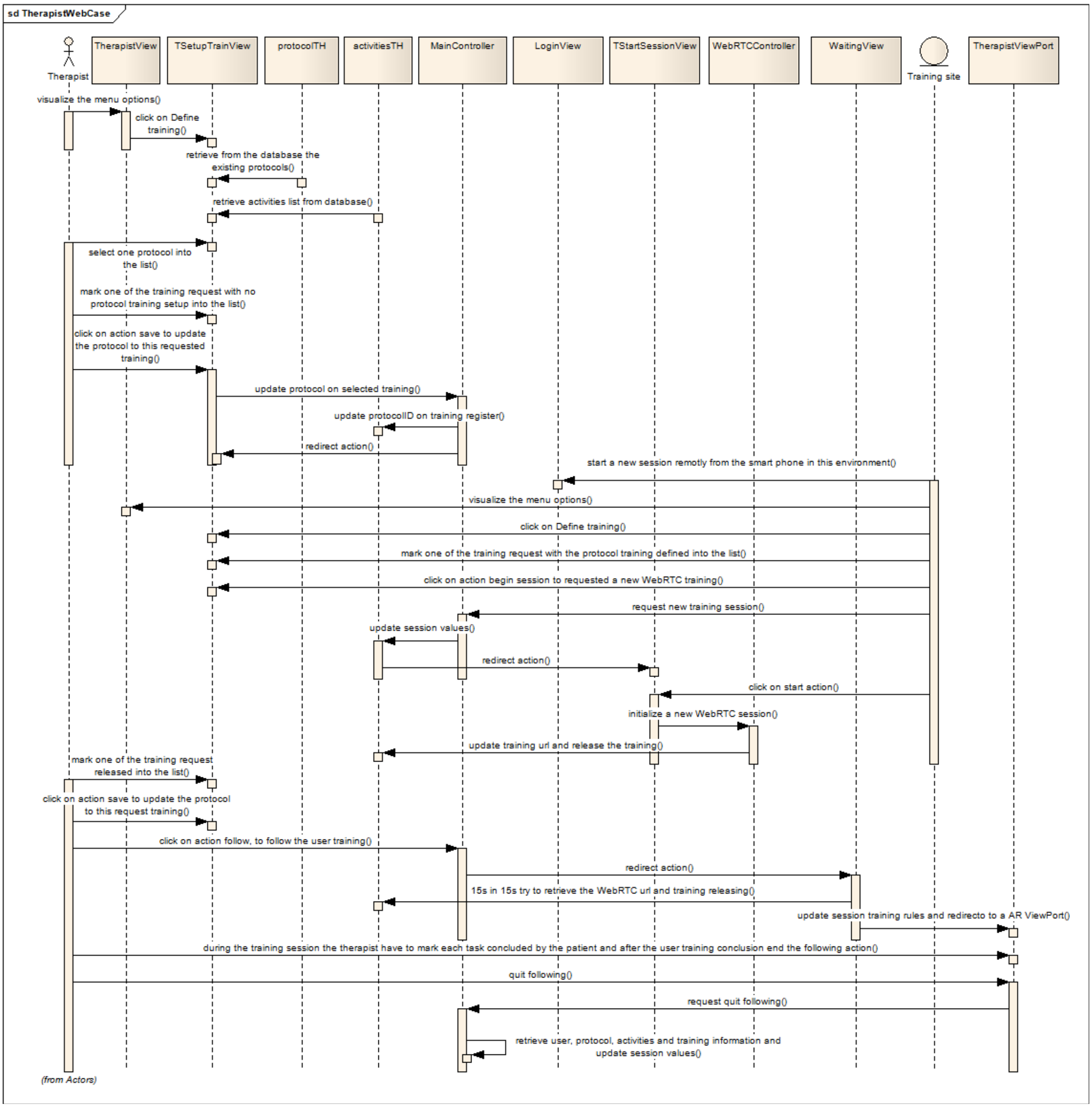

Figure 67 – Web define training view actions - Therapist UML-SD

In the next section, the remaining actions triggered after the followed training are detailed.

4.7.3.5 Therapist evaluate and note training use case UML-SD

As presented in Figure 68, the therapist is invited to evaluate the user training and take notes for each task into the protocol as defined in Figure 38, following the considerations realized in Section 4.5.3.

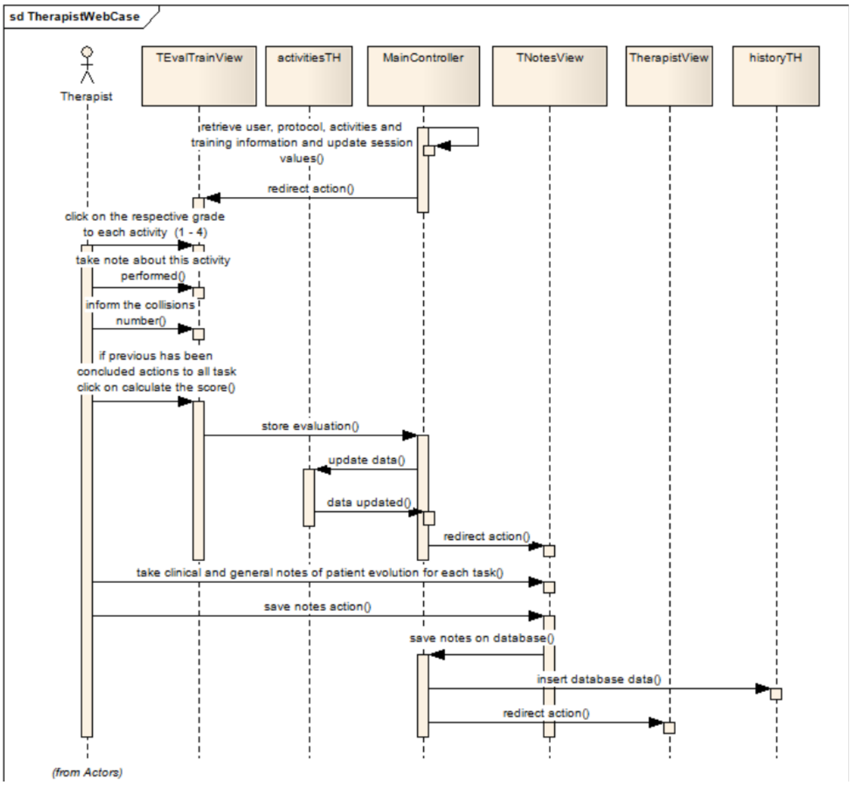

Figure 68 – Web training evaluate and notes view actions - Therapist UML-SD

4.7.3.6 User history accompaniment - Therapist use case UML-SD

The lastest therapist action SD is presented in Figure 69 that's to allow to preview the user evolution for each protocol performed.

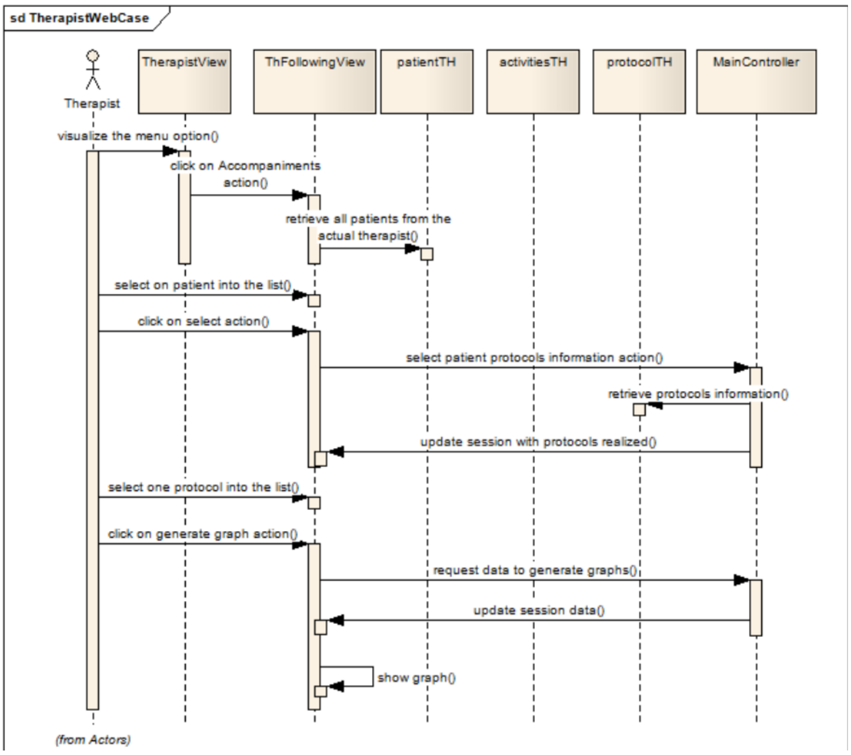

Figure 69 – Web user history accompaniment - Therapist UML-SD

The therapist is allowed, at any time, using bar charts, highlighting the final protocol score and the auxiliary metrics defined.

4.8 Final considerations

This chapter presents an AR-based Telerehabilitation environment for supporting the training of PW users, composed of three sites: patient, training, and therapist. In the training site, the resources and methods used to control the PW, data channel and also video streaming using the WebRTC framework, was described. They are necessary to support remote interaction. From the patients' site, using an adapted USB joystick, the user will be able to control the PW remotely. The AR renderization on clients is processed based on markers to each frame received from the training site using WebRTC. The therapist can perform different tasks even apart of the training and patient site, simultaneously supported by the PMRT, that is a reliable assessment and protocol methodology and also tracks the user evolution using bar charts. Finally, the webserver application components were designed to support all these requirements, and in the end, based on therapist comments and survey filled out by the users, it is possible to have an evaluation of the proposed augmented Telerehabilitation architecture. In the next chapter, the respective implementation details will be presented.

5 Implementation details

5.1 Introduction

This chapter will describe the implementation details related to the software architecture previously defined. To attend software requirements, a local application was developed to establish a data channel connection with the web server application. In the web server application, many Servlets were implemented to compose each different module, responsible for defining a software structure and data flow control.

5.2 Web server application

The web server application[1] is running over Apache-Tomcat-7.0.78 with MySQL Database© using JavaŮ language. This system platform is based in the MVC architecture and each component was describe in Figure 59, in Section 4.7. It makes easy to incorporate different libraries and frameworks (Multi-WebRTC, JSArtoolkit, Boostrap, Web Graphics Library (WebGL) and GL Transmission Format (GLTF) models) to build a reliable web application. Servlets are used in MVC model to control events that come from JSP pages, through POST, GET requests and also external data coming from sockets. In this system, there are two basic actors' roles: therapist and patient. Before initiating all explanations about the implementation details between the front-end and backend, the existent folders (Figures 70 and 71), servlets (Figure 72), files (Figures 73, 74, 75 and 76) and tables (Figure 77) are listed.

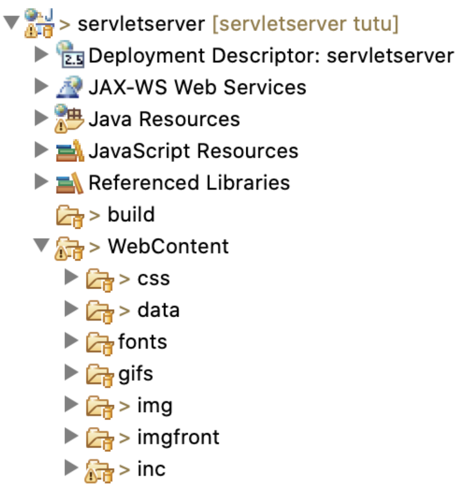

Figure 70 – Project folders part-one

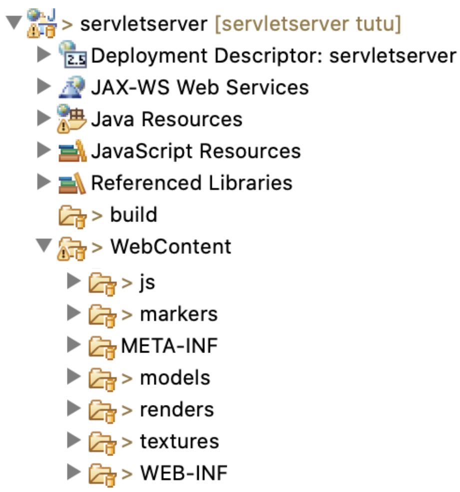

Figure 71 – Project folders part-two

[1] https://www.swheelchairth.com.br:8443/servletserver/

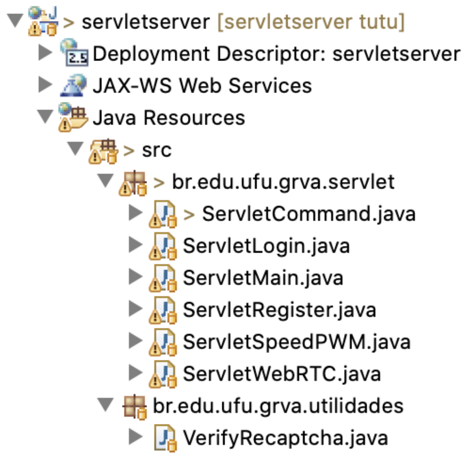

Figure 72 – Java Servlets

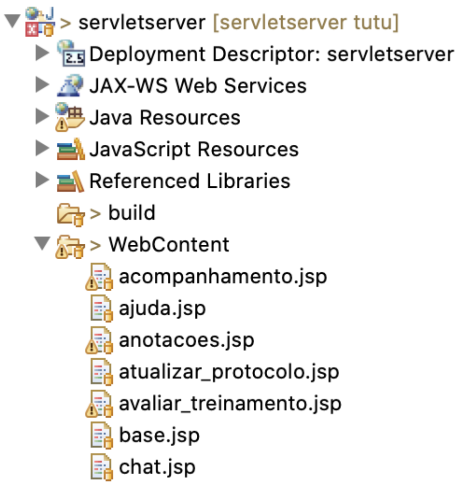

Figure 73 – Files part-one

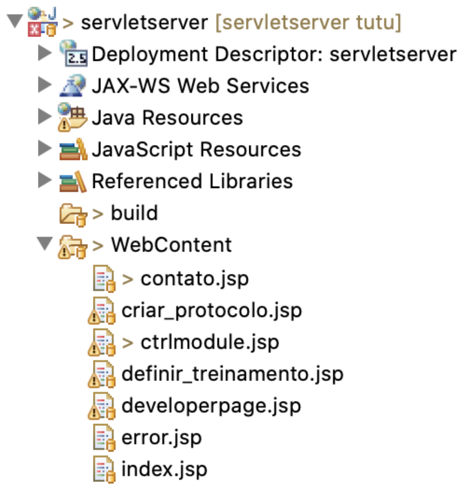

Figure 74 – Files part-two

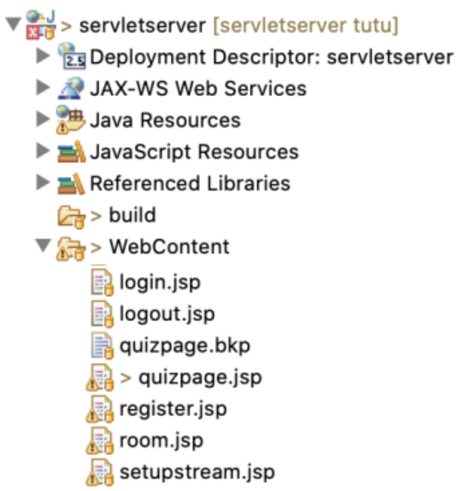

Figure 75 – Files part-three

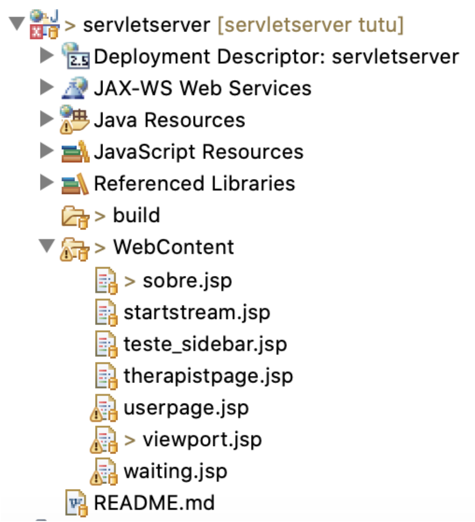

Figure 76 – Files part-four

In the next sections, the explanations containing the implementation details, will follow a flow that starts from each view page, connected with sequence action diagram, the related files (scripts, models, animations), as well as, each controller (Servlet) handler. Providing tips on how to reproduce the test environment, which will be freely shared with the community under the restrictions of the GNU General Public License (GPL).

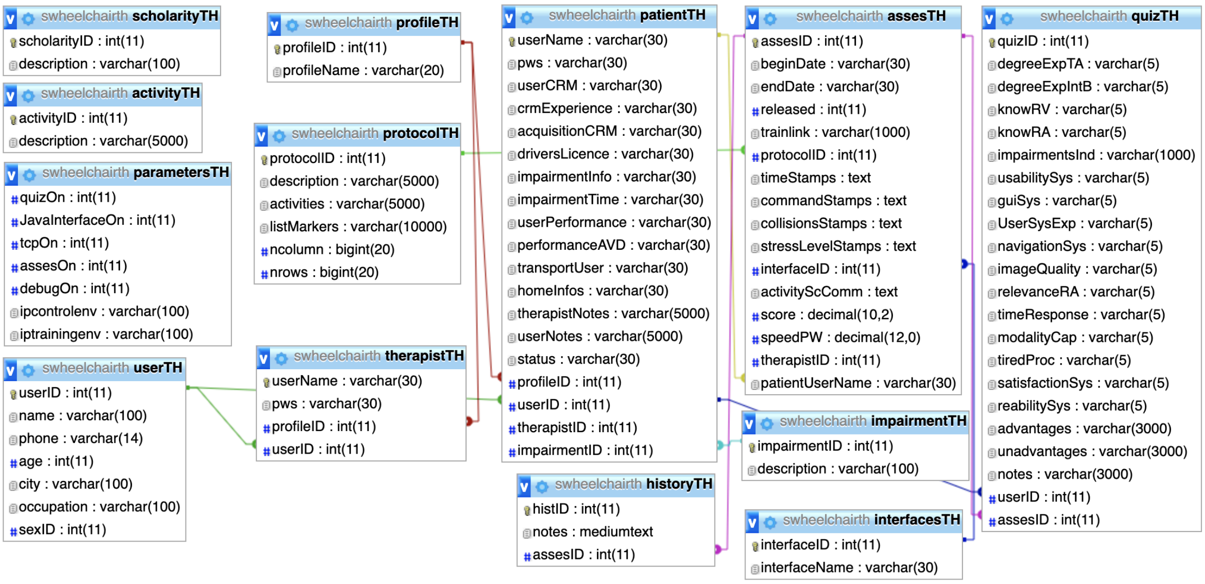

Figure 77 – Tables diagram

5.2.1 Home page

Figure 78 shown the system home page, stored on index.jsp file.

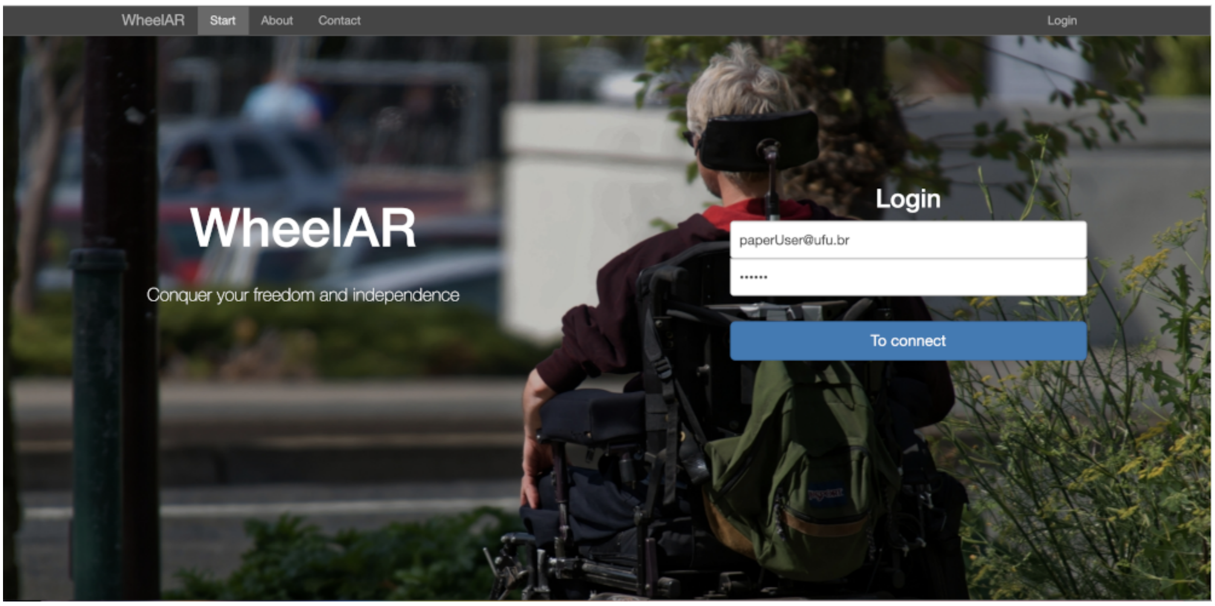

Figure 78 – AR Wheel home page

The navigation bar on top is included on file by the special Java tag below. It is responsible for updating respective headers and footers on view pages, with different contents like navigation menu bar. It has two kinds of files that can be used distinctly: one when the user is not logged into the system and the other one when he/she is logged.

```
<%@ include file="inc/header.jsp" %>
```

In this home page, the users does not need to be logged into the system to access the actions on top. Otherwise, if the user profile is “therapist” the headerLogged.jsp file, stored in “inc” folder is charged, or, if the user profile is “patient” the header_logged_user.jsp, is charged with specific menu bar actions.

From this view page, the user still can access other static contents from the “About” and “Contact” link, on top, stored in files (contato and sobre).jsp. A 360° image preview (Figure 42) from the remote training site was built, using the “A-Frame”[2] framework for building VR experience. For creating this effect, the following embedded body HTML tag is presented. This view page is stored in room.jsp file and can be accessed from the “Contact” link.

```
</head>
<body>
  <a-scene>
    <a-sky src="imgfront/sala_fisica/IMG_20190114_135100.JPG"
   rotation=0 -130 0>
    </a-sky>
  </a-scene>
</body>
```

5.2.1.1 Logging in UC action

These last pages do not interact with the backend. However, there is still the action of logging in to the system (stored in file login.jsp), which is extremely important, as it ensures that each UC is implemented and executed correctly in the future.

Based on the SD actions in Figures 62 and 64, the “loginButton” action is sent to the “ServletLogin”, which checks whether the existing credentials are valid. Whether the credentials are valid, the sessions variables (user name and profile) and databases (user status: online) values, are updated and then, the users are redirected to their respective viewing pages, with the appropriate headers and navigation bar, in agreement with the UC in Figures 37 and 38. Otherwise, it updates user status: offline (table patientTH) and redirects the user back to the login view page (stored as login.jsp file).

[2] https://aframe.io/

5.2.2 User session

Once the user has logged into the system, the user view page (stored as userpage.jsp) that is implements the user web UC actions (Figure 37) is shown in Figure 79.

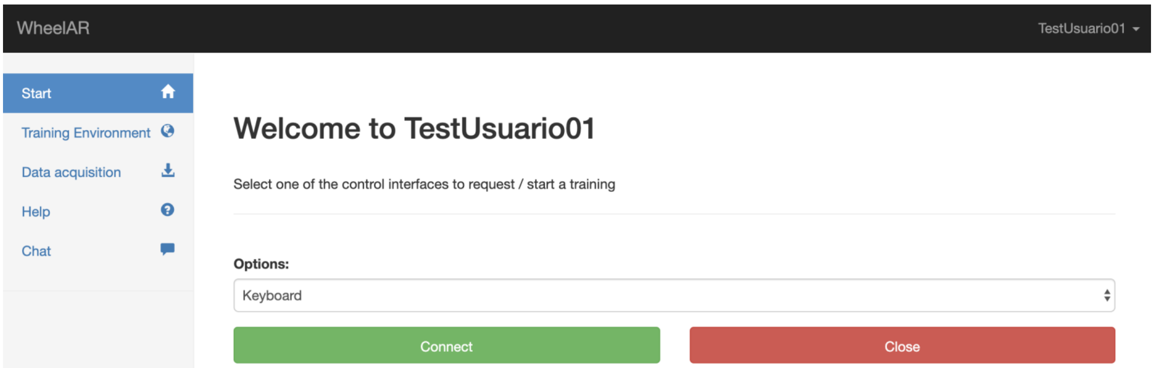

Figure 79 – Main user page interaction

As mentioned before, specific headers are loaded to allow the preview of the navigation menu bar. From the “Connect” button, a new training request is performed and forward to “ServletCommand”. The Java Servlets implemented are prepared to recognize each button action and proceed with each SD (Figure 62) action. Then, if it has no remaining training to be accomplished, a new one is registered (assessTH table). Some credentials are updated (user status: waiting and training ID) into the session and the user is redirected to “Waiting.jsp” view page.

5.2.2.1 Waiting view page

This view page (Figure 80 and stored as waiting.jsp) is as system action used to instruct the users of the virtual objects and also checks when a training session is ready.

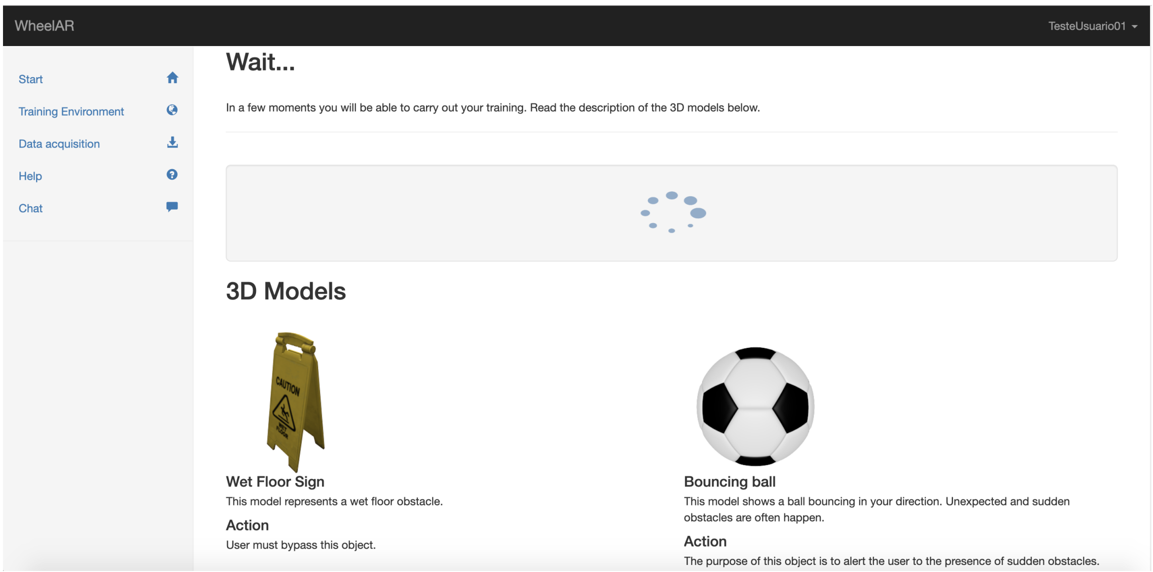

Figure 80 – Waiting release training page

An embedded Java code block is executed periodically to check if a training URL was already defined. After, if a new training protocol were requested, all training protocol data from table protocolTH (protocolID, description, activities, listMarkers and (column and rows) number) is updated into the session. As soon as the therapist initiated the remote video stream, this means that both user and therapist are ready to interact with the training site. From this moment, all command information received and its timestamp are recorded in the "timeStamps" and "commandStamps" columns of the assessTH table. These information are separated by ";" and "," as shown by Figure 81.

Then, the users are redirected to another view page "ViewPort" (stored as viewport.jsp) that allows the users and therapist to perform their actions and also to have an augmented feedback from the training site.

timeStamps	commandStamps
1559067396389;1559067396389;1559067397992;15590673...	4,4,0,0,4,4,0,0,4,4,0,0,4,4,0,0,1,1,0,0,4,4,0,0,3,...

Figure 81 – Data information collecting

5.2.2.2 ViewPort

Figure 82 illustrate the "Viewport" view page, to a patient profile.

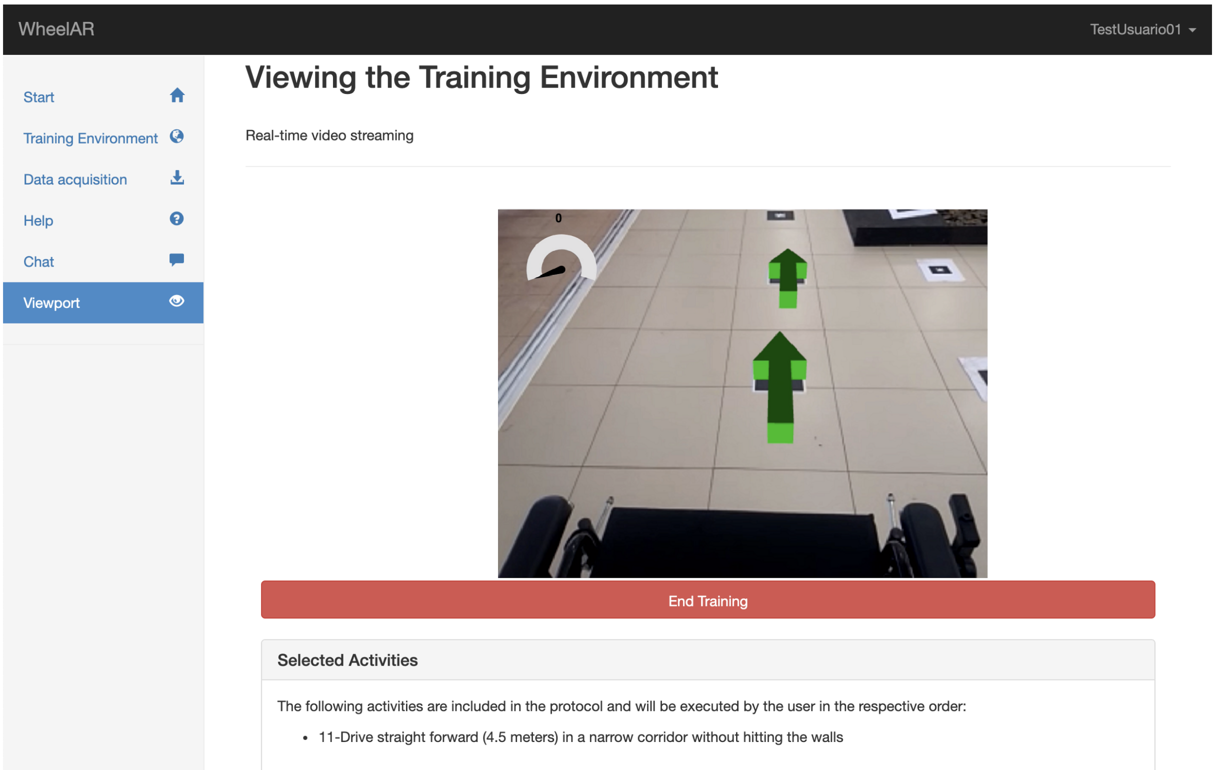

Figure 82 – Real-time video streaming preview page

This view page is responsible for: automatically connect to a shared video stream, provided from the training site; to apply AR techniques for all received frames, to render the virtual objects over the fiducial markers; to update the PW speed value, and also, to provide a data channel using a keyboard to control PW, as needed.

Again, the specific headers are charged to allow the preview of the navigation menu bar on view page load process. Going through the loading page process an HTML5 <div> tag identified as “videos-container” is defined into the view page body, to delimit the space that will be used for rendering graphic objects. The HTML5 <canvas> object will be stored later inside the <div> tag to update each received frame and also to render the virtual elements recognized on the AR markers. Another <canvas> HTML5 tag identified as “speedCanvas” is used to update a graphic speed information of the PW. The code snippet illustrates these HTML5 tags used.

```
<div id="videos-container" style="align:center;">
    <span id="preview-textfield"  </span>
    <canvas id="speedCanvas" width="150"> </canvas> </div>
```

Several JavaScript and libraries functions are imported to support some events on the front-end after the tags including process. Before starting to preview the augmented feedback from training site, the following workflow (Figure 83), is executed:

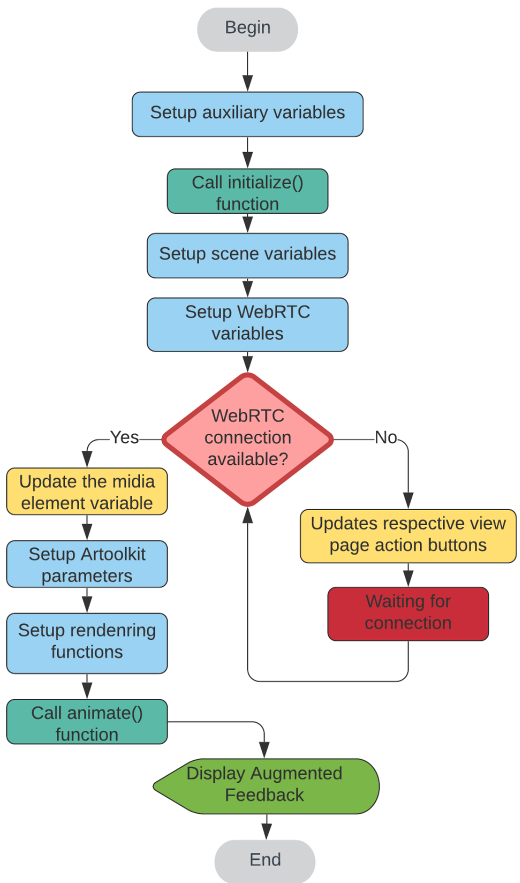

Figure 83 – ViewPort Fluxogram for redering AR feedback

A main JavaScript code block is implemented to ensure that multiple updates and modifications to the content of this “ViewPort” dynamically occur. For this reason, in “Setup auxiliary variables” block, many global variables that represents different class of objects are defined and separated by classes, such as:

- 3D objects: scene, camera, renderer, mixer, clock and div_container;
- ARtoolkit features: artoolkitSource, arToolkitContext and markerRoot;
- PW speedometer: opts, counter, gauge, taxadeAmostragem, totalTime and deltaTime;
- WebRTC features: WebRTCscr and connection; and
- Training features: assesIDViewPort, nMarkers, ncolumn, nrows and nActivities;

The variables belonging to 3D object class are used for any and all operations like rendering, animation and positioning of 3D primitive objects and to import elaborated objects. For that, free libraries like Three.js[3], WebGL™[4] and glTF™[5] which are stored in the “/js” and “js/vendor/three.js/” folders are used.

The Threex-Artoolkit[6] is an extension of the Three.js library that handles JsArtoolkit resources and is stored in “js/vendor/threex/”. Through three classes of objects, ArToolkitSource, ArToolkitContext and ArMarkerControls, you can easily manipulate AR. The ArToolkitSource object is responsible for tracking a marker from different sources such as a webcam, a video, or even an image. The ArToolkitContext object is the main engine and is used to deal with the position of the marker in the image source. Finally, the ArMarkerControls object, which in this case will be represented by the markerRoot variable, is responsible for positioning the content on the marker.

The library Gauge.js[7] is a graphic (Figure 84) object (speedometer) responsible for updating speed values and is stored in “js/”.

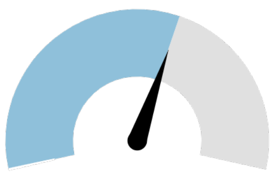

Figure 84 – PW speedometer component

[3] https://threejs.org/
[4] https://developer.mozilla.org/pt-BR/docs/Web/API/WebGL_API
[5] https://www.khronos.org/gltf/
[6] https://github.com/jeromeetienne/AR.js
[7] https://bernii.github.io/gauge.js/

The gauge and opts variables are used respectively to build the object and define its properties.

WebRTC[8] is a framework supported by several browsers to establish the sharing of video, audio, data protocols through a browser, between different points is stored in "js/dist/" folder. The connection and WebRTCscr variables are used respectively to handle the connection and to establish a video and audio stream, and also, to store the remote source element identification to be used by ArtoolkitSource component.

In addition to the previously mentioned variables, the "Training features" are essential. Among them, the most important is "assesIDViewPort" because it is associated with the training session requested by the user, which will be performed. Thus, all other information can be filtered, allowing virtual objects to be adequately rendered in each marker. Such information is established when creating and defining a training protocol.

The block "Call initialize() function" is evoked when the connection between two or more points is established considering, the basic structure for the rendering video being already ready. For this, the actions performed "Setup scene and WebRTC variables" are described.

```
  var target = document.getElementById('speedCanvas');
  scene = new THREE.Scene();
  renderer = new THREE.WebGLRenderer({antialias : true,
     alpha : true });
  div_container = document.getElementById("videos-container");
  div_container.appendChild(renderer.domElement);
  mixer = new THREE.AnimationMixer(scene);
  clock = new THREE.Clock();
  connection = new RTCMultiConnection();
  connection.socketURL =
     'https://rtcmulticonnection.herokuapp.com:443/';
  connection.session = { audio : false ,
     video : true, oneway : true };
  connection.videosContainer = document.getElementById
     ('videos-container');
  window.addEventListener('keydown', onKeyDown, false);

//Call stream available function
  connection.onstream = function(event) {
     webRTCsrc = event.mediaElement; \\updating mediaURL
```

[8] https://github.com/muaz-khan/WebRTC-Experiment

Among these block actions, the canvas object, in which the speedometer will be displayed, is assigned to the “target” variable. Next, the “scene” variable is initialized to be responsible for receiving other objects to be rendered. Additional objects, such as light (ambient and directional) and a camera incorporated into the “scene” are defined. However, properties definition were omitted, but have been established in this code.

The “renderer” object is defined because it is from the properties, every frame information received is processed and updated. It’s properties definitions such as size, lighting and position have also been omitted, but they have been implemented.

The <div> tag identified as “videos-container” is assigned to the “div_container” variable, because it is used as a rendering objects container. Since our idea is to work with dynamic 3D and not only static objects, a “mixer” variable is initialized with the previous “scene” object created for animating objects. For this reason, a “clock” and also “ deltaTime and totalTime” are initialized, in order to help in rendering time process control.

As every rendering process requires a video stream, and in our case, this stream is remotely shared, the “connection” variable is initialized as an object of the RTCMultiConnection class. Thus, a sharing URL server is defined to handle it. Also, it is necessary to define what is this flow property, whether it will have video, audio, etc.

So, before calling the “onstream” function, responsible for handling these connections, a keyboard event listener (handled by “js/keyBoard.js” file) is associated with the page body to allow, the keyboard can also be used as a PW control interface.

After calling the, “onstream” function, the processes are paused, until receiving a confirmation message that the stream has started. For this, the WebSockets API[9] is used to establish communication channels between different points. In the meantime, the action buttons are updated based on the user profile, in addition to the activities list to be performed. The only action button for this profile is “End training” managed by “ServletMain”. It updates on the database, information such as the finishing training time, and the user’s status: online, freeing the use of the training site, redirecting him to the user view page.

However, after receiving the message, first, the variable “webRTCsrc” is updated with the remote media object information. Then, all the actions by the blocks “Setup ArtoolKit and Rendering functions” are performed.

There are three configurations to be made in Artoolkit: the ArToolkitSource, ArToolkitContext and ArMarkerControls. The “ArToolkitSource” variable is initialized according to the first line of code in the command block. As seen, the “webcam” is defined as the streaming source. However, an adaptation was performed in the “js/vendor/threex/threex-

[9] https://developer.mozilla.org/en-US/docs/Web/API/WebSockets_API

artoolkitsource.js" library because the physical device (present on the notebook or computer) address is automatically defined. In our case, this source is remote, for this reason, the "ARjs.Source.prototype._initSourceWebcam" function was modified to receive as a source, the object saved by the variable "webRTCsrc". Thus, the "arToolkitSource.onResize()" function can be performed. The stream renderer object source is no longer null, and then the arToolkitContext information is updated. Thus, the arToolkitSource "onReady()" function initializes the PW speedometer (gauge) and add another event listener, associated with the window resize actions.

```
arToolkitSource = new THREEx.ArToolkitSource({sourceType :
  'webcam',});

function onResize() {
  arToolkitSource.onResize()
  arToolkitSource.copySizeTo(renderer.domElement)
  if (arToolkitContext.arController !== null) {
      arToolkitSource.copySizeTo(arToolkitContext.arController.
      canvas) }}

arToolkitSource.init(function onReady() {
  onResize()
  gauge = new Gauge(target).setOptions(opts); // create gauge!
  });
window.addEventListener('resize', function() { onResize()});
```

Then, the next step is to initialize the variable "arToolkitContext". As described in the code below, the parameters "camera_para.dat" file are loaded and the image detection mode is defined. Finished the loading process, these parameters are duly copied to the artoolkitContext camera.

```
  arToolkitContext = new THREEx.ArToolkitContext({
    cameraParametersUrl : 'data/data/camera_para.dat',
    detectionMode : 'mono'});
  // copy projection matrix to camera when init is complete
  arToolkitContext.init(function onCompleted() {
    camera.projectionMatrix.copy(arToolkitContext.
    getProjectionMatrix()); });
```

The last configuration to be performed in Artoolkit is ArMarkerControls. For this, it is necessary to generate the patterns files (.patt) who defines each fiducial AR marker feature and the 3D object (.glTF) to be loaded. Based on the size of the AR matrix, defined in Section 5.2.3.2, or by the product between the variables ("nrows" and "ncolumns") it is possible to know the amount of markers needed. To generate AR markers image, based on the Artoolkit standard, the Python AR markers[10] library was used. After exporting all images, it is necessary to generate the patterns files to be used by ArMarkerControls. These files were generated using the AR.js Marker training[11] library displayed by Figure 85. From the "upload" button the an image file is loaded and then from the button "Download Marker" the pattern file exported. All generated files are stored in the "data/data/" folder.

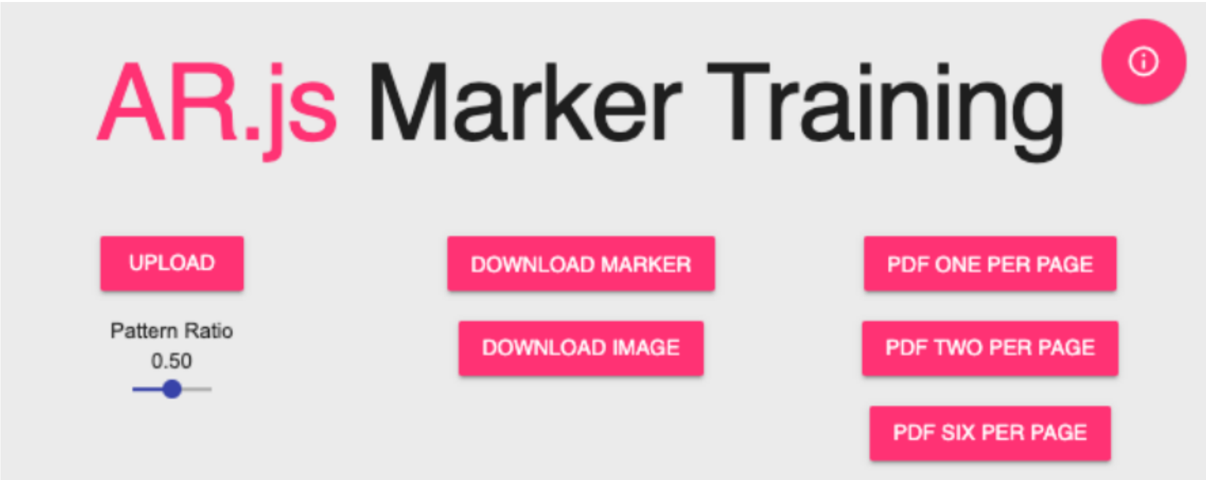

Figure 85 – AR.js Marker Training Maker page

Therefore, the next step is to generate a string vector, where each element is the name of each pattern file, in an example, pattern-00 as exemplified by the code extracted.

```
var patternArray = [];
var nMarkerPatterns = 0;
for (var nr = 0; nr < nrows; nr++) {
  for (var nc = 0; nc < ncolumn; nc++) {
    if (nMarkerPatterns < 10)
       patternArray.push("pattern-0" + nMarkerPatterns);
    else
       patternArray.push("pattern-" + nMarkerPatterns);
  nMarkerPatterns++;
  }
}
```

10 https://github.com/MomsFriendlyRobotCompany/ar_markers
11 https://jeromeetienne.github.io/AR.js/three.js/examples/marker-training/examples/generator.html

The 3D objects were generated using Blender[5]. After animating and drawing, the following export process must be performed. First, a 3D model is selected (Figure 86), then click on the menu “File> Export> glTF 2.0”. In the following dialog box (Figure 87), select the highlighted format (glTF Separated + textures). In the Textures field, inform the path where the texture will be saved, for example, “myModels/textures”. Check the “selected object” option and leave the animation options checked, as ilustrated by (Figure 87). If the Blender version is prior to 2.8, it is necessary to proceed with the plugin[12] installation. Finally, press “Export glTF 2.0” button and select the folder where the models will be stored. In this project, the glTF models are stored in “models/gltf” folder.

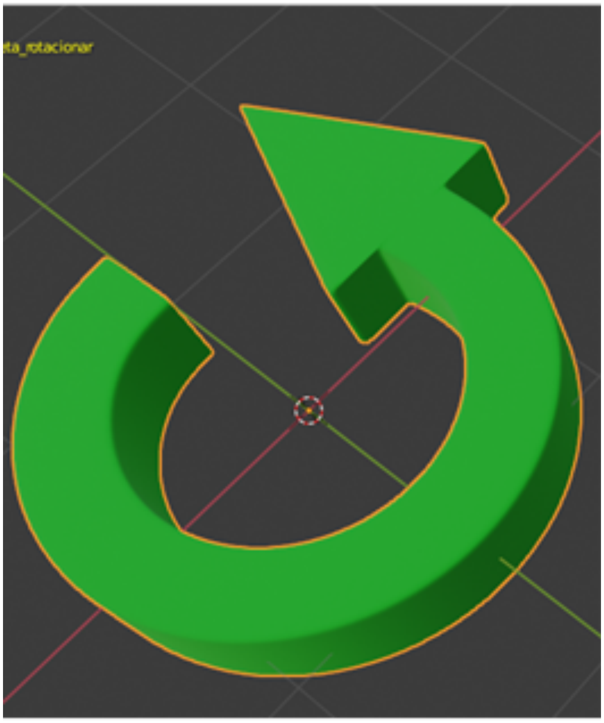

Figure 86 – 3D animated Blender Model

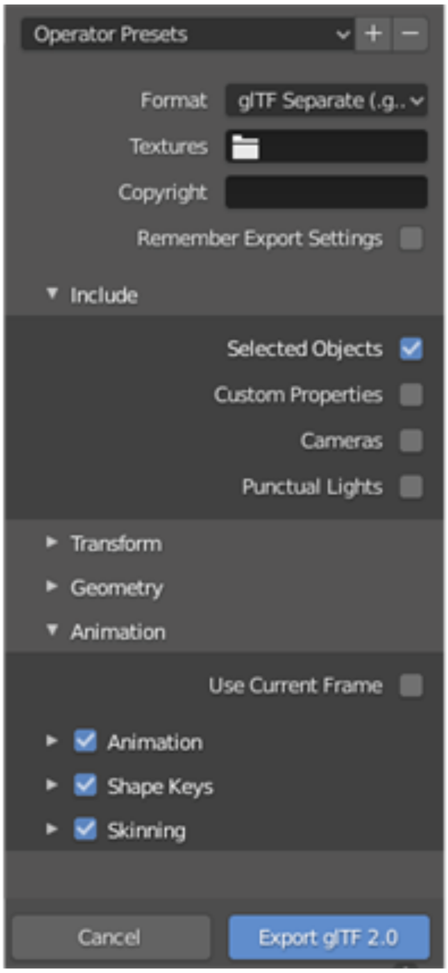

Figure 87 – glTF Export Settings

To complete the process, each pattern file has to be associated with the respective model and adjust its properties. The following snippet code demonstrates these implemented steps. The “nMarkers” variable is a “string” containing the 3D objects name, associated by the therapist in each AR matrix position. Each element of the “ObjectToRender ” vector is filled with these split names, whose size equals to the variable “nMarkerPatterns”. Thus, through the implemented repeating structure, it is possible

[12] https://github.com/KhronosGroup/glTF-Blender-IO

to assign the "markerControls" variable to each marker pattern to the controller. Then, through the GLTFLoader library, stored in the "js/" folder, it is possible to read each 3D model file. For those AR matrix positions, where no objects were associated, the assigned value is "none". Therefore, before calling the "loadAnimation()" function, it is checked of the "ObjectToRender" vector element is equal to "none". So, no object is rendered in that marker. On the other hand, it is verified whether the 3D model is static or animated. If it is an animation, the 3D model is linked to a "mixer" object, with its properties duly changed, allowing them to be animated in the future. Finally, the object is added to the scene "markerRoot" list elements.

```
var ObjectToRender = [];
ObjectToRender = nMarkers.split(';');
for (let i = 0; i < nMarkerPatterns; i++) {
  scene.add(markerRoot);
  let markerControls = new THREEx.ArMarkerControls(
     arToolkitContext, markerRoot, {type : 'pattern',
     patternUrl : "data/data/" + patternArray[i]+ ".patt",});
   var loader = new THREE.GLTFLoader();
   var path_model = "models/gltf/";
   if (ObjectToRender[i] != "none") {
      loadAnimation();
   }
function loadAnimation() {
  var filename = path_model + ObjectToRender[i] + ".gltf";
  loader.load(filename, function(gltf) {
  if (gltf.animations[0] != null) {
     mixer = new THREE.AnimationMixer(modelo);
     mixer.timeScale = 1;
     mixer.clipAction(gltf.animations[0]).play();
    }
    markerRoot.add(modelo);
    }, undefined, function(e) {
    console.error(e);});
} ;
} //fim for
```

Once, having configured all the components responsible for generating the AR feedback from the training site, it is necessary to define the rendering functions. From the code snippet below, the "update()" function is responsible for updating virtual objects over each fiducial AR marker.

```
function update() {
  // update artoolkit on every frame
  if (arToolkitSource != undefined && arToolkitSource.ready
     !== false)
     arToolkitContext.update(arToolkitSource.domElement); }
```

Next, the “render()” function, updates the runtime parameters of the 3D models, the scene objects, camera and speedometer. Every 10 fps the “ajaxSyncRequest()” function make a GET request to “ ServletSpeedPW ” that retrieves from the assessTH table the current PW speed value to update the speedometer.

```
function render() {
  mixer.update(clock.getDelta());
  renderer.render(scene, camera);
  if (gauge != undefined) {
    if(taxaDeAmostragem==10){
      ajaxSyncRequest(assesIDViewPort);
      taxaDeAmostragem=0;
      gauge.setTextField(document.getElementById(preview-
      textfield));
      gauge.set(counter);
      }else{
         taxaDeAmostragem++;   } } }
```

Thus, the function “animate()” is evoked by a received frame event, afford the AR feedback as shown in Figure 82. However, if the connection is closed by the user, some inconsistency, or due to quality restrictions of the WebRTC itself, the 3D rendering objects are automatically hidden and disabled.

```
function animate() {
requestAnimationFrame(animate);
deltaTime = clock.getDelta();
totalTime += deltaTime;
update();
render(); }
```

5.2.2.3 Data acquisition

Since a web browser is a sandbox application, to issue commands inputs to a remote PW, the user has to download the cross-platform Java™ application shown in Figure 88 and 89. From this application, a data connection with the "ServletCommand" is established.

Figure 88 – Starting dataflow

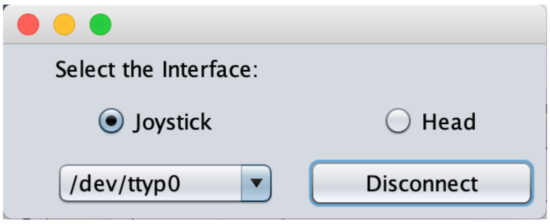

Figure 89 – Close dataflow

This servlet is responsible for forwarding all control input to the training site. However, when a keyboard is used as an interface control, this application is not requested, because the browser recognizes the keyboard as basic input.

The application implementation core is based on the Java Interfaces (shown in the code snippet) concept.

```
public interface deviceConnector {
  public void deviceSensor();
  public void dataProcessor();
  public void forwardData();   }
```

Each control interface (EMG, EEG, Eye-tracking, and others) has the same control actions, although the data is different. The UML Class Diagram shown in Figure 90 illustrates it.

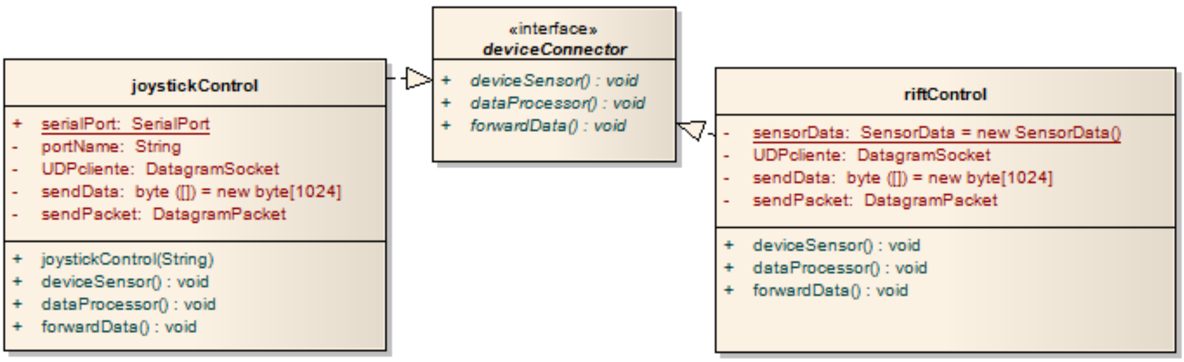

Figure 90 – Class Diagram for handling with different class of data

As a concept proof, it was used the joystick and head movements control interfaces. Since, to form the control commands using the joystick, voltage values are analyzed and for the head movements values (yaw, pitch and row). Thus, to any interface control used the following workflow will be followed:

1. deviceSensor: it is responsible for recognizing each interface controle conected in a computer or notebook;
2. dataProcessor: it is responsible for collection and proceeds with data processing. For each signal, have to make some pre-processing procedures to let this data ready to be classified. After, in the agreement of for each class of signal recognized it belongs of one this command protocol defined: 5 - PW stopped; 1 - PW turn right; 2 - PW turn left; 3 - PW move backward; 4 - PW move forward;
3. forwardData: using the HTTP POST method[13], as described by the code block, a single string carrying the numeric value is sent to the “ServletCommand”. After the therapist releasing, this servlet proceeds with all metrics measuring in or order to provide the relevant data for the therapist training session evaluation.

```
String url = "http://server:8080/webApp/command/"+aux;
HttpClient client = new DefaultHttpClient();
HttpPost post=null;
post = new HttpPost(url);
post.setHeader("User-Agent", "Mozilla/5.0");
HttpResponse response = client.execute(post);
```

To start the data-flow, the user has to select an option. If it is “joystick” then select the port and then press the button “Connect” or “Disconnect” to close data-flow and application.

5.2.3 Therapist session

The following UC actions, described in Figure 38, were implemented to support the therapist’s actions in the telerehabilitation process of PW user’s.

5.2.3.1 User register

The view page presented by Figure 91 (stored as register.jsp) illustrates the second UC implementation performed by the therapist.

[13] https://developer.mozilla.org/en-US/docs/Web/HTTP/Methods/POST

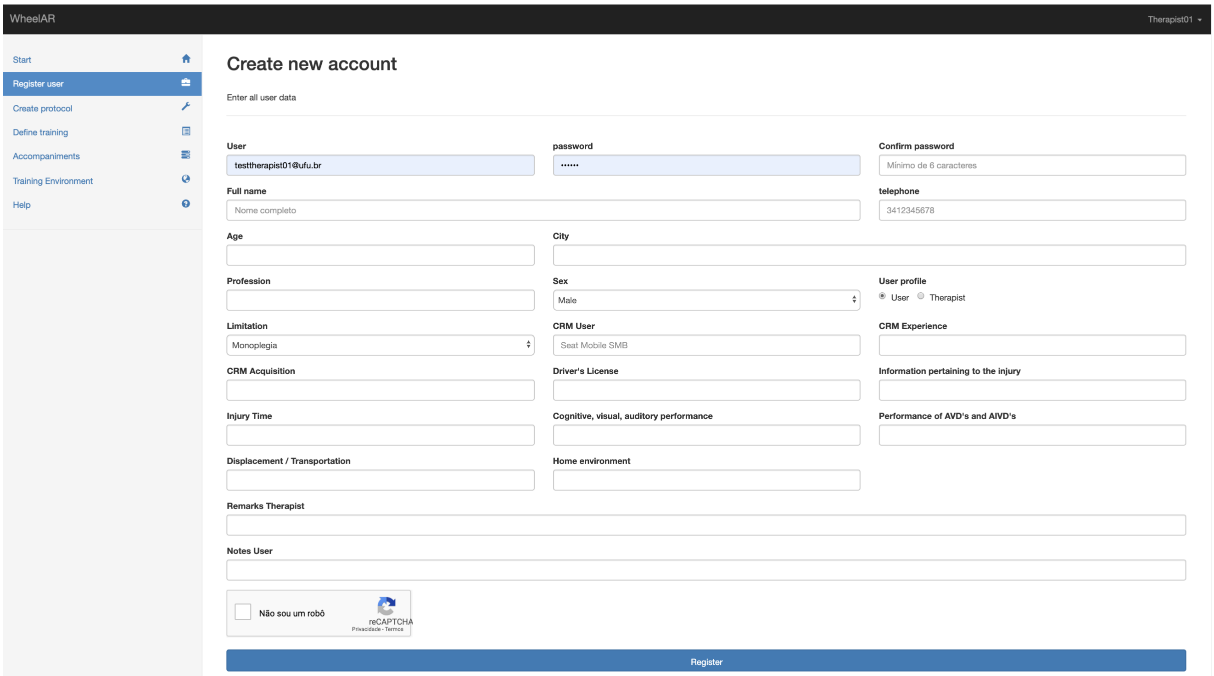

Figure 91 – Register a new user page

According to the selected profile option, a JavaScript method action "showForm" is triggered by a radio button event. It updates field information to be stored in the database. Before submitting the "Register" action to the "ServletRegister" controller, it's necessary to validate the captcha, where the "VerifyRecaptcha" controller is responsible. After, a "Register" button action is submitted to the respective controller, which implements the actions described in the SD action shown in Figure 65. The impairments list is retrieved from the database using the following embedded Java code on .jsp file:

```
rs = st.executeQuery(select * from impairmentTh order by
impairmentID);
 while (rs.next()) {
  out.print(<option value= + rs.getString("impairmentID") + >);
  String[] listDescript = rs.getString("description").split(":");
  out.print(listDescript[0]);
  out.println("</option>");}
```

5.2.3.2 Create protocol

Figure 92 and 93 represent the view page (stored as criar_protocolo.jsp) that illustrates the implementation of the third UC performed by the therapist.

When "Create protocol" action is select into menu, different data are retrieved, such as activities and image lists to promote the PMRT adaptation actions implementation.

A user guide, that describes how to proceed with "Create protocol" SD action, is shown in Appendix D.2.2.2.

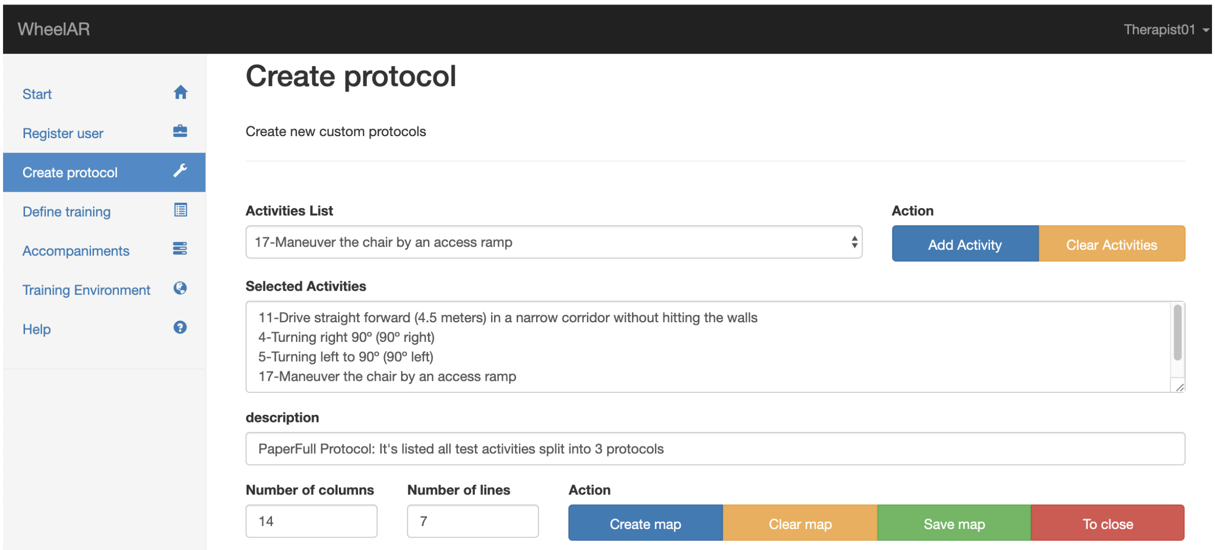

Figure 92 – Defining the activities for each protocol

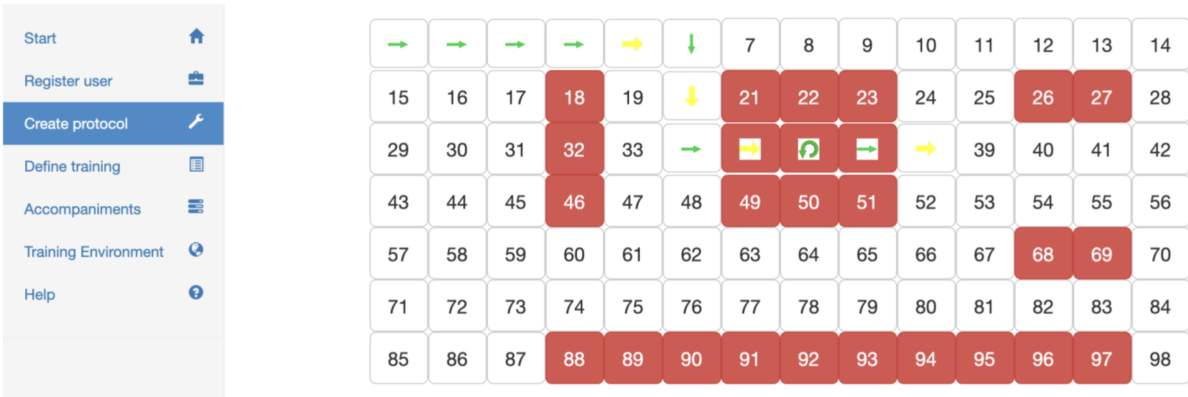

Figure 93 – Create a training activities and protocol map example

From the headerLogged.jsp file, stored in "inc" folder, loaded every time that's the user has logged into the system, many JavaScript files are included in the view pages. The "matrixAR.js" and "formProtocol.js" stored in "js" folder are very important to the "Add and Clear Activity" and to "Create and Clear map" actions. The code imported from matrixAR.js is a function example.

```
function addAtividade() {
  var conteudo = document.getElementById('listActivities').value;
  var atividade =document.getElementById('activityID').options
      [document.getElementById("activityID").selectedIndex].text;
  document.getElementById('listActivities').value = conteudo +
      atividade +"\n"; }
```

The “addAtividade and clearAtividades” onclick event methods from “matrixAR.js”, are inherited on “Add and Clear Activity” buttons. Thus, is possible update information on “Selected activities” field (Figure 92). Also, the “adicionaLinha and removeLinha” onclick event methods from “matrixAR.js”, are inherited on “Create and Clear map” buttons allowing to add or remove an empty AR matrix buttons (Figure 93). Red buttons shown in the AR matrix represent physical obstacles present in the training site.

As mentioned before, an image list from folder “img” is created from an embedded Java code block on “create_protocolo.jsp” file and save on the user session. The following event button methods (selectModel, onSubmit) are incorporated into each AR matrix button stored in “formProtocol.js” file to create “Select model” dialog, which use the image list stored in user session.

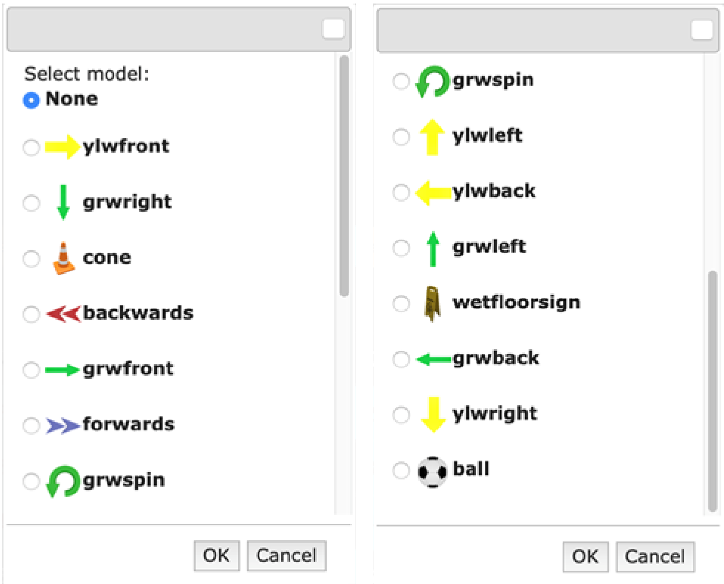

Figure 94 – Virtual objects (animated/statics) list

Then, the therapist is able to define the virtual objects that can be used as guidance or avoidance and also can be static or animated, a protocol example is presented in Figure 93. Thus, it is possible to even in a controlled environment to have a non-structural activity where the user has to decide what he has to do in front of an unexpected event.

The “Save map” button action is handled by “ServletMain” used to record a new protocol in the protocolTH (Figure 77) table, with the number of tasks that will be performed based on the map created by the therapist. The yellow arrows mark the end and the beginning of a new activity, while the green ones are used to guide the user during the protocol execution. The button “To close” is used to exit the system. This Servlet is responsible for handling many different requests from different views. To distinct each request, all button event is filtered to ensure each SD action be performed appropriately, as described by the following snippet code.

```
protected void doPost(HttpServletRequest request,
HttpServletResponse response) throws ServletException,
IOException {
  userButton = request.getParameter("userButton");
  //Verificacao de eventos para registro do survey
  if (userButton.equals("registrar"))
     buttonRegistrar(request, response);
  //Acao selecionar paciente da pagina: acompanhamentos
  if (userButton.equals("selecionarPaciente"))
      buttonSelecionarPaciente(request, response);
```

5.2.3.3 Define protocol

Figure 95 shown the view page (stored as definir_treinamento.jsp) that illustrates the implementation of the fourth UC performed by the therapist.

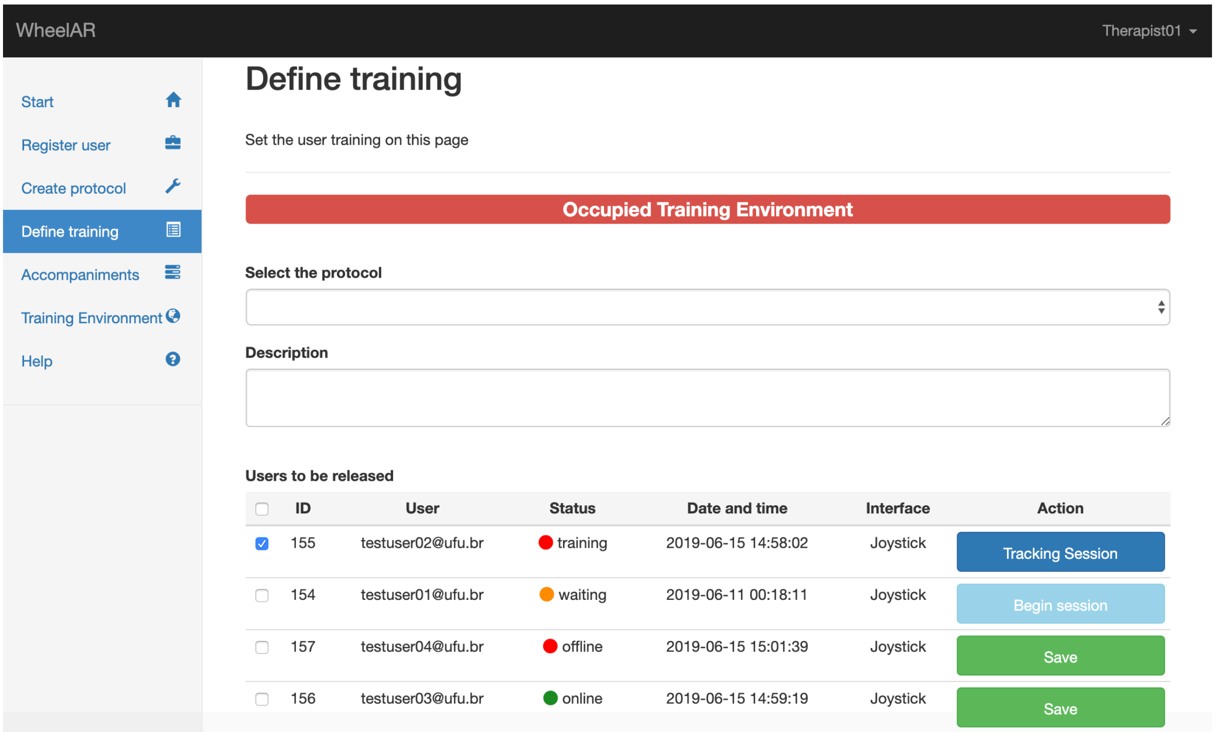

Figure 95 – Define training protocol

From the SD action (Figure 67) all steps implemented in this UC are detailed and explained on user guide in Appendix D.2.2.3. After the action “Define training” is chosen on the menubar, three different Java code blocks are embedded on “create_protocolo.jsp” file and executed before the therapist starts with his actions.

The first one is responsible for checking if the training environment status. When the environment status is “Occupied”, the “Begin session” button is disabled, until training in session in progress has finished.

```
//Checking if there are any users in training
Integer qtd = 0;
rs = st.executeQuery(select COUNT(userID) as Qtd from patientTH
     where status='training');
if (rs.next())
  {
  qtd = rs.getInt("Qtd");
  if (qtd > 0){%>
    <h3><label class= label label-danger center-block for=
    "statusEnvironment">Occupied Training Environment</label>
    </h3> <% }
  else { %>
   <h3> <label class= label label-success center-block for=
   "statusEnvironment">Free Training Environment</label>
   </h3>
   <% }
 }
```

The second one check if in the current session, the therapist already defined a training protocol, which means, he intends to start a new session. Thus, the “Select the protocol and Description” fields are hidden until the therapist accomplishes the following session. However, if none protocol were previously defined, another embedded Java code block is executed, retrieving from the database the protocol and activities list.

The third one is responsible for list all training request by the users on charge of this therapist.

The last actions were updated only on the front-end. However, when a training protocol is selected by the therapist, an Ajax[14] Script is also embedded in this file, request from a GET method, the protocol description. The next “Track session, Begin session and Save” actions are handle by “ServletMain” that filters each one by button action, proceeding just like described in SD action (Figure 67).

Based on training ID where the “Save” button is pressed, basic information like protocolID is updated on table assesTH. All information related to the protocol (tasks and virtual objects list) and the user profile are updated on the current session and redirect to the same view page again.

[14] https://developer.mozilla.org/en-US/docs/Web/Guide/AJAX/Getting_Started

When the "Begin session" button actions are received on "ServletMain", its only redirects the therapist to the view page "Start streaming" (stored as startstream.jsp). This action is remotely performed only from the training site and the implementation details is describe in Section 5.3.1.

After a training session has initiated, the "Tracking session" action can be requested and "ServletMain" redirects the therapist to the waiting view page presented in Section 5.2.2.1. As a training session is already defined, it redirects the therapist to the "Therapist ViewPort" view page shown in Figure 96 that were implemented similar to "User ViewPort" presented in Section 5.2.2.2.

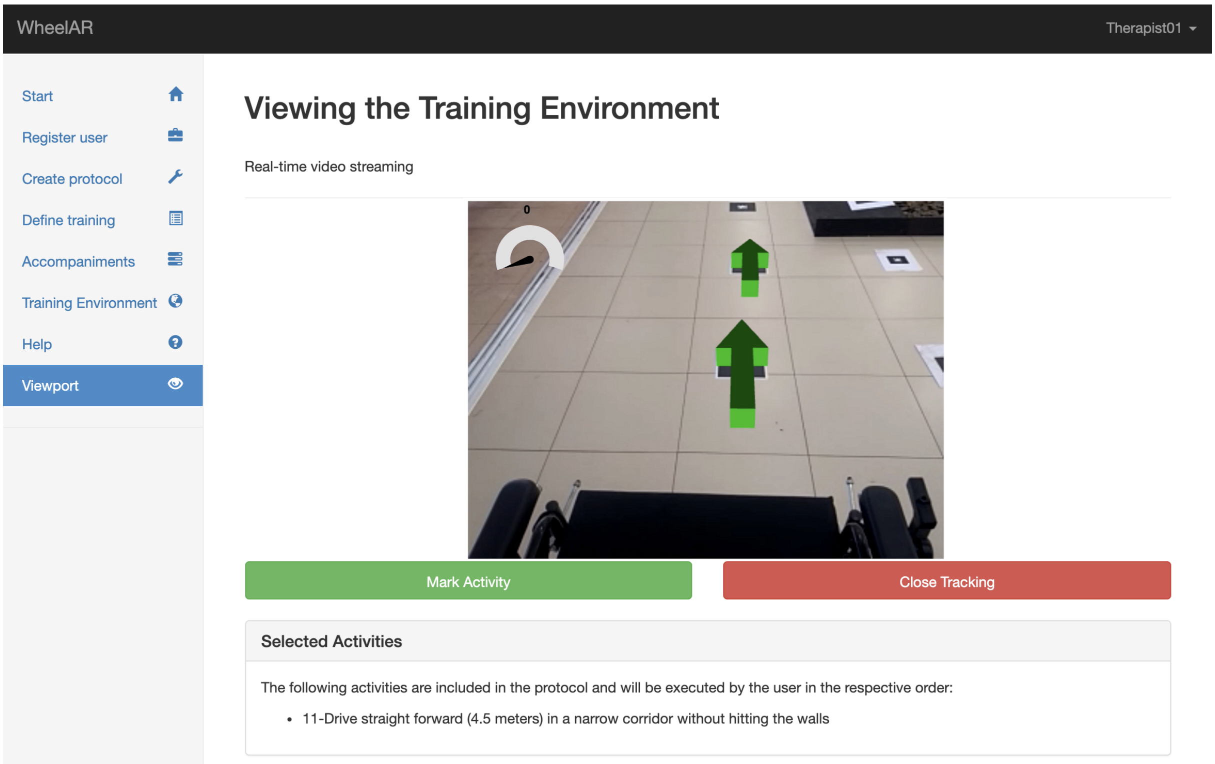

Figure 96 – Tracking session and Therapist ViewPort page

Thus, it allows having augmented feedback from the training site. Furthermore, "ViewPort" view page has the button action dynamically update according to the user profile and also brings the activity list to be performed by the user on bottom. For the therapist profile, two different button actions are included ("Mark Activity and Close training").

The "Mark Activity" button action is very important, once the commandStamps and timeStamps are stored on assessTH table to ensure a future evaluation. Each training protocol can have different tasks number. Then, to mark when a performed task has accomplished by the user, this button action was implemented and its function were attached with "markTask.js" file stored in "js" folder. It's a simples action, when this button is pressed, a specific command is sent to “ServletCommand” which is responsible for handling it, a “-” is inserted into the command and timestamp string allowing to apply a separated measure for each task later.

Therefore, when the user concludes the training session, the therapist trigger the “Close training” handled by “ServletMain”. Before being redirected to the next UC action “Evaluate training”, the data stored during the user’s training session is processed. Information such as the participant and protocol name, execution date, beginning and end training time, session time, commands amount and elapsed time for each activity are separated and updated in the session.

5.2.3.4 Evaluate training

Beyond allowing the PW user to perform telerehabilitation activities as they do in rehabilitation centers, the therapist must be enabled to perform their assignments at a distance. Also, creates individualized training activities, he must be able to assess the user’s performance after the training section. Thus, an adaptation to the PMRT assessment form was implemented (stored as avaliar_treinamento.jsp), as shown in Figure 97 to ensure it.

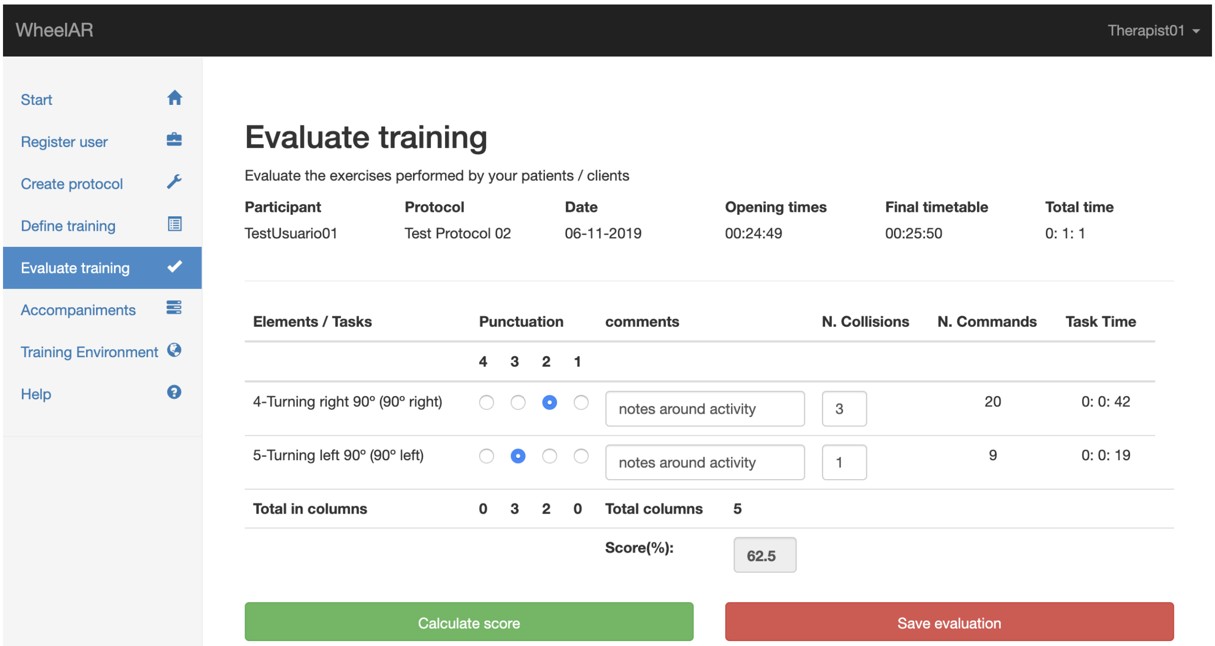

Figure 97 – Adapted PMRT Evaluation Form

The PMRT Assessment Form is automatically generated on onload view page process by an embedded Java Code, responsible for collecting all training data on the session and render the evaluation form with the “Calculate score and Save evaluation” button action.

The therapist has to fill out the comments around, collision number and then choose a relative score for each activity. Before saving the evaluation, the “Calculate score” button is triggered to update the score, where a "onclick" JavaScript action is attached. Thus, when the "Save evaluation" action button is pressed the "ServletMain" update the assessment information on the "assessTH" table and system redirects user for the next therapist UC action "Anottations".

5.2.3.5 Annotations

After the redirect action to the "anotacoes.jsp" view page (Figure 98) that implements the last task to be concluded by the therapist of the user training session evaluation.

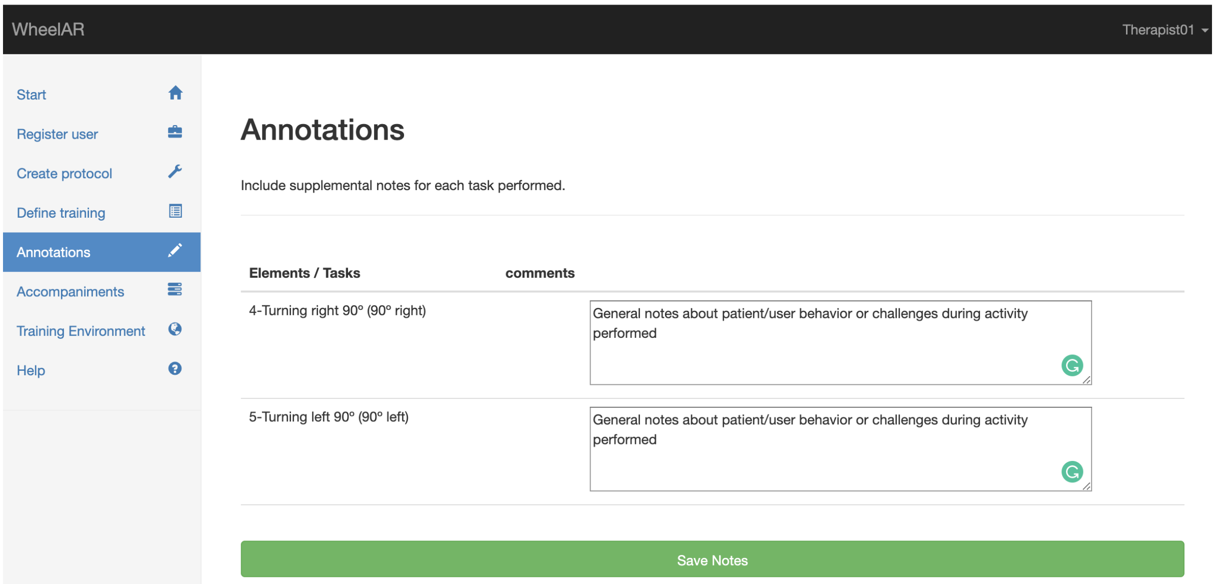

Figure 98 – General and clinicians notes around the user evolution

On onload view page process, another embedded Java code block is executed. It retrieves from session variables the current training tasks performed by the user. Allowing the therapist to take notes related to the user evolution, and after, pressing the button "Save notes" another POST action is sent to the "ServletMain". It recognizes the request and stores the information filled out by the therapist on the "historyTH" table.

Then, redirects the therapist to the main page from where he is able at any time to follow the user's evolution history.

5.2.3.6 Accompaniments

In order to provide to the therapist clues of the user evolution after the training sessions, the "Accompaniments" view page (stored as a acompanhamento.jsp) is presented by Figure 99. This therapist UC action can be accessed at anytime because all training metrics are merged in a bar chart graph generate in real-time.

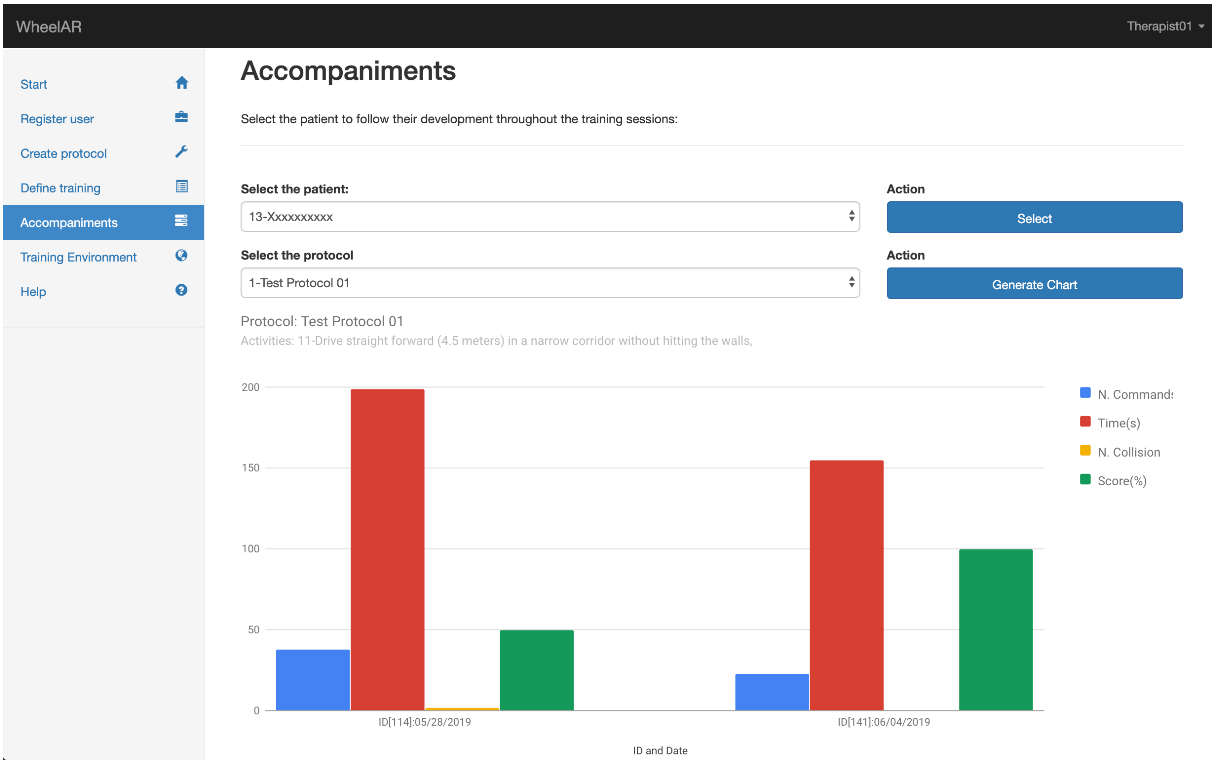

Figure 99 – Comparative chart users training protocols performed

Firstly, an embedded Java code responsible to fill the "Select the user" list is executed on onload view page process. To generate a chart, the therapist has to select a user on the list and press the "Select" button action that is sent to the "ServletMain". The servlet retrieve from the "assessTH" table all training records and respective metrics and update it on session. Now, the therapist is able to select from "Select the protocol" list all training sessions performed and to preview the chart the "Generate chart" button have to be pressed.

Using the "Google Charts"[15] free JavaScript library, it is easy to generate a different kind of graphics information. Then, following the library documentation all session data is properly used to fill each function and render the visual graphics.

In addition to this graph, information about the SI or excitation from the biosignals allows the evaluation of the emotional state of the same, helping also in the understanding of the real difficulties and observing the overcoming of them after each session.

5.3 Training site

It is from this site that a large part of the telerehabilitation process takes place. The user can control the PW, safely increasing their driving skills remotely. The therapist

[15] https://developers.google.com/chart

can define and create protocols remotely, that the user will execute, if necessary, interact with the PW. Also, simultaneously they preview augmented feedback from the training to be conducted. For this reason, the implementation details are divided into two parts: opening and transmitting the video stream and PW embedded program for remote control.

5.3.1 Start streaming

As previously mentioned in Section 5.2.3.3 the action “Begin session” interfaced through the page “Start Streaming” (Figure 100) is performed only from the training site.

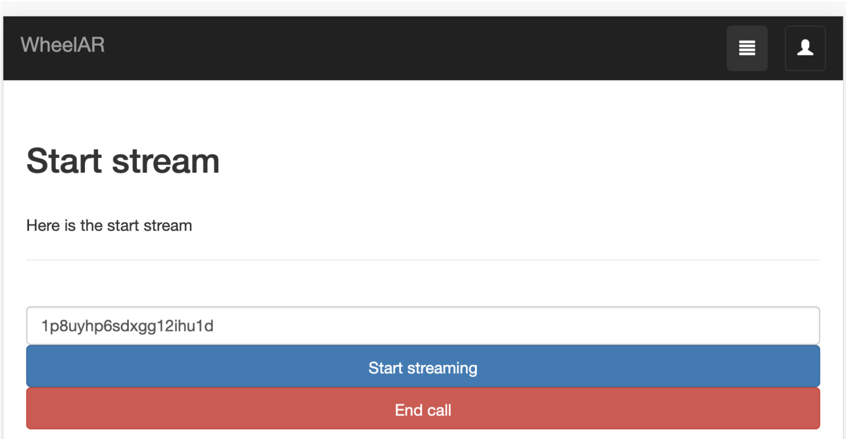

Figure 100 – Start streaming therapist page

The buttons displayed on the page, as well as the text field that displays the code automatically generated for connecting to the room, are demonstrated in the HTML code snippet.

```
<div class="row">
  <div class="col-md-6">
   <input type="text" id="room-id" value="abcdef">
  </div>
  <div class="col-md-3">
   <button id="open-room">Start streaming</button>
  </div>
  <div class="col-md-3">
   <button id="" onclick="endStreaming()">End call</button>
  </div>
</div>
<div class="hidden␣text-center␣container" id="videos-container">
</div>
```

To implement the WebRTC streaming, same libraries from “js/dist/” and also “js/dev” (getHTMLMediaElement.js and adapter.js) were used. Before the “Start streaming” action button is pressed, where a JavaScript event click is attached, an automatic video device detection was implemented. It is needed because there is a difference in detecting devices on smartphones (which have more than one device (front or back)) to a desktop or notebook (which has only one video device (front)). The code snippet below exemplifies the actions implemented.

```
var videodeviceid;
var videoList=[];

navigator.mediaDevices.enumerateDevices().then(gotDevices).
  catch(handleError);
function gotDevices(deviceInfos)
{
  for (var i = 0; i !== deviceInfos.length; ++i)
   {
    //implements a video and audio devices detection
    //add devices detected to the videoList vector
   }
  if(DetectRTC.isMobileDevice)
   {
   //retrieve the second element from the videoList
   }
  else
   {
   //retrieve the first element from the videoList
   }
}
```

Using the “adapter.js” library is possible to enumerate audio and video inputs. The deviceInfos variable has this information and using a repeating structure; it is possible to filter and store on videoList vector, those are interested. Then using the “DetectRTC class” from the “getHTMLMediaElement.js” library, it is possible to know if the user is using a desktop, notebook, or smartphone and select the specific video device. When it is a “MobileDevice”, the second element of the videoList selected to use the back camera device.

To start a shared video call, the “ Start streaming ” button must be pressed. Through the click event associated with it, another function in JavaScript is executed.

It displays the video element previously hidden, because an HTML canvas object for rendering the video, will be returned. Next, the room-id randomly generated, and also, the video-source-id of the streaming, are retrieved. Through the "socket.io.js " library, a new "WebSocket" is created to wait for the connections to be established through a shared link. After this process is completed on the front-end, the video is updated in <div> (videos-container), another JavaScript function that executes an HTTP POST method, sends the generated room-id to the "ServletWebRTC". Thus, the servlet proceeds with updates process: the connection training link and release column to "true" in the table "assessTH", the user status for "training" in the table "patientTH". These updates allow the commands to be forwarded to the training site and metrics measuring by the "ServletCommand".

5.3.2 PW Control

To ensure that the PW can be remotely operated, embedded software has been implemented. This software works as a polling IO process. Then, it is possible to receive the commands through WiFi, start the engines properly and update their PW speed information.

The first step is to change the Dlink DWR-922B 4G router modem settings so that it correctly forwards the received packets from the external network to the internal network. This feature is known as the "port forwarding" setup (Figure 101).

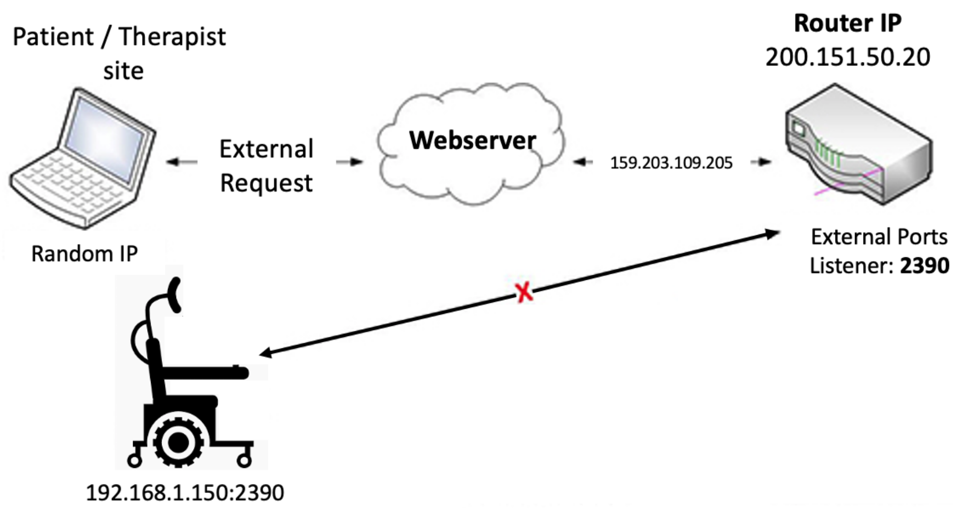

Figure 101 – General Port Forwarding Network Diagram

Following the router's user manual, installation is straightforward. For this, it is necessary to define a name for the routing, the public port as (2390), traffic type as UDP, define the Arduino internal IP and the internal port as (2390). With this, the embedded software is ready to receive commands and transmit information with the web server.

Before describing part of the code that was implemented to perform the control, emergency stop and PW speed update, it is necessary to set up all the microcontroller resources to be used, such as external interrupts and digital pins. The code snippet below describes this configuration.

```
//SETTING UP PW PINS
pinMode(2, OUTPUT); // PW control 2 pin
pinMode(3, OUTPUT); // PW control 3 pin
pinMode(4, OUTPUT); // PW control 4 pin
pinMode(5, OUTPUT); // PW control 5 pin
pinMode(6, OUTPUT); // PW control 6 pin

//SETTING UP RPM SENSOR
pinMode(30, OUTPUT); //VCC Pin
pinMode(32, OUTPUT); //GND Pin
digitalWrite(30, HIGH); //Turning VCC on
digitalWrite(32, LOW);  //Turning GND on

//SETTING UP External Interrupt (Speed Sensor)
attachInterrupt(digitalPinToInterrupt(Speed_sensor_interrupt),
 debounceInterrupt, CHANGE);

//SETTING UP WIFI CONNECTION
setupWifiConnection();
```

The five settings up PW pins described will be used by a function responsible for verifying which command (string) received from the server and adjusting different voltage values for each pin, promoting the proper activation of the PW.

The RPM sensor configurations pins were performed due to a limitation of the microcontroller pins number (VCC and GND) necessary for feeding the sensor. Next, a function configuration for treating external interrupts detection by the infrared sensor reflection variation was defined.

However, without the WiFi Shield configuration, which is responsible for handling receiving and sending information through the router, none of this is of use. For this, an UDP data communication[16] example was used, provided by the manufacturer to deals with it, is represented by the setupWifiConnection() function.

The polling IO process is implemented by the "void loop()" function.

[16] https://www.arduino.cc/en/Tutorial/WiFiSendReceiveUDPString

```
void loop() {
  checkRPMValues(); //Checking sensor state

  // if there's data available, read a packet
  int packetSize = Udp.parsePacket();
  if (packetSize) {
    timeIn = millis(); // Storing the incoming packet timestamp

    // read the packet into packetBufffer
    int len = Udp.read(packetBuffer, 255);
    if (len > 0) {
      packetBuffer[len] = 0;
    }
    lastCommand=packetBuffer[1];
    updateWheel_kmh();
    deltaTime.concat(wheel_kmh);
    deltaTime.toCharArray(packetBuffer, deltaTime.length() + 1);
    //reply, to the IP address and port that sent us the packet
    Udp.beginPacket(Udp.remoteIP(), Udp.remotePort());
    Udp.write(packetBuffer);
    Udp.endPacket();
    deltaTime = "";
  }
  activateMotors(lastCommand);
  securityStop(timeIn);
}
```

Continually, the revolutions per minute (RPM) number of the PW is updated, and also, if there is any data packet received. If it exists, then the received package time is stored, and immediately the package is read. After due checks, the transmitted command value is correctly assigned to the “lastCommand” variable, as it will be used to start the PW engines. Thus, the RPM value is converted into kilometers per hour (Km/h). This value is assigned to the received package and forwards it back to the “ServletCommand” to update this value into the “assessTH” table to allow “ServletSpeedPW” to collect valid speed information and update it on the speedometer. Finally, the functions “activateMotors” and “securityStop” are called to respectively activate the PW engines and if the time without receiving packets is more than three seconds, stop the PW.

5.4 Final considerations

This chapter described the implementation details of the proposed system architecture to support telerehabilitation for training PW users, using Augmented Reality techniques. So far, it has been found in the literature no architecture that allows the therapist and users to continue this fundamental process, despite the distance.

In order to overcome this distance, the WebRTC framework was used to allow even in a different site (therapist and patient) to be connected to the training site. However, it is not just about being connected. It is also needed that the user has a safe and enriching training experience within their conditions.

For this, it is also necessary for the therapist to be able to use some technological resource that, even at a distance, the user can be guided in a real scenario, performing personalized tasks, and the therapist still is able to evaluate and monitor his development. For this reason, the use of Augmented Reality techniques is essential for allowing this remote customization where the entire process can be carried out safely.

Many challenges have been found during this process, since the implementation of the web server responsible for meeting all these demands, so that everyone could use it easily without any program installation and that it could be accessed from any computer with the Internet, is not trivial. The integration of WebRTC with Augmented Reality was challenging as the AR libraries were not prepared to work with remote video sources, and also, with the dynamic 3D objects update in the environment's markers in agreement with therapist definition.

The development of this architecture is not just the one purpose of this work. But also to demonstrate the architecture capability to afford telerehabilitation. Thus, adaptative and customized training protocols, training evaluation, realistic and safe training conditions were implemented. Eligible users have evaluated the architectural features and the results obtained are presented in the next chapter.

6 Results and Discussion

6.1 Introduction

This chapter presents obtained results. Through the experiments with eligible volunteers, a set of important quantitative metrics were collected, which allows an evaluation, based on PMRT. Qualitative data were obtained from the survey filled by the volunteers and therapist about the system acceptance and limitations during their trial experience.

6.2 Trials performance evaluation information

Table 10 present the performance evaluation realized by the therapist.

Table 10 – PMRT Evaluation Summary

<table>
<tr><th>Participant</th><th>Protocol / Tasks</th><th>Command</th><th>Collision</th><th>Time(s)</th><th>Score(%)</th></tr>
<tr><td rowspan="4">1</td><td>1.1</td><td>38</td><td>2</td><td>199</td><td>50</td></tr>
<tr><td>2.1</td><td>37</td><td>1</td><td>328</td><td rowspan="2">50</td></tr>
<tr><td>2.2</td><td>7</td><td>0</td><td>57</td></tr>
<tr><td>3.1</td><td>54</td><td>0</td><td>354</td><td>75</td></tr>
<tr><td rowspan="4">2</td><td>1.1</td><td>27</td><td>0</td><td>282</td><td>75</td></tr>
<tr><td>2.1</td><td>17</td><td>0</td><td>127</td><td rowspan="2">75</td></tr>
<tr><td>2.2</td><td>21</td><td>0</td><td>67</td></tr>
<tr><td>3.1</td><td>66</td><td>0</td><td>178</td><td>75</td></tr>
<tr><td rowspan="4">3</td><td>1.1</td><td>14</td><td>0</td><td>227</td><td>75</td></tr>
<tr><td>2.1</td><td>9</td><td>0</td><td>98</td><td rowspan="2">50</td></tr>
<tr><td>2.2</td><td>13</td><td>0</td><td>51</td></tr>
<tr><td>3.1</td><td>34</td><td>0</td><td>236</td><td>75</td></tr>
</table>

6.3 System requirements information

Figures 102 and 104 represent the average and standard deviation value of each participants' evaluation based on survey questionnaire questions present by Tables 8 and 9 in Section 4.6.1. Figures 103 and 105 represents visual qualitative information about advantages, disadvantages and comments inputed of each training experiment performed by the user's. The questions applied were divided into two groups: good aspects or limiting aspects. Where, for questions where the average value was greater than or equal to three, it is considered good; otherwise, it was considered a limitation.

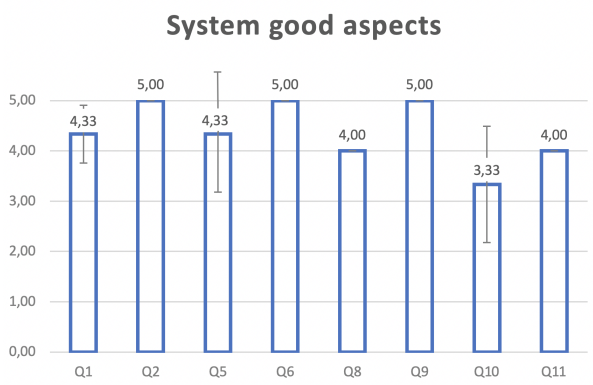

Figure 102 – System Good Aspects

Figure 103 – Good evaluations

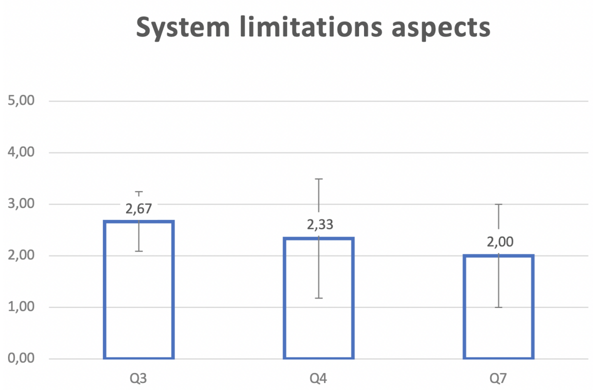

Figure 104 – System Limitations Aspects

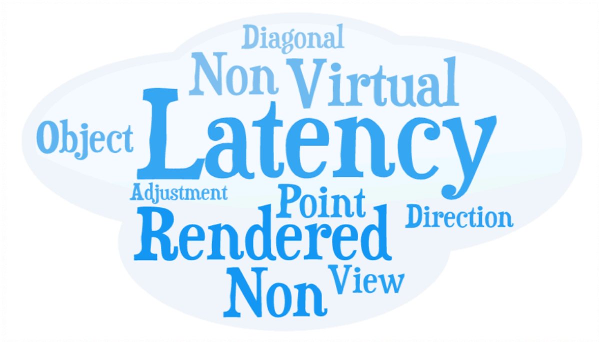

Figure 105 – System limitations evaluations

The discussion around the extracted graphic data that represents the users' evaluation will be carried out in Section 6.5.

6.4 Protocols evaluation

6.4.1 Electrodermal Activity Analysis

The ISCR (obtained after processing EDA) Descriptive Statistics is presented in Table 11 (BRAITHWAITE; WATSON, 2015). It is possible to observe that Skin Conductance Responses are skewed and can produce non-normal distributions (BRAITHWAITE; WATSON, 2015), as observed in the difference between ISCR average and ISCR median.

Table 11 – ISCR Descriptive Statistics

Group	Count	Mean	SD	Median
Protocol 01	83	-4.65e-18	0.988	-0.110
Protocol 02	111	-9.01e-12	0.991	-0.263
Protocol 03	123	-2.44e-11	0.992	-0.274

Columns meaning:

- Count: number of observations;
- Mean: ISCR average on each protocol;
- SD: Standard Deviation of ISCR on each protocol; and
- Median: ISCR Median of each protocol.

Results of statistical analysis of ISCR as a variable in each protocol are: **Kruskal-Wallis chi-squared = 0.012995, df = 2, p-value = 0.9935**, showing no statistical significant differences between each protocol applied related to ISCR (BODKIN; HART; WERNER, 2019). These results refer only to the sample utilized, to demonstrate system's capabilities. A higher number of volunteers in future studies will be necessary to draw broader and more general conclusions. Therefore, future studies should consider a higher number of participants.

6.4.2 Stress Index Analysis

It is important to monitor subject conditions during training to be able to safely conduct activities and to objectively determine causes of failure during wheelchair driving in order to provide a course of action towards acquisition of good driving skills (AFFANNI et al., 2018; HEALEY; PICARD, 2005).

Stress (both physical and psychological) affects subject abilities to safely drive vehicles, and driving PW is no different. Some studies were conducted aiming to provide stress measures using biosignal monitoring and processing (HEALEY; PICARD, 2005).

It is not an objective of this work to propose a new stress measure. Instead, was used a stress measure already discussed in the literature (BAEVSKY; BERSENEVA, 2008) that is easily obtainable through a free version software Kubios (HRV-SOFTWARE, 2017).

Aiming obtain the stress index for each protocol and each participant, we used the IBI time series prepared for processing using Kubios.

Table 12 present the Stress Zone and corresponding SI (Stress Index) band values.

Table 12 – Stress zone boundaries (HRV, 2018)

Stress Zones	SI
Very High	>30
High	22.4 - 30
Elevated	12.2 - 22.4
Normal	7.1 - 12.2
Low	<7.1

Participants comparison results are presented in Table 13:

Table 13 – Stress zone participants comparison

User	SI Protocol 1	SI Protocol 2	SI Protocol 3
Participant 1	12.0769	11.4139	9.9194
Participant 2	17.5959	14.8135	16.9240
Participant 3	6.0430	5.2265	8.0705

Finally, data presented on Table 13 is translated to stress zones in Table 14:

Table 14 – Stress zone participants translation

User	SI Protocol 1	SI Protocol 2	SI Protocol 3
Participant 1	Normal	Normal	Normal
Participant 2	Elevated	Elevated	Elevated
Participant 3	Low	Low	Normal

All participants did not have a significant change in their stress index between protocols, which supports the conclusion that the protocols might not have an impact on subject's stress. A bigger sample can support more strongly this conclusion, which can be done in future studies.

6.5 Discussion

To better understand the participant's acceptance of the developed tool/architecture and its requirements, the following considerations are presented.

Questions 1, 2 (Figure 102) and 3 (Figure 104) seek to evaluate usability. It is possible to note that the participants considered the GUI handy and that the system is easy to learn. According to participants, the two main faults in the system were the latency (response time - Q7 (Figure 104)) and failure to render virtual objects (Figure 105) shown in Figures 106, 107 and 108. In Figure 106, the guidance arrow is rendered at a wrong place, in Figure 107 and 108 the guidance and final activity arrows were not rendered properly, due to image quality, marker size or illumination. Other facts can be considered, with less relevance such as the PW does not possess diagonal movements Q4 (Figure 104) and adjustments from the participant (Figure 105).

On the other hand, questions 5, 6, 8, 10 and 11 (Figure 102) confirm that the application of telerehabilitation techniques fused with the AR techniques present itself as a great tool to support the users driving skills improvement, without leaving their home, in agreement with participants evaluations in Figures 102 and 103.

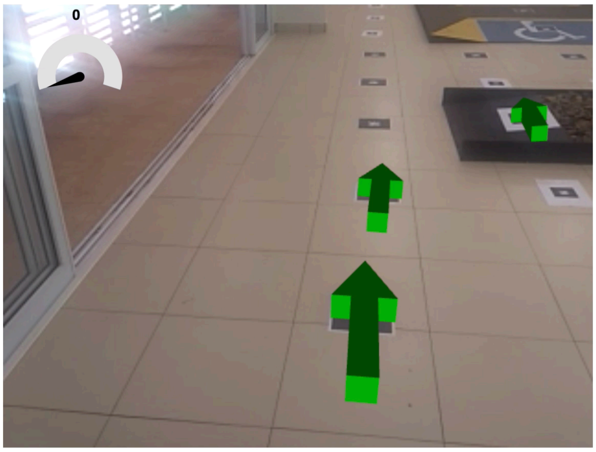

Figure 106 – Rendering failure-01

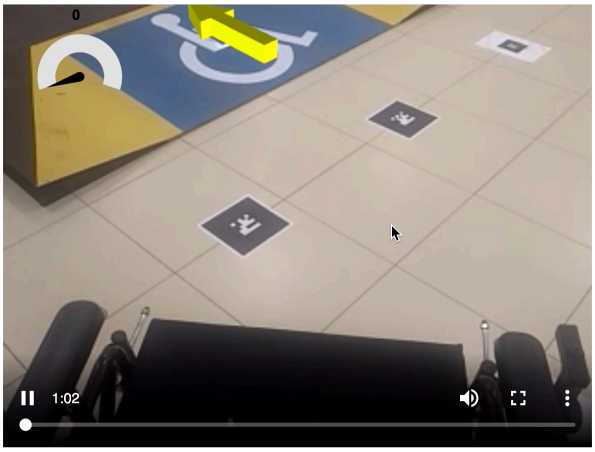

Figure 107 – Rendering failure-02

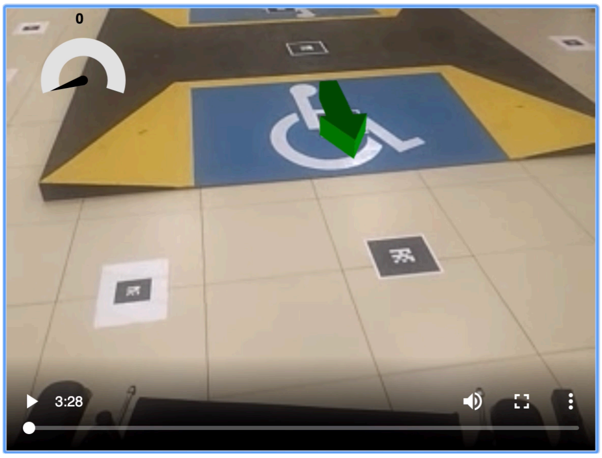

Figure 108 – Rendering failure-03

This is due to the realism, by controlling a real PW, through a real scenario, in addition to listening to the sounds of triggering and pausing the PW, during the training execution, as shown in Figures 109 and 110.

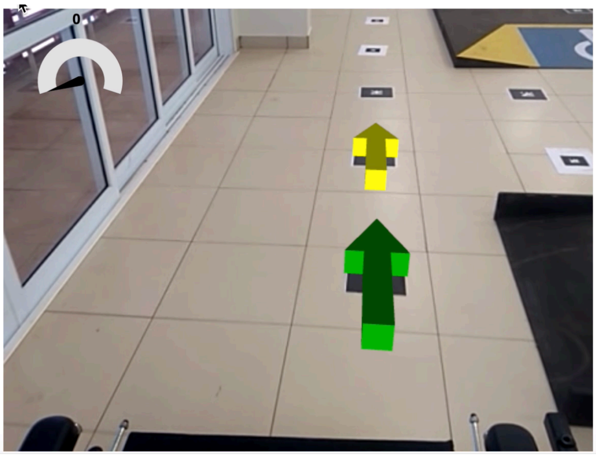

Figure 109 – End first activity

Figure 110 – Spin the PW

During the execution of each training protocol, the therapist is able to monitor the participants' performance in the proposed activities. Upon completion of the training process, the therapist must fill the adapted PMRT assessment form. Information such as number of commands and elapsed-time are retrieved from the database. The therapist must still fill in the number of collisions and comment on the participant's performance, before assigning a score (4, 3, 2, or 1) to the activity, following the criteria established in Section 2.4. After each activity scores are applied, the final score of the protocol is calculated as described in Equation (6.1).

$$Y = \sum_{i}^{n} \left(\frac{x_i}{n * 4} \right) * 100\% \tag{6.1}$$

Where:

- Y: final score obtained;
- n: tasks number defined for each training protocol;
- i: present task index; and
- x_i: present task value attributed;

The evaluation summary from the participants is presented by Table 10 and as defined, a score greater the 95% is needed to be considered approved (MASSENGALE et al., 2005). Nobody passed the experiments! Observing the criteria for grading and monitoring the participants training, it is understandable that this did not happen. Among them, some had severe collisions, or to complete the activity, they had to restart a maneuver several times. It reduces the task score value. But the objective was not to approve or not each participant but to demonstrate that the system also offers resources for user evaluation by the therapist. Also, the therapist can follow the evolution of the participant's abilities through the comparative bar charts, shown in Figure 111. Furthermore, he can define the design of future protocols that will prepare the user to drive a PW in their daily activities confidently.

Biosignals can provide important information related to participant's performance connected to the emotional state, which can prove useful in future training applications and on strategies for improving safety during PW use.

The participant's emotional state can constitute a barrier to good driving performance. Thus, it is important to understand, whenever these issues arise, whether the underlying cause is related to the participant's motor skills or associated to their emotional state, looking to correctly address these issues. Additionally, in training protocols, it is desired that the user is not overwhelmed by the training difficulty level, which could be observed through his biosignals with appropriate methodology and detection algorithms.

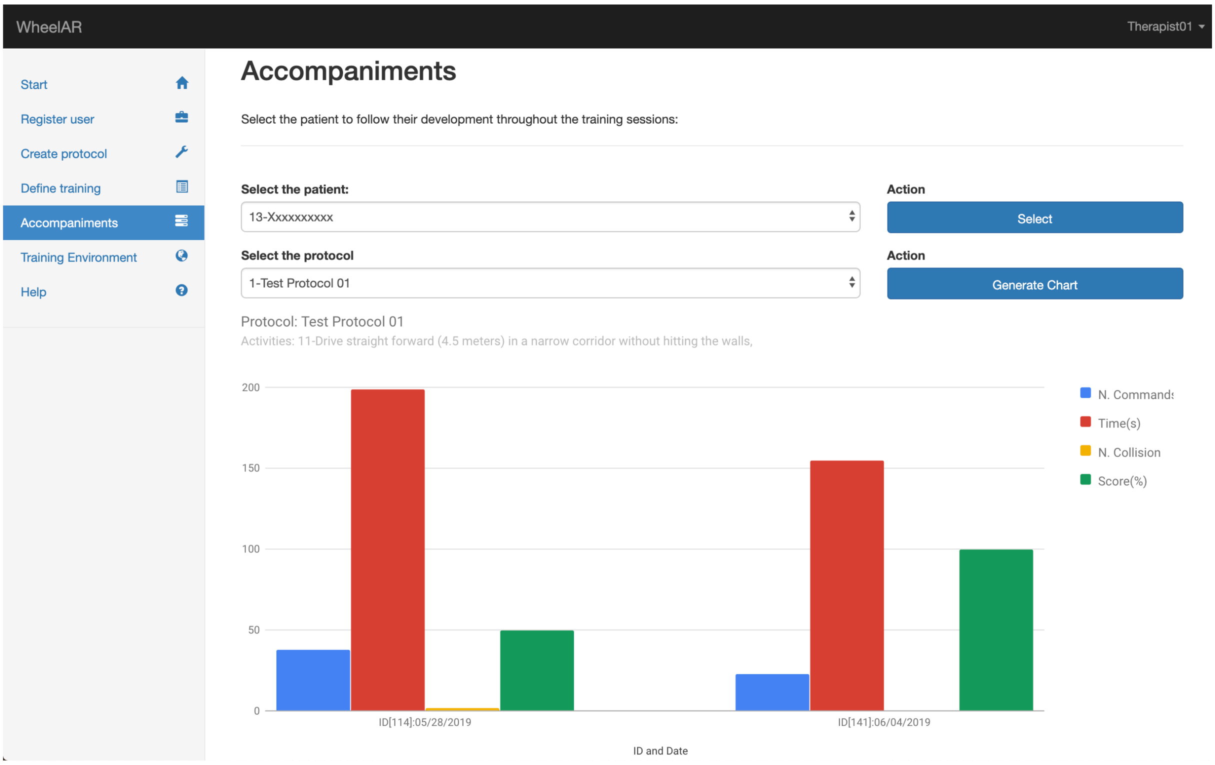

Figure 111 – User training protocol comparison

As can be seen from question 9 evaluation, none of the users felt tired after completing the proposed protocols. What allows us to observe another benefit made possible by the architecture, which is the adaptation of the PMRT, allowing the adjustment in the number of activities of the protocols.

This means that, in this specific case, there was no relevant difference on participants performance considering the three different protocols. However, this does not represent a final conclusion given that the sample was small and the protocol duration, considered as short - longer protocols, might present different results. The intention of this preliminary test is to show the system architecture capabilities. Having a different impact across individuals may emphasize the importance of having individualized or personalized protocols that could be based on therapist observations complemented by biosignal data.

6.6 Final considerations

First collaborations that the system brought to the participants are: increased well-being after each session, level of realism and immersion and still listening to the PW engines and collisions. All of this is due to the adaptation made in the PMRT merged with AR techniques, which allow the therapist to define a protocol that best suits the participant in real-time. Even though in this study, everyone used the same protocol.

In addition, the analysis of biosignals was presented as a good assessment alternative because it allows realizing how deeper and challenging a protocol can be for a user, allowing for another assessment, which is not based on the therapist's visual analysis.

However, still talking about the system, a significant challenge encountered by all telerehabilitation systems was present: latency. It reduces the impression of real-time interaction with the increased environment. This is an Internet limitation, in general, some flaws, such as rendering objects, because the images have a reduced quality to maintain the connection. However, the architecture already presents its potential for both therapists and users, but it still requires some improvements like fiducial AR marker recognition avoiding failure on virtual objects rendering, to exchange the current PW by another one with diagonal movements and promote studies about how to reduce latency effects on the video stream.

In the next section, general conclusions about the work and future improvement actions will be presented.

7 Conclusions and Future Work

7.1 Introduction

In this work, an augmented telerehabilitation architecture for supporting PW driving skills training is proposed. Being aware of PW user's abilities and limitations in the rehabilitation process (get back to perform daily activities), driving skills might be developed. Also, the therapist responsible for the rehabilitation process, finds necessary to identify resources to meet the individual user needs, creating and evaluating training. For this, telerehabilitation and AR techniques are presented as a solution. Thus, it is hoped that, in the future, travel restrictions faced by users and so that the lack of resources (physical and technological) for the therapist will no longer be a barrier as well. This section presents the conclusions about the study carried out and also future work that can be presented as an improvement or as possible contributions to the scientific community within the context presented.

7.2 Conclusions

Not only in Brazil the PW is considered the most recommended AT for people who, for various reasons, have a mobility decrease, preventing them from carrying out ADL normally (CARTILHA, 2012; JOHN et al., 2018; CARO; COSTA; CRUZ, 2018). There are many users around the world who depend on it to regain their independence, joy and good mental and emotional health (JOHN et al., 2018; CARO; COSTA; CRUZ, 2018; MACGILLIVRAY et al., 2018; CARTILHA, 2012). However, if good training is not carried out, in addition to AT being abandoned, the user might injury and lose their life quality (ORGANIZATION, 2020; CARO; COSTA; CRUZ, 2018; MACGILLIVRAY et al., 2018; DORRINGTON et al., 2016; PETTERSSON et al., 2014). As demonstrated in this work, there are several limitations and therapists encounter difficulties to offer an appropriate care. These are some reasons for the development of the proposed solution, to be support for the reintegration of the user's life.

The questionnaires were applied before the beginning of the research development so that the solution was a user-centered design (DORRINGTON et al., 2016). Besides, as the therapist is an essential part of the process, professional considerations and literature have been consulted (VALENTINI et al., 2019). Then, it was detected that users needed personalized training to reduce wear and also meet their daily needs and still be carried out safely. And also, a therapist needs a tool that allows him to personalize, evaluate and follow the user's training.

During the development process, three distinct sites, physically separated, were defined: training, therapist and patient. The combination of WebRTC and AR techniques enables Telerehabilitation architecture development. The remotely accessed training site was fully developed based on user's surveys. It has a PW properly equipped to be remotely controlled and provides the visualization of remote control requests. The therapist site, through which the therapist remotely creates, defines, tracks (from an augmented environment preview) and evaluates user training. At last, the patient's site is the environment in which the user will carry out his training session. In this environment, a conventional joystick was adapted, to be connected to the computer where it will interact (insert commands and having an augmented environment preview) with the training site.

Thus, based on the characteristics of the architecture and the training experience that the user will have, a questionnaire was developed. The objective is to evaluate the quality of the experience that he had, in addition to verifying whether the developed resources allow to reach the initials objective set. Then, based participants' survey answers, we believe that the purpose of the system architecture was achieved with some limitations. In this preliminary study, all tests were conducted in a rehabilitation center.

From the results of these experiments, in general, the architecture met its objectives, because 77% of the questions were evaluated above the average score. Questions (Q2, Q6 and Q9) obtained 100% of users' satisfaction and among the items evaluated are: the graphical interface, virtual objects and well-being after training. Other questions (Q1, Q5, Q8, Q10 and Q11) did not obtain 100% satisfaction, which refers to improvements related to the use of the system, image quality, the ability of the tool to assist in the development of driving skills, system characteristics satisfaction and whether the system does what has been proposed. Much of this assessment is due to the difficulty in controlling the PW, due to latency and lack of diagonal movements, which interfere with navigation experience making it difficult to use the system at the training time. All of this is related to the low evaluation in the questions (Q3, Q4 and Q7).

It can also be observed that due to the adaptation at the moment of composing the activities of each protocol, they increased the users' well-being after training, which is important in terms of performance. Another observation is that the defined evaluation methodology allows the therapist, based on the visual perception of the training, to evaluate the user with quality and also monitor their development through comparative graphics. Another contribution of this work is related to collected biological signals. It allows, from an emotional point of view, to check other variables that may be interfering with the user's performance. From these results, it is concluded that the protocols did not show the difference in the participants. Participant 3 was the only one to change the stress zones. However, it is believed that it represents a normal variation towards a state of rest in the normal stress zone, not caused by the protocols.

7.3 Future work

Future work can be divided into two strands: increase users' experience and scientific contributions. Based on the ADL driving challenges survey to enrich the next training site versions with different assets not contemplated, for example, holes. In order to correct the rendering failure of the augmented objects, fiducial markers shall be removed and replaced by rendering based on the Cartesian position of the PW (ALVES; LOPES; VELOSO, 2016). By implementing a proximity sensor, all virtual objects within range are rendered, as in the Poke-mon GO game (MIEDANY, 2019). Otherwise, the use of deep learning techniques can be investigated in order to reduce rendering failure (MATTIOLI et al., 2019). Studies will be conducted, to improve the control signals and video stream latency. With the release of 5G Networks, many problems related to latency faced in this work due to the 4G Internet and Internet speed provide by concessionary, in the rehabilitation center can be addressed (**??**). Finally, collect the therapist's opinion about the system architecture, to replace the PW model used by another one with less inertia breaking time and also with diagonal movements, for increasing user navigation meets and system usage.

Based on the volunteer evaluations and the discussions carried out, pointed out that the video stream latency is a major limiter in the user's experience quality. Several times, it was not possible to start the training process because very slow Internet speed, so that the video connection between the environments was not completed, due to the framework quality restrictions. For this reason, it was decided to interrupt the collections, not going forward with the other existing volunteers. Since the maximum time previously agreed with each one, to perform the experiment, was exceeded. With this, the volunteers could get tired, due to the individual restrictions shown by Table 5, or concerned with other activities to be developed, or even the taxi used for commuting, could not wait any longer. For this reason, was carried out with only one collection of each of the three volunteers.

However, in the future, after the issues found in this research have been fixed, only the first session will be performed in a rehabilitation center and futures sessions might be accomplished at home, in agreement with the user conditions. In addition, different subject segmentation based on the type of injury, severity, age and experience in the use of assistive technologies can be implemented to assess the learning curve connected to the evolution of the participants' biosignals over time and identify obstacles in each protocol. Monitoring user stress is also important not only to address the learning but also to ensure safety during regular use. Also, further studies should be done in this direction to classify the user's stress better and provide a risk assessment to develop improved strategies to prevent accidents.

Since the beginning of the system architecture development, it was opted to use only open-source tools and libraries. It is hoped in the future to incorporate this system on the rehabilitation centers connected with Brazilian Unified Health System and share[1] this project with the community as open-source for non-commercial license use.

[1] https://github.com/dantutu/servletserver

Bibliography

ABDALLAH, S. B. et al. Augmented reality for real-time navigation assistance to wheelchair users with obstacles' management. In: SPRINGER. *International Conference on Computational Science*. [S.l.], 2019. p. 528–534. doi: <https://doi.org/10.1007/978-3-030-22750-0_47>. Citado 3 vezes nas páginas 12, 2, and 34.

AFFANNI, A. et al. Driver's stress detection using skin potential response signals. *Measurement*, Elsevier, v. 122, p. 264–274, 2018. doi: <https://doi.org/10.1016/j.measurement.2018.03.040>. Citado 7 vezes nas páginas 12, 2, 24, 25, 34, 50, and 97.

ALVES, R.; LOPES, C. R.; VELOSO, M. Checkpoint coverage with wifi localization for indoor service robots. In: *JCAI 2016 WS Autonomous Mobile Service Robots*. [s.n.], 2016. p. 10–17. Disponível em: <https://www.dropbox.com/sh/wp6abcswxstce3f/AADtfgehld7j0I9cNgZP2Zoua?dl=0>. Citado na página 105.

AQUINO, C.; GANDEE, T. *Front-End Web Development: The Big Nerd Ranch Guide*. [S.l.]: Pearson Technology Group, 2016. Citado na página 125.

ARLATI, S. et al. Virtual reality-based wheelchair simulators: A scoping review. *Assistive Technology*, Taylor & Francis, p. 1–12, 2019. doi: <https://doi.org/10.1080/10400435.2018.1553079>. Citado na página 1.

ASSOCIATION, A. O. T. et al. Occupational therapy practice framework: Domain and process 2nd edition. *Am J Occup Ther*, v. 62, p. 625—683, 2008. doi: url=10.5014/ajot.62.6.625. Citado na página 4.

ASSOCIATION, A. O. T. et al. Occupational therapy practice framework : Domain and process 3rd edition. *Am J Occup Ther*, v. 68, p. S1–S48, 2014. doi: url=10.5014/ajot.2014.682006. Citado na página 4.

ATTITALLA, S.; CHOKSI, V.; POTDAR, M. Web and cloud based home automation systems: An overview. 2016. Citado 2 vezes nas páginas 8 and 9.

BAEVSKY, R.; BERSENEVA, A. Use of kardivar system for determination of the stress level and estimation of the body adaptability. *Methodical recommendations. Standards of measurements and physiological interpretation. Moscow-Prague*, 2008. Citado 2 vezes nas páginas 49 and 97.

BARRIGA, A. et al. A vision-based approach for building telecare and telerehabilitation services. *Sensors*, Multidisciplinary Digital Publishing Institute, v. 16, n. 10, p. 1724, 2016. doi: <https://doi.org/10.3390/s16101724>. Citado 2 vezes nas páginas 2 and 4.

BASHAM, B.; SIERRA, K.; BATES, B. *Head First Servlets e JSP: aprovação no exame Sun Certified Web Component Developer*. [S.l.], 2008. Citado na página 53.

BENEDEK, M.; KAERNBACH, C. A continuous measure of phasic electrodermal activity. *Journal of neuroscience methods*, Elsevier, v. 190, n. 1, p. 80–91, 2010. doi: <https://doi.org/10.1016/j.jneumeth.2010.04.028>. Citado na página 48.

BENEDEK, M.; KAERNBACH, C. Ledalab. In: . Accessed: 16/06/19, 2016. Disponível em: <http://www.ledalab.de/>. Citado na página 47.

BLETZER, K. V. Visualizing the qualitative: making sense of written comments from an evaluative satisfaction survey. *Journal of educational evaluation for health professions*, National Health Personnel Licensing Examination Board of the Republic of Korea, v. 12, 2015. doi: <https://doi.org/10.3352/jeehp.2015.12.12>. Citado na página 50.

BODKIN, S.; HART, J.; WERNER, B. C. Common statistical tests. In: *Basic Methods Handbook for Clinical Orthopaedic Research*. [S.l.]: Springer, 2019. p. 153–161. doi: <https://doi.org/10.1007/978-3-662>. Citado na página 97.

BORRESEN, A. et al. Usability of an immersive augmented reality based telerehabilitation system with haptics (artesh) for synchronous remote musculoskeletal examination. *International Journal of Telerehabilitation*, v. 11, n. 1, p. 23–32, 2019. doi: <https://doi.org/10.5195/ijt.2019.6275>. Citado 6 vezes nas páginas 12, 2, 27, 28, 34, and 51.

BRAITHWAITE, J. J.; WATSON, D. G. *Issues Surrounding the Normalization and Standardisation of Skin Conductance Responses (SCRs). Technical Research Note. Selective Attention & Awareness Laboratory (SAAL), Behavioural Brain Sciences Centre, School of Psychology, University of Birmingham.* 2015. Citado na página 96.

BRAZIL. Includes wheelchair procedures and wheelchair postural adaptation in the unified health system table of procedures, drugs, orthotics, prosthetics and special materials (opm). Accessed: 04/04/19, 2013. Portuguese version. Disponível em: <http://bvsms.saude.gov.br/bvs/saudelegis/gm/2013/prt1272_25_06_2013.html>. Citado 2 vezes nas páginas 1 and 5.

BRAZIL. Supplementary info. Accessed: 04/04/19, 2013. Portuguese version. Disponível em: <http://bvsms.saude.gov.br/bvs/saudelegis/gm/2013/anexo/anexo_prt1272_26_06_2013.pdf>. Citado 2 vezes nas páginas 1 and 5.

BRENNAN, D. M. et al. A telerehabilitation platform for home-based automated therapy of arm function. In: IEEE. *Engineering in Medicine and Biology Society, EMBC, 2011 Annual International Conference of the IEEE*. [S.l.], 2011. p. 1819–1822. doi: <https://doi.org/10.1109/IEMBS.2011.6090518>. Citado na página 7.

BURDEA, G. C. Invited paper: Low-cost telerehabilitation. In: *Proceedings of Third International Workshop on Virtual Rehabilitation,*. [S.l.: s.n.], 2004. p. 3297–3300. Citado 2 vezes nas páginas 41 and 46.

CAETANO, D. et al. [demo] on the use of augmented reality techniques in a telerehabilitation environment for wheelchair users' training. In: IEEE. *Mixed and Augmented Reality (ISMAR), 2014 IEEE International Symposium on*. [S.l.], 2014. p. 329–330. doi: <https://doi.org/10.1109/ISMAR.2014.6948473>. Citado na página 2.

CAETANO, D. et al. Adaptation of a usb interface for vr2 joystick applied to the training of wheelchair users. *Assistive Technology: Development and Application*, Canal6 Editora, v. 1, n. 1, p. 261–267, 2018. Portuguese version. Citado 3 vezes nas páginas 13, 45, and 46.

CARDOSO, A.; LAMOUNIER, E. Fundamentals and technology of virtual and augmented reality. Editora SBC, 2006. Portuguese version. Citado na página 5.

CARO, C. C.; COSTA, J. D.; CRUZ, D. M. C. The use of assistive devices for mobility and functional independence in subjects with stroke / the use of mobility assistive devices and the functional independence in stroke patients. In: . [S.l.]: [Portuguese version], 2018. v. 26, n. 3. doi: <https://doi.org/10.4322/2526-8910.ctoAO1117>. Citado 2 vezes nas páginas 1 and 103.

CARTILHA, d. c. Disabled people. *Disabled people. Luiza Maria Borges Oliveira / Secretary of Human Rights of the Presidency of the Republic (SDH / PR) / National Secretary for the Promotion of the Rights of Persons with Disabilities (SNPD)*, p. 17, 2012. Portuguese version. Citado 2 vezes nas páginas 1 and 103.

CHOUITEN, M.; DIDIER, J.-Y.; MALLEM, M. Distributed augmented reality systems: how much performance is enough? In: IEEE. *2012 IEEE International Conference on Multimedia and Expo Workshops*. [S.l.], 2012. p. 337–342. doi: <https://doi.org/10.1109/ICMEW.2012.64>. Citado na página 38.

CHU, J.-U.; MOON, I.; MUN, M.-S. A real-time emg pattern recognition system based on linear-nonlinear feature projection for a multifunction myoelectric hand. *IEEE Transactions on Biomedical Engineering*, IEEE, v. 53, n. 11, p. 2232–2239, 2006. doi: <https://doi.org/10.1109/TBME.2006.883695>. Citado na página 38.

COOPER, R. A. Wheelchair research progress, perspectives, and transformation. *J. Rehabil. Res. Dev*, v. 49, n. 1, p. 1–5, 2012. doi: <https://doi.org/10.1682/JRRD.2011.10.0199>. Citado 4 vezes nas páginas 12, 32, 33, and 34.

CORFMAN, T. A. et al. Tips and falls during electric-powered wheelchair driving: effects of seatbelt use, legrests, and driving speed. *Archives of physical medicine and rehabilitation*, Elsevier, v. 84, n. 12, p. 1797–1802, 2003. doi: <https://doi.org/10.1016/S0003-9993(03)00467-2>. Citado na página 25.

DAWSON, D.; CHAN, R.; KAISERMAN, E. Development of the power-mobility indoor driving assessment for residents of long-term care facilities: A preliminary report. *Canadian Journal of Occupational Therapy*, SAGE Publications Sage CA: Los Angeles, CA, v. 61, n. 5, p. 269–276, 1994. doi: <https://doi.org/10.1177/000841749406100507>. Citado na página 22.

DEUTSCH, J. E.; LEWIS, J. A.; BURDEA, G. Technical and patient performance using a virtual reality-integrated telerehabilitation system: preliminary finding. *Neural Systems and Rehabilitation Engineering, IEEE Transactions on*, IEEE, v. 15, n. 1, p. 30–35, 2007. doi: <https://doi.org/10.1109/TNSRE.2007.891384>. Citado na página 7.

DHURJATY, S. The economics of telerehabilitation. *Telemedicine Journal & E-Health*, Mary Ann Liebert, Inc. 2 Madison Avenue Larchmont, NY 10538 USA, v. 10, n. 2, p. 196–199, 2004. doi: <https://doi.org/10.1089/tmj.2004.10.196>. Citado na página 7.

DORRINGTON, P. et al. User-centered design method for the design of assistive switch devices to improve user experience, accessibility, and independence. *Journal of usability studies*, Usability Professionals' Association Bloomingdale, IL, v. 11, n. 2, p. 66–82, 2016. doi: <https://doi.org/10.5555/2993215.2993218>. Citado na página 103.

E4. E4 data - ibi expected signal – empatica support. In: . Accessed: 13/02/20, 2020. Disponível em: <https://support.empatica.com/hc/en-us/articles/360030058011-E4-data-IBI-expected-signal>. Citado na página 49.

E4; LEDALAB; KUBIOS. Recommended tools for signal processing and data analysis. In: . Accessed: 17/07/20, 2020. Disponível em: <https://support.empatica.com/hc/en-us/articles/202872739-Recommended-tools-for-signal-processing-and-data-analysis>. Citado 2 vezes nas páginas 47 and 49.

ECKERT, M.; VOLMERG, J.; FRIEDRICH, C. *Augmented Reality in Medicine: Systematic and Bibliographic Review. JMIR MHealth and UHealth, 7 (4), e10967.* 2019. doi: <https://doi.org/10.2196/10967>. Citado na página 2.

EDAN, N.; MAHMOOD, S. A. Design and implement a new mechanism for audio, video and screen recording based on webrtc technology. *International Journal of Electrical and Computer Engineering*, IAES Institute of Advanced Engineering and Science, v. 10, n. 3, p. 2773, 2020. doi: <https://doi.org/10.11591/ijece.v10i3.pp2773-2778>. Citado na página 53.

FATTOUH, A.; SAHNOUN, M.; BOURHIS, G. Force feedback joystick control of a powered wheelchair: preliminary study. In: IEEE. *Systems, Man and Cybernetics, 2004 IEEE International Conference on.* [S.l.], 2004. v. 3, p. 2640–2645. doi: <https://doi.org/10.1109/ICSMC.2004.1400729>. Citado 2 vezes nas páginas 12 and 4.

GAAL, R. P. et al. Wheelchair rider injuries: causes and consequences for wheelchair design and selection. *Journal of rehabilitation research and development*, v. 34, n. 1, p. 58–71, 1997. Citado na página 23.

GARCÍA, B. et al. Assessment of qoe for video and audio in webrtc applications using full-reference models. *Electronics*, Multidisciplinary Digital Publishing Institute, v. 9, n. 3, p. 462, 2020. doi: <https://doi.org/10.3390/electronics9030462>. Citado na página 53.

GREENE, S.; THAPLIYAL, H.; CABAN-HOLT, A. A survey of affective computing for stress detection: Evaluating technologies in stress detection for better health. *IEEE Consumer Electronics Magazine*, IEEE, v. 5, n. 4, p. 44–56, 2016. doi: <https://doi.org/10.1109/MCE.2016.2590178>. Citado na página 24.

HA, V. K. L. et al. A telepresence wheelchair with 360-degree vision using webrtc. *Applied Sciences*, Multidisciplinary Digital Publishing Institute, v. 10, n. 1, p. 369, 2020. doi: <https://doi.org/10.3390/app10010369>. Citado na página 53.

HANSEN, S.; FOSSUM, T. V. Refactoring model-view-controller. *Journal of Computing Sciences in Colleges*, Consortium for Computing Sciences in Colleges, v. 21, n. 1, p. 120–129, 2005. Citado na página 125.

HEALEY, J. A.; PICARD, R. W. Detecting stress during real-world driving tasks using physiological sensors. *IEEE Transactions on intelligent transportation systems*, IEEE, v. 6, n. 2, p. 156–166, 2005. doi: <https://doi.org/10.1109/TITS.2005.848368>. Citado 2 vezes nas páginas 2 and 97.

HERNANDEZ, J. et al. Autoemotive: bringing empathy to the driving experience to manage stress. In: ACM. *Proceedings of the 2014 companion publication on Designing interactive systems*. [S.l.], 2014. p. 53–56. doi: <https://doi.org/10.1145/2598784.2602780>. Citado na página 2.

HOGAN, N.; STERNAD, D. Sensitivity of smoothness measures to movement duration, amplitude, and arrests. *Journal of motor behavior*, Taylor & Francis, v. 41, n. 6, p. 529–534, 2009. doi: <https://doi.org/10.3200/35-09-004-RC>. Citado na página 25.

HOLDEN, M. K.; DYAR, T. A.; DAYAN, L. C. Telerehabilitation using a virtual environment improves upper extremity function in patients with stroke. *Neural Systems and Rehabilitation Engineering, IEEE Transactions on*, IEEE, v. 15, n. 1, p. 36–42, 2007. doi: <https://doi.org/10.1109/TNSRE.2007.891388>. Citado 3 vezes nas páginas 12, 7, and 8.

HRV-SOFTWARE. Heart rate variability - kubios. In: . Accessed:2019-06-16, 2017. Disponível em: <www.kubios.com>. Citado 2 vezes nas páginas 49 and 97.

HRV, U.-G. Kubios hrv (ver. 3.1) user's guide. In: . Accessed: 11/07/19, 2018. Disponível em: <https://www.kubios.com/downloads/Kubios_HRV_Users_Guide.pdf>. Citado 3 vezes nas páginas 16, 50, and 97.

INES, D. L.; ABDELKADER, G. Mixed reality serious games: The therapist perspective. In: IEEE. *Serious Games and Applications for Health (SeGAH), 2011 IEEE 1st International Conference on*. [S.l.], 2011. p. 1–10. doi: <https://doi.org/10.1109/SeGAH.2011.6165462>. Citado na página 5.

ISLAM, T. U. Ranking of normality tests: An appraisal through skewed alternative space. *Symmetry*, Multidisciplinary Digital Publishing Institute, v. 11, n. 7, p. 872, 2019. doi: <https://doi.org/10.3390/sym11070872>. Citado na página 50.

JOHN, N. W. et al. The implementation and validation of a virtual environment for training powered wheelchair manoeuvres. *IEEE transactions on visualization and computer graphics*, IEEE, v. 24, n. 5, p. 1867–1878, 2018. doi: <https://doi.org/10.1109/TVCG.2017.2700273>. Citado 12 vezes nas páginas 12, 1, 2, 5, 6, 17, 19, 20, 21, 22, 34, and 103.

JUREČKOVÁ, J.; PICEK, J.; SCHINDLER, M. *Robust statistical methods with R*. [S.l.]: Chapman and Hall/CRC, 2019. Citado na página 50.

KAMARAJ, D. C. et al. Interrater reliability of the power mobility road test in the virtual reality–based simulator-2. *Archives of physical medicine and rehabilitation*, Elsevier, v. 97, n. 7, p. 1078–1084, 2016. doi: <https://doi.org/10.1016/j.apmr.2016.02.005>. Citado 10 vezes nas páginas 12, 1, 2, 5, 17, 25, 26, 34, 49, and 51.

KENNEDY, R. S. et al. Simulator sickness questionnaire: An enhanced method for quantifying simulator sickness. *The international journal of aviation psychology*, Taylor & Francis, v. 3, n. 3, p. 203–220, 1993. doi: <https://doi.org/10.1207/s15327108ijap0303_3>. Citado na página 21.

KHALFA, S. et al. Event-related skin conductance responses to musical emotions in humans. *Neuroscience letters*, Elsevier, v. 328, n. 2, p. 145–149, 2002. doi: <https://doi.org/10.1016/S0304-3940(02)00462-7>. Citado na página 48.

KIRBY, R. L. *Wheelchair Skills Program (WSP), Version 4.1. Wheelchair Skills Test (WST) Manual*. 2008. Citado na página 23.

KIRBY, R. L. et al. Effectiveness of a wheelchair skills training program for powered wheelchair users: a randomized controlled trial. *Archives of physical medicine and rehabilitation*, Elsevier, v. 96, n. 11, p. 2017–2026, 2015. doi: <https://doi.org/10.1016/S0304-3940(02)00462-7>. Citado na página 25.

KOVATSCH, M.; MAYER, S.; OSTERMAIER, B. Moving application logic from the firmware to the cloud: Towards the thin server architecture for the internet of things. p. 751–756, 2012. doi: <https://doi.org/10.1109/IMIS.2012.104>. Citado na página 9.

LAINE, M. et al. Toward unified web application development. *IT Professional Magazine*, IEEE Computer Society, v. 13, n. 5, p. 30, 2011. doi: <https://doi.org/10.1109/MITP.2011.55>. Citado na página 8.

LANATÀ, A. et al. How the autonomic nervous system and driving style change with incremental stressing conditions during simulated driving. *IEEE Transactions on Intelligent Transportation Systems*, IEEE, v. 16, n. 3, p. 1505–1517, 2014. doi: <https://doi.org/10.1109/TITS.2014.2365681>. Citado 3 vezes nas páginas 2, 51, and 52.

LEUNG, D. C.-M. et al. Remote augmented reality for multiple players over network. In: ACM. *Proceedings of the international conference on Advances in computer entertainment technology*. [S.l.], 2007. p. 220–223. doi: <https://doi.org/10.1145/1255047.1255094>. Citado na página 8.

LIKERT, R. A technique for the measurement of attitudes. *Archives of psychology*, 1932. Citado na página 51.

LIN, Y.; SONG, S.; MENG, M. Q.-H. The implementation of augmented reality in a robotic teleoperation system. In: IEEE. *2016 IEEE International Conference on Real-time Computing and Robotics (RCAR)*. [S.l.], 2016. p. 134–139. doi: <https://doi.org/10.1109/RCAR.2016.7784014>. Citado na página 2.

LORETO, S.; ROMANO, S. P. Real-time communications in the web: Issues, achievements, and ongoing standardization efforts. *IEEE Internet Computing*, IEEE, v. 16, n. 5, p. 68–73, 2012. doi: <https://doi.org/10.1109/MIC.2012.115>. Citado na página 9.

LUDY, R.; BLUNT, M. Assistive technology resources: Building bridges for institutions of higher education. ERIC, 1995. Citado na página 4.

MACGILLIVRAY, M. K. et al. Goal satisfaction improves with individualized powered wheelchair skills training. *Disability and Rehabilitation: Assistive Technology*, Taylor & Francis, v. 13, n. 6, p. 558–561, 2018. doi: <https://doi.org/10.1080/17483107.2017.1353651>. Citado 6 vezes nas páginas 1, 2, 6, 23, 34, and 103.

MAHAJAN, H. P. et al. Assessment of wheelchair driving performance in a virtual reality-based simulator. *The journal of spinal cord medicine*, Taylor & Francis, v. 36, n. 4, p. 322–332, 2013. doi: <https://doi.org/10.1179/2045772313Y.0000000130>. Citado 5 vezes nas páginas 1, 2, 5, 17, and 21.

MANRING, L. et al. Augmented reality for interactive robot control. In: *Special Topics in Structural Dynamics & Experimental Techniques, Volume 5*. [S.l.]: Springer, 2020. p. 11–18. doi: <https://doi.org/10.1007/978-3-030-12243-0_2>. Citado 3 vezes nas páginas 12, 2, and 6.

MARTINS, F. et al. *Simulador para treinamento de cadeirantes em ambiente virtual acionado por comandos musculares e/ou visuais*. Brazil: [s.n.], 2017. doi: <https://doi.org/10.14393/ufu.di.2017.504>. Citado 3 vezes nas páginas 12, 21, and 22.

MARWEDEL, P. Embedded and cyber-physical systems in a nutshell. *DAC. COM Knowledge Center Article*, v. 20, n. 10, 2010. Citado na página 9.

MARWEDEL, P. *Embedded system design*. [S.l.]: Springer, 2018. Citado 2 vezes nas páginas 12 and 10.

MASSENGALE, S. et al. Effect of visual perception, visual function, cognition, and personality on power wheelchair use in adults. *Assistive Technology*, Taylor & Francis, v. 17, n. 2, p. 108–121, 2005. doi: <https://doi.org/10.1080/10400435.2005.10132101>. Citado 5 vezes nas páginas 2, 6, 7, 49, and 100.

MATTIOLI, F. et al. An experiment on the use of genetic algorithms for topology selection in deep learning. *Journal of Electrical and Computer Engineering*, Hindawi, v. 2019, 2019. doi: <https://doi.org/10.1155/2019/3217542>. Citado 2 vezes nas páginas 105 and 125.

MAULE, L. et al. Augmented robotics for electronic wheelchair to enhance mobility in domestic environment. In: SPRINGER. *International Conference on Augmented Reality, Virtual Reality and Computer Graphics*. [S.l.], 2017. p. 22–32. doi: <https://doi.org/10.1007/978-3-319-60928-7_2>. Citado 4 vezes nas páginas 12, 2, 15, and 34.

MIEDANY, Y. E. Virtual reality and augmented reality. In: *Rheumatology Teaching*. [S.l.]: Springer, 2019. p. 403–427. doi: <https://doi.org/10.1007/978-3-319-98213-7>. Citado na página 105.

MITSUMURA, S. et al. Development of remote controllable visiting robot considering local situation. In: IEEE. *Micro-NanoMechatronics and Human Science (MHS), 2014 International Symposium on*. [S.l.], 2014. p. 1–4. doi: <https://doi.org/10.1109/MHS.2014.7006142>. Citado 8 vezes nas páginas 12, 1, 5, 29, 30, 31, 34, and 45.

MORTENSON, W. B.; MILLER, W. C.; MILLER-POGAR, J. Measuring wheelchair intervention outcomes: development of the wheelchair outcome measure. *Disability and Rehabilitation: Assistive Technology*, Taylor & Francis, v. 2, n. 5, p. 275–285, 2007. doi: <https://doi.org/10.1080/17483100701475863>. Citado na página 23.

NUNNERLEY, J. et al. Training wheelchair navigation in immersive virtual environments for patients with spinal cord injury–end-user input to design an effective system. *Disability and Rehabilitation: Assistive Technology*, Taylor & Francis, v. 12, n. 4, p. 417–423, 2017. doi: <https://doi.org/10.1080/17483107.2016.1176259>. Citado 2 vezes nas páginas 21 and 50.

ORGANIZATION, W. H. Guidelines on the provision of wheelchairs in less-resourced settings. In: . Accessed: 05/04/20, 2020. Disponível em: <http://www.who.int/disabilities/publications/technology/wheelchairguidelines/en/>. Citado 2 vezes nas páginas 23 and 103.

ORTIZ-CATALAN, M. et al. Emerging therapies in neurorehabilitation. *Emerging Therapies in Neurorehabilitation*, Springer, v. 4, p. 249–265, 2014. doi: <https://doi.org/10.1007/978-3-642-38556-8>. Citado na página 7.

PANI, D. et al. A device for local or remote monitoring of hand rehabilitation sessions for rheumatic patients. *Translational Engineering in Health and Medicine, IEEE Journal of*, IEEE, v. 2, p. 1–11, 2014. doi: <https://doi.org/10.1109/JTEHM.2014.2299274>. Citado 5 vezes nas páginas 12, 7, 28, 29, and 34.

PETTERSSON, C. et al. Men's and women's perspectives on using a powered mobility device: Benefits and societal challenges. *Scandinavian journal of occupational therapy*, Taylor & Francis, v. 21, n. 6, p. 438–446, 2014. doi: <https://doi.org/10.3109/11038128.2014.905634>. Citado 3 vezes nas páginas 1, 23, and 103.

PGVR2, J. PG Drivers Technology - Wheelchair Control System. In: . Accessed: 18/03/20, 2020. Disponível em: <http://www.cw-industrialgroup.com/getattachment/439a3b95-d06f-4c98-bbd8-7f28cb9b1f71/vr2_brochure>. Citado 2 vezes nas páginas 12 and 4.

PMS, H. Hoveround Personal Mobility Solutions. In: . Accessed: 19/03/20, 2020. Disponível em: <https://www.hoveround.com/yellow-ball-knob>. Citado 2 vezes nas páginas 12 and 5.

POLTAVSKYI, D. A.; ZASELSKIY, V. I. Augmented reality-based historical guide for classes and tourists. 2020. Citado na página 125.

PONS, J. L.; TORRICELLI, D. *Emerging Therapies in Neurorehabilitation*. [S.l.]: Springer, 2014. doi: <https://doi.org/10.1007/978-3-642-38556-8>. Citado na página 7.

POSTOLACHE, G. et al. Rehabilitative telehealthcare for post-stroke outcome assessment. In: IEEE. *Pervasive Computing Technologies for Healthcare (PervasiveHealth), 2011 5th International Conference on*. [S.l.], 2011. p. 408–413. doi: <https://doi.org/10.4108/icst.pervasivehealth.2011.246141>. Citado na página 7.

POWELL, W.; POWELL, V.; SIMMONDS, M. Virtual reality for gait rehabilitation-promises, proofs and preferences. In: ACM. *Proceedings of the 7th International Conference on Pervasive Technologies Related to Assistive Environments*. [S.l.], 2014. p. 16. doi: <https://doi.org/10.1145/2674396.2674450>. Citado na página 5.

QUONG, R. Limiting application access to sensitive data and resources through use of a sensitive data sandbox. 2020. Citado 2 vezes nas páginas 53 and 55.

RECHY-RAMIREZ, E. J.; HU, H.; MCDONALD-MAIER, K. Head movements based control of an intelligent wheelchair in an indoor environment. In: IEEE. *2012 IEEE International Conference on Robotics and Biomimetics (ROBIO)*. [S.l.], 2012. p. 1464–1469. doi: <https://doi.org/10.1109/ROBIO.2012.6491175>. Citado na página 4.

RIZZO, A.; KOENIG, S. T.; TALBOT, T. B. Clinical results using virtual reality. *Journal of Technology in Human Services*, Taylor & Francis, p. 1–24, 2019. doi: <https://doi.org/10.1080/15228835.2019.1604292>. Citado na página 50.

RODRIGUEZ, N. Development of a wheelchair simulator for children with multiple disabilities. In: IEEE. *2015 3rd IEEE VR International Workshop on Virtual and Augmented Assistive Technology (VAAT)*. [S.l.], 2015. p. 19–21. doi: <https://doi.org/10.1109/VAAT.2015.7155405>. Citado na página 19.

RSI. Guidelines on the provision of wheelchairs in less-resourced settings. In: . Accessed: 10/07/20, 2020. Disponível em: <http://robotservices.org/>. Citado na página 30.

RUBIO, S. et al. Evaluation of subjective mental workload: A comparison of swat, nasa-tlx, and workload profile methods. *Applied Psychology*, Wiley Online Library, v. 53, n. 1, p. 61–86, 2004. doi: <https://doi.org/10.1111/j.1464-0597.2004.00161.x>. Citado na página 25.

SCHERER, M. J.; FEDERICI, S. Why people use and don't use technologies: Introduction to the special issue on assistive technologies for cognition/cognitive support technologies. *NeuroRehabilitation*, IOS Press, v. 37, n. 3, p. 315–319, 2015. doi: <https://doi.org/10.3233/NRE-151264>. Citado na página 1.

SCHUTTE, J. et al. Evaluation of a telerehabilitation system for community-based rehabilitation. *International Journal of Telerehabilitation*, University Library Systems, University of Pittsburgh, v. 4, n. 1, p. 15, 2012. doi: <https://doi.org/10.5195/ijt.2012.6092>. Citado na página 27.

SILVA, M. D. *Realidade aumentada distribuída na Web com independência de servidor para manipulação de objetos virtuais na camada cliente*. Dissertação (Mestrado) — Universidade Federal de Uberlândia, Brazil, 2011. Citado na página 6.

STROULIA, E. Towards the web-based architectural style. In: CITESEER. *First ASERC Workshop on Software Architecture*. [S.l.], 2001. Citado na página 8.

SUN, D.; WONG, K.; MOISE, D. Lessons learned in web site architectures for public utilities. In: IEEE. *Fifth IEEE International Workshop on Web Site Evolution, 2003. Theme: Architecture. Proceedings*. [S.l.], 2003. p. 93–100. doi: <https://doi.org/10.1109/WSE.2003.1234013>. Citado 3 vezes nas páginas 12, 9, and 52.

SYP, B. Bodypoint Strengthen your Position. In: . Accessed: 19/03/20, 2020. Disponível em: <https://www.bodypoint.com/ECommerce/product/pcpt04/u-shaped-joystick-handles>. Citado 2 vezes nas páginas 12 and 5.

TAIVALSAARI, A. et al. Web browser as an application platform. In: IEEE. *2008 34th Euromicro Conference Software Engineering and Advanced Applications*. [S.l.], 2008. p. 293–302. doi: <https://doi.org/10.1109/SEAA.2008.17>. Citado na página 53.

TILLEY, S.; HUANG, S. Evaluating the reverse engineering capabilities of web tools for understanding site content and structure: A case study. In: IEEE. *Software Engineering, 2001. ICSE 2001. Proceedings of the 23rd International Conference on*. [S.l.], 2001. p. 514–523. doi: <https://doi.org/10.1109/ICSE.2001.919126>. Citado na página 8.

TORKIA, C. et al. Power wheelchair driving challenges in the community: a users' perspective. *Disability and Rehabilitation: Assistive Technology*, Taylor & Francis, v. 10, n. 3, p. 211–215, 2015. doi: <https://doi.org/10.3109/17483107.2014.898159>. Citado na página 21.

VAILLAND, G. et al. User-centered design of a multisensory power wheelchair simulator: towards training and rehabilitation applications. In: . [S.l.: s.n.], 2019. doi: <https://doi.org/10.1109/ICORR.2019.8779496>. Citado 6 vezes nas páginas 12, 1, 5, 16, 17, and 34.

VALENTINI, C. A. M. et al. *Protocolo para Condução de Cadeira de Rodas Motorizada usando Realidade Virtual*. Dissertação (Mestrado) — Universidade Federal de Uberlândia, Brazil, 2019. doi: <https://doi.org/10.14393/ufu.di.2019.2048>. Citado 10 vezes nas páginas 12, 5, 17, 18, 21, 22, 34, 47, 51, and 103.

WEI, Y.-H. et al. Rt-wifi: Real-time high-speed communication protocol for wireless cyber-physical control applications. In: IEEE. *Real-Time Systems Symposium (RTSS), 2013 IEEE 34th*. [S.l.], 2013. p. 140–149. doi: <https://doi.org/10.1109/RTSS.2013.22>. Citado 4 vezes nas páginas 12, 31, 32, and 34.

WIEDERHOLD, M. D. *Augmented Reality: Poised for Impact*. [S.l.]: Mary Ann Liebert, Inc., publishers 140 Huguenot Street, 3rd Floor New . . . , 2019. doi: <https://doi.org/10.1089/cyber.2019.29140.mdw>. Citado 2 vezes nas páginas 2 and 5.

WOROBEY, L. et al. Increases in wheelchair breakdowns, repairs, and adverse consequences for people with traumatic spinal cord injury. *American journal of physical medicine & rehabilitation/Association of Academic Physiatrists*, NIH Public Access, v. 91, n. 6, p. 463, 2012. doi: <https://doi.org/10.1097/PHM.0b013e31825ab5ec>. Citado na página 25.

XIANG, H.; CHANY, A.; SMITH, G. A. Wheelchair related injuries treated in us emergency departments. *Injury prevention*, BMJ Publishing Group Ltd, v. 12, n. 1, p. 8–11, 2006. doi: <https://doi.org/10.1136/ip.2005.010033>. Citado na página 23.

ZAMBONELLI, F. Towards a general software engineering methodology for the internet of things. *arXiv preprint arXiv:1601.05569*, 2016. Citado na página 8.

ZHENG, R. et al. Biosignal analysis to assess mental stress in automatic driving of trucks: Palmar perspiration and masseter electromyography. *Sensors*, Multidisciplinary Digital Publishing Institute, v. 15, n. 3, p. 5136–5150, 2015. doi: <https://doi.org/10.3390/s150305136>. Citado na página 24.

ZHOU, X. et al. Cross-platform online visualization system for open bim based on webgl. *Multimedia Tools and Applications*, Springer, v. 78, n. 20, p. 28575–28590, 2019. doi: <https://doi.org/10.1007/s11042-018-5820-0>. Citado na página 125.

ZOLOTAS, M.; ELSDON, J.; DEMIRIS, Y. Head-mounted augmented reality for explainable robotic wheelchair assistance. In: IEEE. *2018 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*. [S.l.], 2018. p. 1823–1829. doi: <https://doi.org/10.1109/IROS.2018.8594002>. Citado 5 vezes nas páginas 12, 2, 13, 14, and 34.

A Appendix - ADL driving challenges survey

A.1 General User Information

1. Gender: ( ) male ( ) female
2. Age:
3. Scholarly degree:
   (a) ( ) Elementary school(1^o ate 8^o degree),
   (b) ( ) High school (1^o ate 3^o year),
   (c) ( ) Technical education,
   (d) ( ) College
   (e) ( ) Postgraduate
4. Contact phone number:

A.2 Patient profile

1. How long have you been a PW user?
   (a) What kind of PW?
   (b) What kind of interface control?
2. Which scenario/environment do you find most challenging to control/direct your PW? Why?
   - Outside:
     (a) ( ) Public (parks, squares, events venues);
     (b) ( ) Street (Sidewalks);
     (c) ( ) Others:
   - Inside:
     (a) ( ) Job;
     (b) ( ) Home;
     (c) ( ) School;
     (d) ( ) Others:

3. Describe this scenario! What does it represent? Your characteristics? What is part of it, for example: spine, ramp, sidewalk (rattling, monkey stone, holes, different pavements), portals. What challenges were encountered, including transportation?

B Apêndice - Formulário de Consentimento

TERMO DE CONSENTIMENTO LIVRE E ESCLARECIDO

Você está sendo convidado(a) para participar da pesquisa intitulada "Arquitetura de Telereabilitação baseada em realidade aumentada para apoiar o treinamento de usuários de cadeiras de rodas motorizadas" , sob a responsabilidade dos pesquisadores Eduardo Lázaro Martins, Edgard Afonso Lamounier Jr, Alexandre Cardoso e Daniel Stefany Duarte Caetano.

Esta pesquisa pretende proporcionar a você condições de se reabilitar, ou seja, recuperar sua independência na realização das atividades diárias antes de sua mobilidade ser restringida. Acredita-se que por meio do ambiente de Telereabilitação aumentada desenvolvido, você possa com a intervenção e acompanhamento do terapeuta, executar tarefas personalizadas que atenda as suas necessidades, remotamente. Com base em seus desafios diários, com segurança e o mais próximo possível da realidade. Você e o terapeuta, serão capazes de interagir com este ambiente, cuja infraestrutura foi desenvolvida baseado em suas observações, e objetos virtuais que auxiliarão neste processo.

A fusão das técnicas de Realidade Aumentada (RA) com as características advindas da Telereabilitação, te possibilitará a visualização aumentada, instantaneamente, dos comandos de controle enviados a CRM remota. Utilizando as técnicas de RA, o terapeuta definirá o trajeto a ser executado por você, onde os virtuais poderão ser utilizados como guias, e outros deverão ser evitados. O terapeuta ainda avaliará, tomará notas e acompanhará o seu treinamento. Tudo para que você realize diversas manobras para desenvolverão suas habilidades de controle da CRM. Você será instruído, sobre como utilizar e solicitar o treinamento no sistema, e por meio de um joystick adaptado, conectado ao computador, enviará os comandos para controlar a CRM a distância sem ser necessário deslocar-se, com segurança e com mais realismo.

O presente Termo de Consentimento Livre e Esclarecido será fornecido pelo pesquisador Daniel Stefany Duarte Caetano e deverá ser apresentado antes da realização do experimento no Núcleo de Tecnologias Assistivas da Universidade Federal de Uberlândia.

Após a conclusão de cada protocolo você deverá preencher um questionário parcial, descrevendo suas percepções sobre o funcionamento do sistema e do treinamento realizado. E após o último protocolo de treinamento, você deverá preencher também um questionário com perguntas pontuais sobre alguns requisitos do sistema, usabilidade e avaliação de sua experiência.

Em nenhum momento você será identificado, a não ser entre os responsáveis pelo estudo, sendo assegurado o sigilo sobre sua participação. Os resultados da pesquisa deverão ser publicados, porém ainda assim sua identidade será preservada.

Você não terá nenhum gasto e ganho financeiro por participar na pesquisa.

Os riscos envolvidos consistem na possível fadiga mental durante a realização dos protocolos de treinamento remoto.

Os benefícios que se espera com este estudo são: ter uma avaliação da arquitetura de sistema desenvolvida, para aprimorá-lo a partir das sugestões coletadas de cada participante. Futuramente, traçar-se-á abordagens de melhorias futuras, para que nas próximas etapas do projeto sejam implantadas, objetivando uma melhor a experiência no treinamento na condução de CRM além deixar a arquitetura mais robusta para toda a comunidade, permitindo alcançar melhores contribuições científicas com os dados futuramente obtidos.

Você é livre para deixar de participar da pesquisa a qualquer momento sem que haja qualquer prejuízo ou coação por parte dos envolvidos.

Uma cópia deste Termo de Consentimento Livre e Esclarecido ficará com você, e a segunda cópia será arquivada pelos pesquisadores.

Qualquer dúvida a respeito da pesquisa, você poderá entrar em contato com: Eduardo Lázaro Martins Naves (34) 3239-4769; Daniel Stefany Duarte Caetano (34) 99645-6207 (sdc.daniel@gmail.com) – Universidade Federal de Uberlândia: Av. João Naves de Ávila, nº 2121, bloco A, sala 220, Campus Santa Mônica – Uberlândia –MG. Poderá também entrar em contato com o Comitê de Ética na Pesquisa com Seres-Humanos – Universidade Federal de Uberlândia: Av. João Naves de Ávila, nº 2121, bloco A, sala 224, Campus Santa Mônica – Uberlândia –MG, CEP: 38408-100; fone: 34-32394131

Uberlândia, 20 de Maio de 2019.

Assinatura do(s) pesquisador(es)

Eu aceito participar do projeto citado acima, voluntariamente, após ter sido devidamente esclarecido.

____

Participante da pesquisa

Eu,____
responsável pelo ____
autorizo e responsabilizo a participação do mesmo no projeto descrito acima.

C Appendix - Consent Form

FREE AND CLARIFIED CONSENT TERM

You are being invited to participate in the research entitled “An Augmented Reality-based Telerehabilitation Architecture for Supporting the Training of Powered Wheelchair Users”, under the responsibility of researchers Eduardo Lázaro Martins, Edgard Afonso Lamounier Jr, Alexandre Cardoso and Daniel Stefany Duarte Caetano.

This research intends to provide the conditions for rehabilitation or to recover its independence in carrying out activities that, before mobility, are restricted. It is believed that through the developed augmented telerehabilitation environment, you can remotely, with the intervention and monitoring of the therapist, performing personalized tasks that meet your needs. Based on your daily challenges, safely and as close to reality as possible. You and the therapist will be able to interact with this environment, whose infrastructure was created based on your applications, and virtual objects that will assist you in this process.

A fusion of the Augmented Reality (AR) techniques with the advanced features of Telerehabilitation, allows increased responses received, instantly, from the control commands sent in the remote PW. Using AR techniques, the therapist will define or execute it for you, where users can use it as guides, and others will be avoided. The therapist still evaluates, takes notes and monitors your training. All for you to perform several maneuvers to develop your PW control skills. You will be instructed on how to use and request training on the system, and through an adapted joystick, connected to the computer, you will send the commands to control a PW remotely without having to move, safely and with more realism.

This Free and Informed Consent Term will be used by the researcher Daniel Stefany Duarte Caetano and will be released before the experiment is carried out at the Assistive Technologies Center of the Federal University of Uberlândia.

After completing each protocol, you must complete a partial questionnaire, describing your perceptions of the system’s functioning and the training conducted. After the last training protocol, you can also complete a questionnaire with specific questions about some system requirements, use and evaluation of your experience.

At no time will you be identified, you will not be among those responsible for the study, you will be assured of confidential about your participation. The results of the research must be published, but your identity will still be preserved.

You will have no financial expense and gain to participate in research.

The risks involved are possible mental fatigue during remote training protocols.

The benefits that await with this study are: an assessment of the architecture of the developed system, to improve it based on the suggestions collected from each participant. In the future, to track future improvement approaches, for the next stages of the project, be implemented, aiming at a better training experience in conducting PW, in addition to leaving a more robust architecture for the whole community, allowing better performances with the data obtained in the future.

You are free to stop participating in the research at any time without prejudice or coercion by those involved.

A copy of this Free and Informed Consent Form is blocked with you, and a second copy will be filed by the researchers.

Any questions regarding the research, you can contact: Eduardo Lázaro Martins Naves (34) 3239-4769; Daniel Stefany Duarte Caetano (34) 99645-6207 (sdc.daniel@gmail.com) - Federal University of Uberlândia: Av. João Naves de Ávila, nº 2121, block A, room 220, Campus Santa Mônica - Uberlândia - MG. You can also contact the Human Research Ethics Committee - Federal University of Uberlândia: Av. João Naves de Ávila, nº 2121, block A, room 224, Campus Santa Mônica - Uberlândia –MG, CEP: 38408-100 ; phone: 34-32394131

Uberlândia, May 20, 2019.

Researcher(s) Signature(s)

I accept to participate in the project mentioned above, voluntarily, after having been duly clarified.

____

Survey participant

I, ____ responsible for ________________________________ authorize and hold responsible for its participation in the project described above.

D Appendix - User's guide

D.1 Introduction

This chapter describes some steps about how to use the application developed in details. Since the how to login to the system, the therapist actions and user actions.

D.2 Web server application

The web server application[1] shown in Figure 112 was implemented using JavaŮ Servlets and Multi-WebRTC framework and different channels to receive/redirect data.

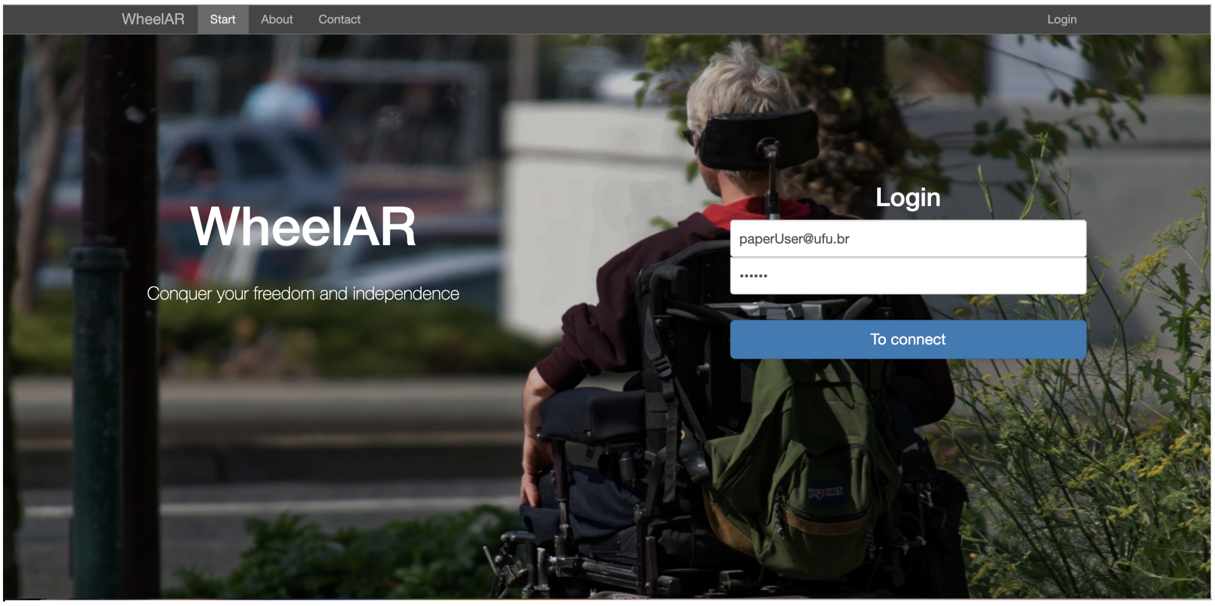

Figure 112 – AR Wheel home page

Thus, the system platform is based on the MVC(HANSEN; FOSSUM, 2005). This makes it easy to incorporate different libraries and frameworks (JSArtoolkit, Boostrap, Web Graphics Library (WebGL) and GL Transmission Format (GLTF) models) to build a reliable web application (POLTAVSKYI; ZASELSKIY, 2020; ZHOU et al., 2019; MATTIOLI et al., 2019; AQUINO; GANDEE, 2016). Servlets are used in MVC model to control events that come from JSP page through POST, GET requests and also external data coming from sockets. In this system, there are two basic actors' roles: therapist and patient.

The following sections, explain the main implementation details about each site and respective session.

[1] https://www.swheelchairth.com.br:8443/servletserver/

D.2.1 Training site

The release to interact and visualize information of this environment by the user is given only by the therapist.

The "Start streaming" is a web page that can be accessed from "Begin session" action inside the "Define training" menu. From the therapist desktop, a remote connection is established to the smartphone using the Team Viewer QuickSupport. Then, from a new therapist session the "Define training" menu is accessed and through the "Begin session" action is redirected to the page shown in Figure 113. Each new streaming (video/audio) session that is implemented over WebRTC API has an id randomly defined. When the "Start streaming" button is pressed streaming is started. Thus, some updates are performed in order to lock the training site, change the patient status from "waiting" to "training", and a shared Uniform Resource Locator (URL) is also updated. Then the "Waiting page" recognize this changes and redirect each user profile to respective "ViewPort". After the training protocol is finished by the user, the therapist ends the video streaming pressing the "End call" button, logout the web page and close the remote connection.

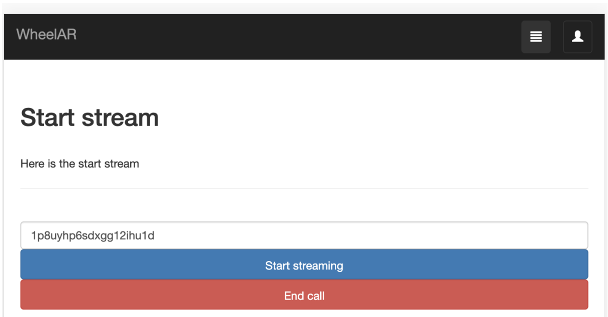

Figure 113 – Start streaming therapist page

D.2.2 Therapist session

The menu sessions information is presented bellow:

D.2.2.1 User register

Used to register new patients and therapists as presented in Figure 114. According to the selected profile (therapist/patient) the system asks different information related to the user that will be stored into database. Some patients information asked are PW model, impairment time, health state (cognitive, visual and auditory) , ADL and AIVD performance and transport.

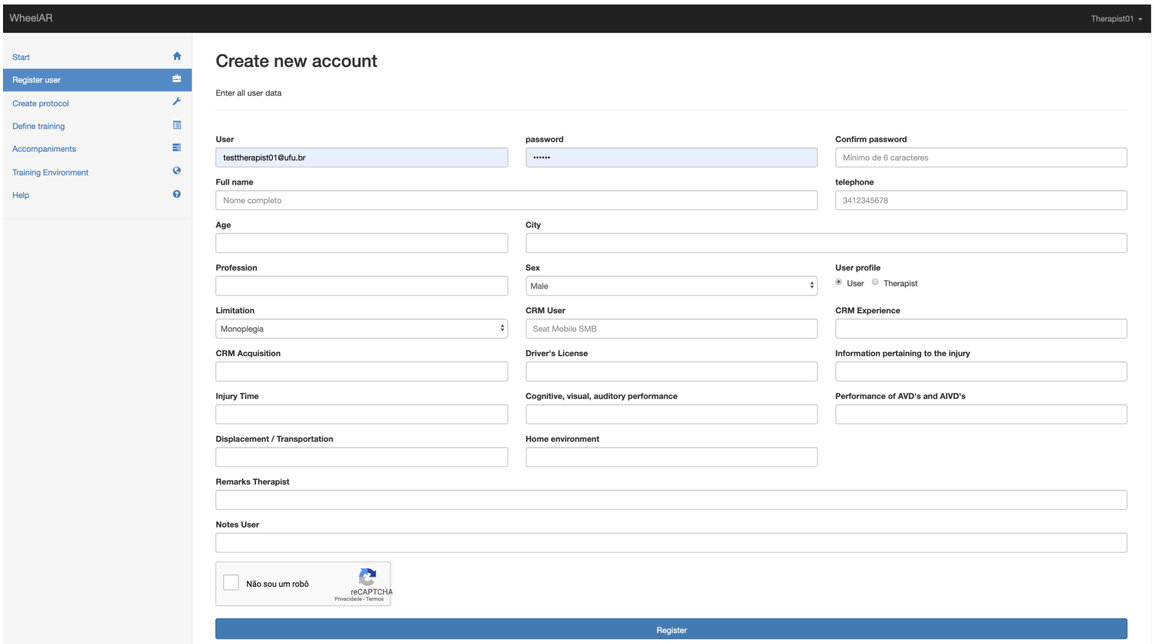

Figure 114 – Register a new user page

D.2.2.2 Create protocol

An adaptation of PMRT was implemented in order to allow the therapist to customise different activities providing the user with their needs. The first step is to select all activities requested to the new protocol from "Activities list" clicking on "Add activity" to add or "Clear activities" clear all as presented on Figure 115.

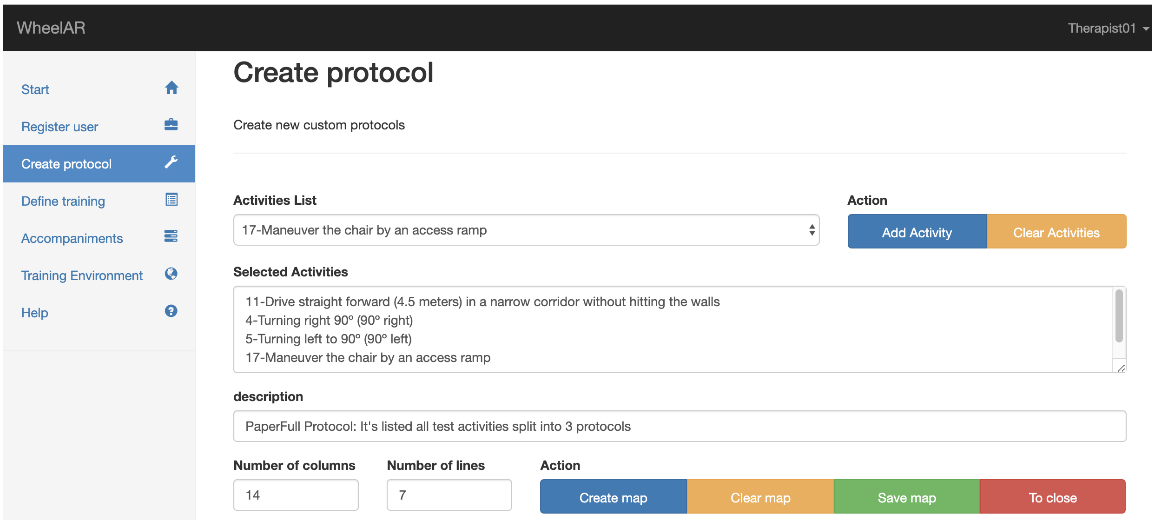

Figure 115 – Defining the activities for each protocol

Next step is to fill a short description and next, to create the map of fiducial markers that's customise the training protocol. To use the whole area is necessary to set 14 columns and 7 lines number and then click on "Create map" to create an empty map or click on "Clear map" to remove the created map. The fiducial AR matrix is initially filled with numbered indexed buttons which means that no virtual object was attached yet. All red buttons presented in Figure 116 have physical equipments that can be used by the therapist on training protocol.

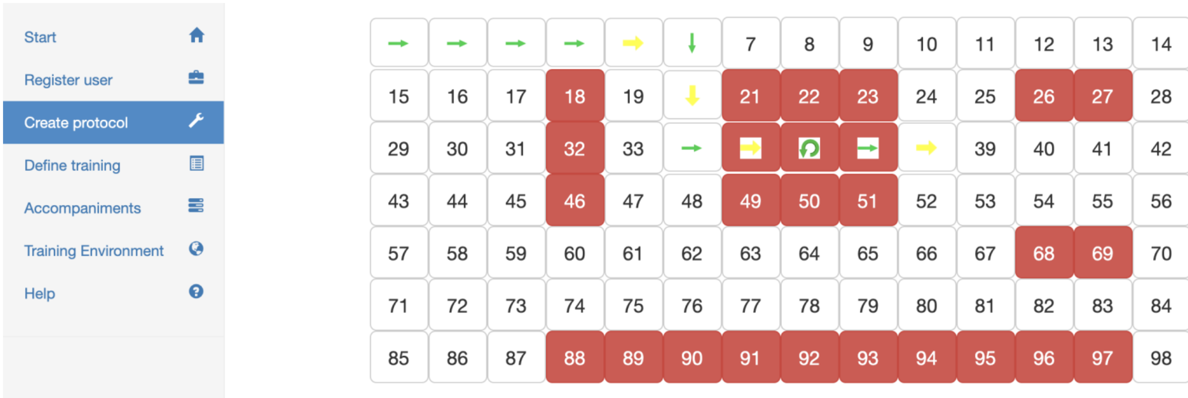

Figure 116 – Create a training activities and protocol map example

Virtual object that can be used as a guidance or avoidance and also can be static or animated. Thus, is possible even in a controlled environment have non-structural activity in where the user have to decide what he have to do in front of an unexpected event. To insert a virtual object it is necessary to click in each marker and then select one of the objects presented in Figure 117. Green arrows is used as a guidance and the yellows arrows means the end of an activity proposed by the therapist.

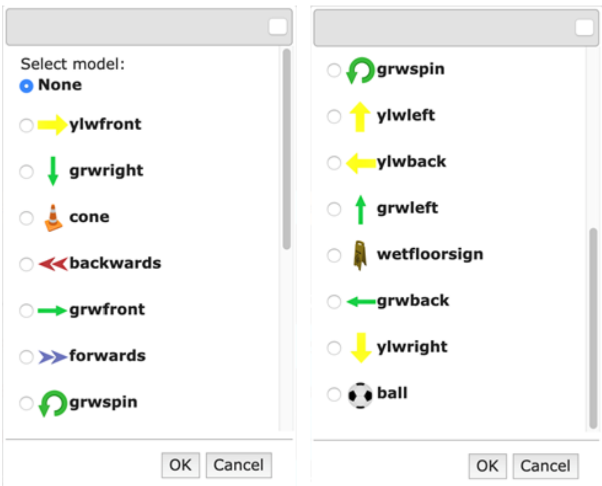

Figure 117 – Virtual objects (animated/statics) list

Figure 116 is a protocol example. Protocols can be saved clicking on "Save map" or to exit to the system "To close".

D.2.2.3 Define protocol

In this section page, the therapist preview all training sessions requested from different user's. From "Select the protocol", the therapist is able to choose all training protocol created from him and preview some informations about it, as presented from Figure 118 and also, to visualise the "Training Environment" is **Free** or **Occupied**.

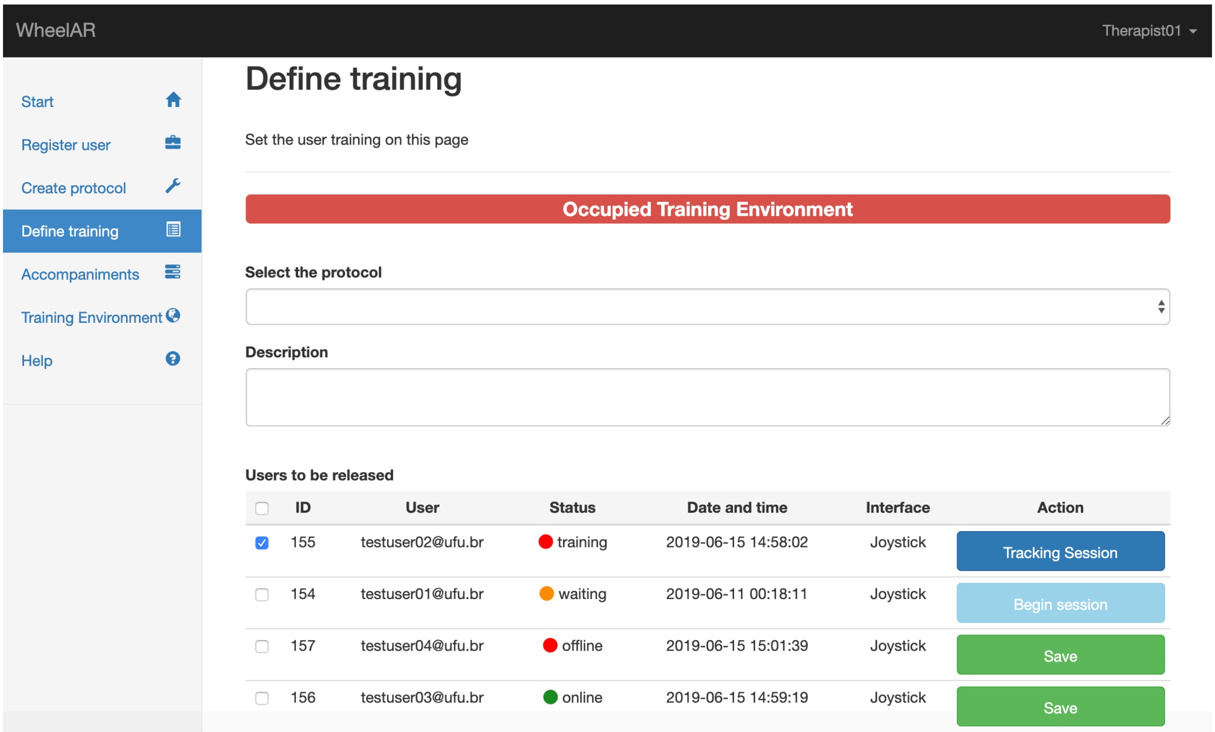

Figure 118 – Define training protocol

Before selecting one of the existents actions: "Save", "Begin session" and "Tracking session" is necessary to be aware of each users status means, as presented by Figure 118:

1. *Status*:

   (a) **Offline**: The user may have already requested a training, but is not connected into the system;

   (b) **Online**: The user may have already requested a training, but is not waiting for the release. After a request is made, the system will only include a new one after the last request is made;

   (c) **Waiting**: After clicking on the connect button, as shown in Figure 123, the user should wait for the therapist to release the training;

   (d) **Training**: Defined the training protocol, released and initialized video streaming, the control commands are forwarded allowing the user to execute the protocol defined by the therapist. The environment is locked during this time.

2. *Actions*: The actions below have to execute following the order.

   (a) **Save**: Check the training request and press the button. Now, the therapist is able to perform the next action;

(b) **Begin session**: All training requisition who have a training protocol defined can be started while the training environment is free. Them, press the button to be redirected to "Start streaming page" action was mentioned before in Section D.2.1.

(c) **Tracking session**: Soon as the training is released by pressing this button the therapist is redirected to the "Waiting pages" and then to the "Therapist Viewport page" presented in Figure 119. Now, he can follow the user training and interact with the PW. Throughout the session, the therapist has to press the "Mark activity" button when the user passes over a yellow marker, to counts commands entered and also the time spent during the activity. Finished the training by the user, the "Close tracking" has to be pressed to be redirected to the next action.

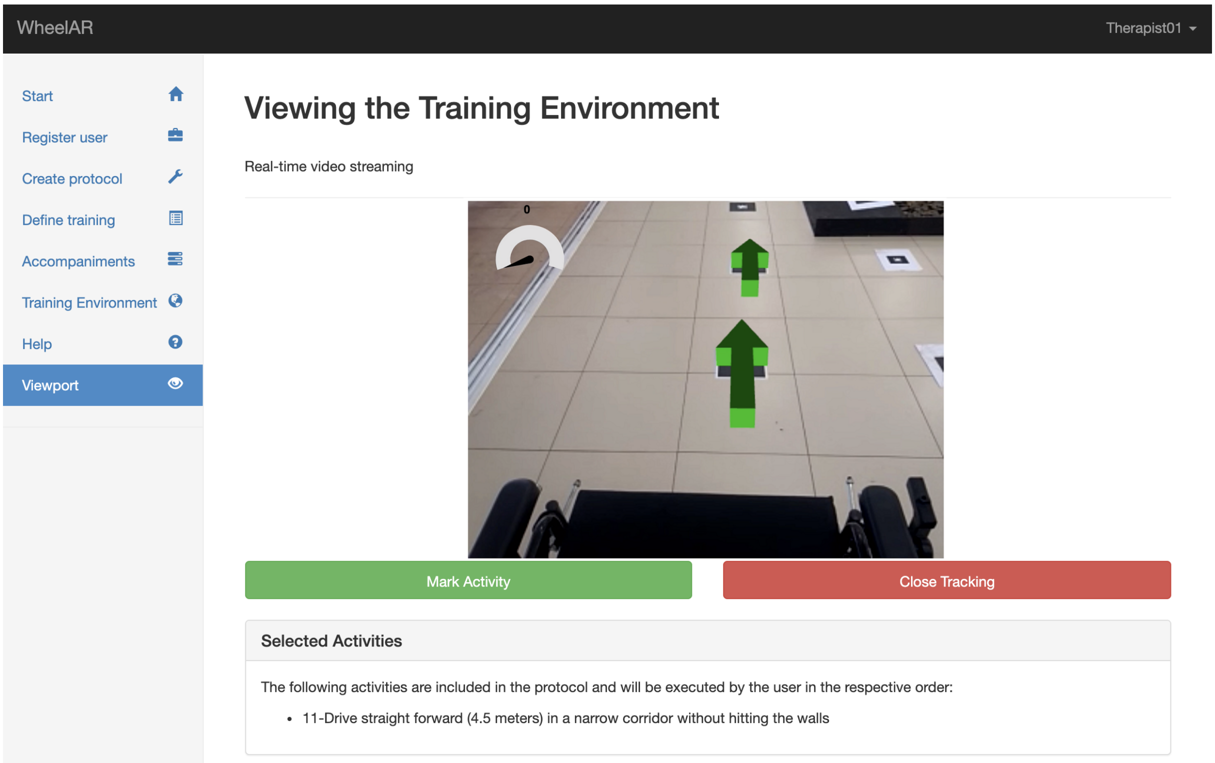

Figure 119 – Tracking session and Therapist ViewPort page

D.2.2.4 Evaluate training

Based on PMRT Assessment Form, the system retrieves all information stored into the database of each activity. The therapist only have to fill out the comments around, collision number and then choose a relative note. Before saving the evaluation, the "Calculate score" button is triggered to update the score. Thus, the system redirects to the therapist "Annotations page".

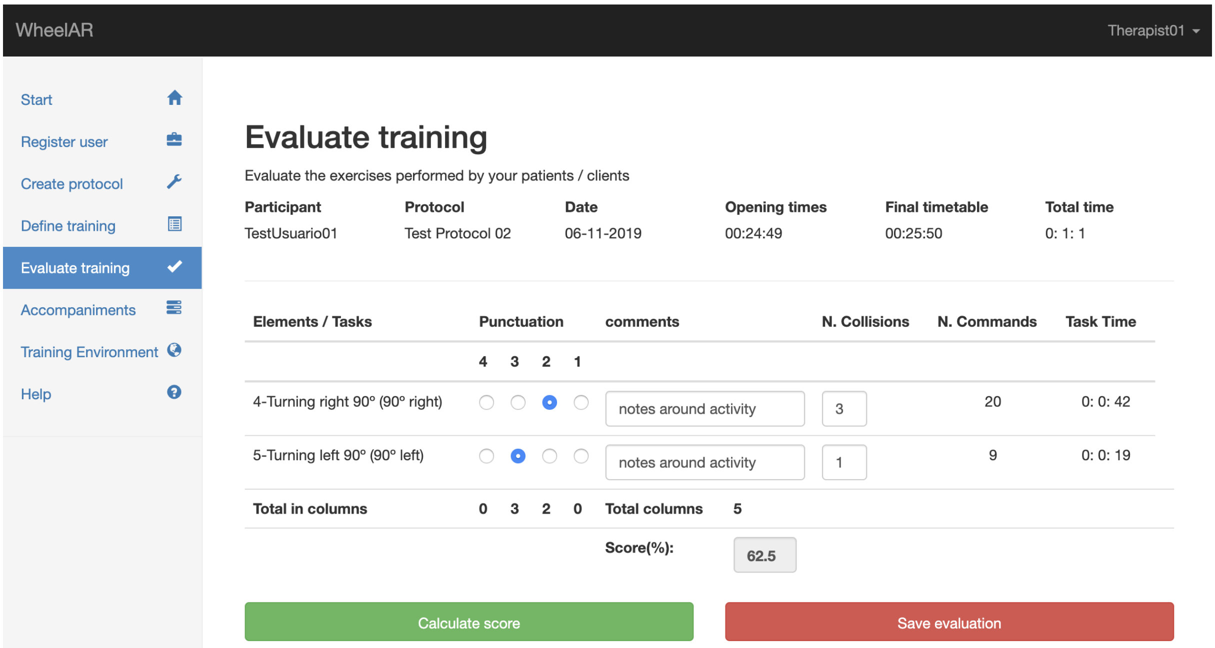

Figure 120 – Adapted PMRT Evaluation Form

D.2.2.5 Annotations

In this page, the therapist is able to take some general or complementary notes information about the user evolution, during training sessions, to all activities into to training protocol, as shown in Figure 121. To end this task, the "Save notes" button is pressed saving the data into the "historyTH" database and finally redirected to "Start page" where to start any other action like "Accompaniments".

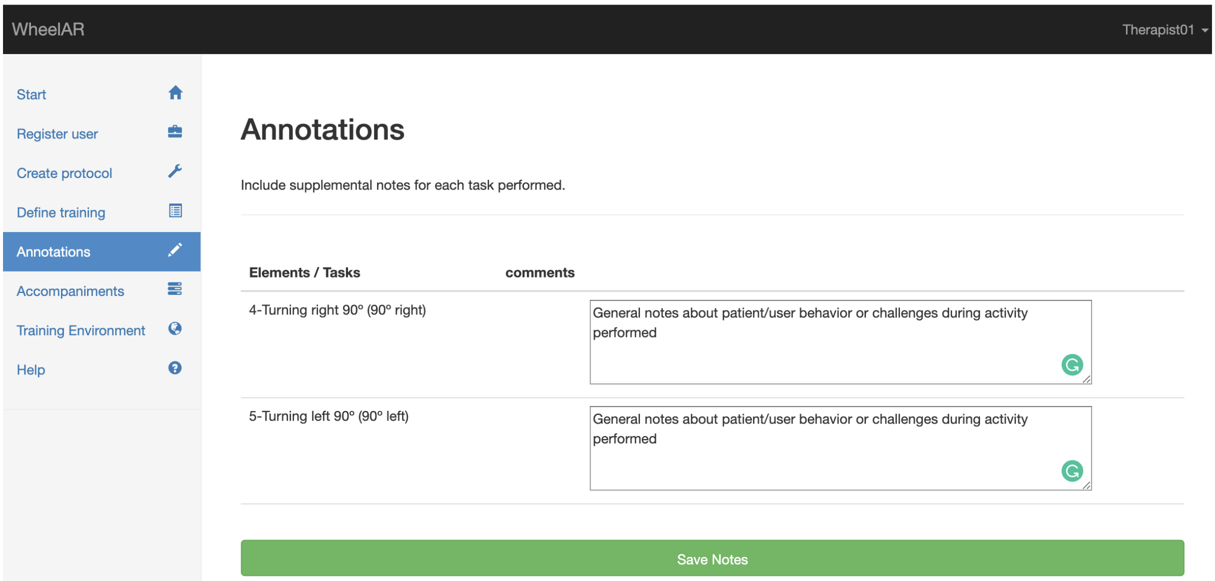

Figure 121 – General and clinicians notes around the user evolution

D.2.2.6 Accompaniments

Looking for clues of the user evolution after the training sessions, the therapist evaluates the graph presented by Figure 122. This graph can be generated in real-time and to do it, the following actions must be performed:

- **Select**: Select a patient from the "Select patient" list and click on the "Select" button to retrieve the files executed by the patient without a database.
- **Generate graph**: Afterwards, select one of the files in the "Select the protocol" list and click the "Generate graph" button.

On the y-axis, there are quantitative information regarding a number of commands, collisions, time spent and note reached, as shown in the chart legend. On the x-axis, the protocols are separated into sets by ID and Data. The activities in each are grouped, allowing a different analysis.

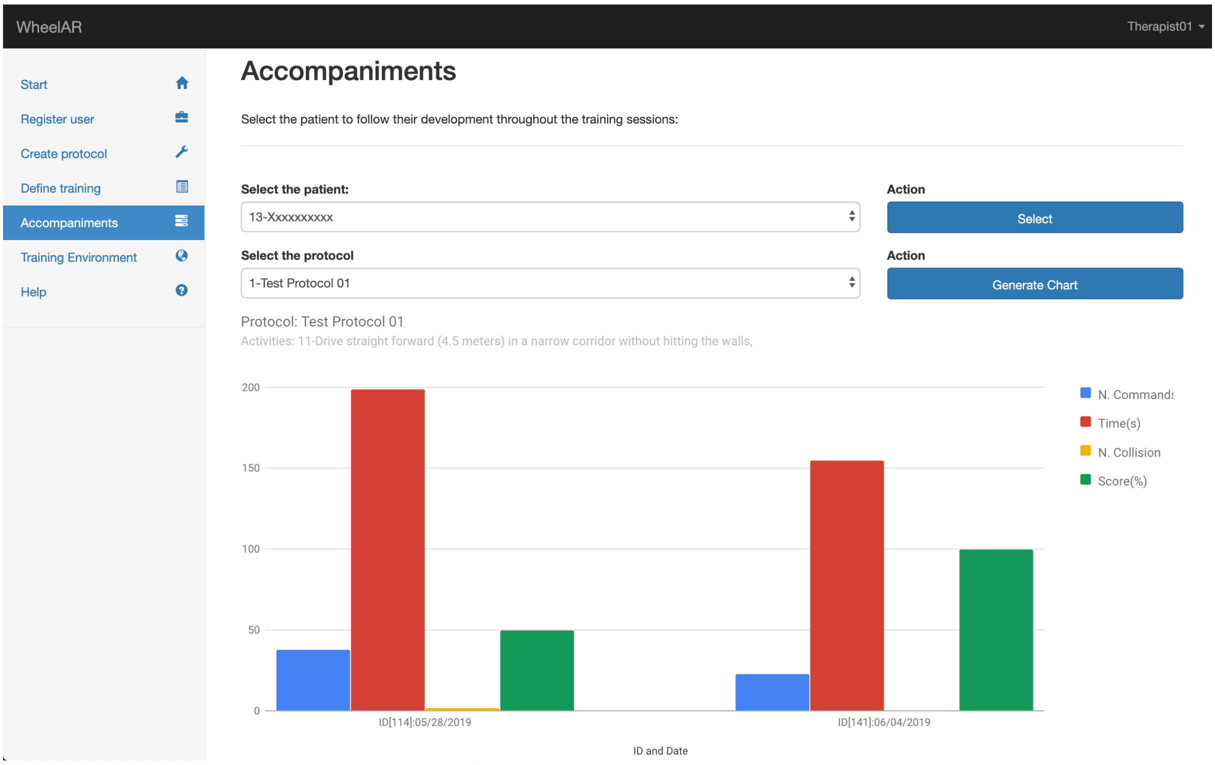

Figure 122 – Comparative chart users training protocols performed

In addition to this graph, information about the SI or excitation from the biosignals allows the evaluation of the emotional state of the same, helping also in the understanding of the real difficulties and observing the overcoming of them after each session.

D.2.3 User session

Once the user has logged into the system, his status is updated to "on-line", which means that he is connected but not in training process. After, the user is invited to select an interface control existent such as a keyboard, joystick, and others and then press the button "Connect" to request a new training session, as presented in Figure 123. A new blank record is inserted on "assessTH" table responsible to store all data from training session changing the user status from "on-line" to "waiting". Otherwise, the user can press the button "Close" to exit the system changing, his status to "off-line".

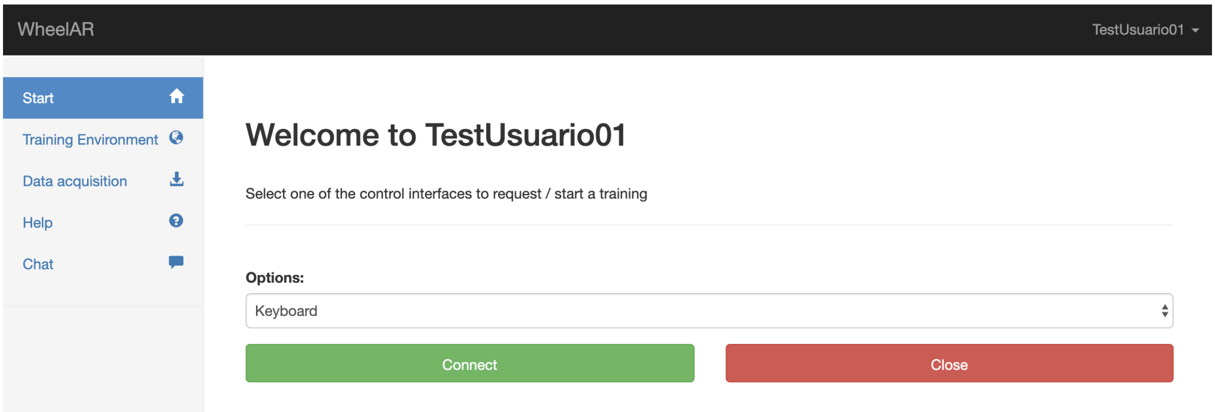

Figure 123 – Main user page interaction

If the "Connect" button is pressed, the user will be redirected to the "Waiting page" as presented in Figure 124, until the Health professional, responsible for his process, releases the training environment. While the user is waiting, he has to read the 3D's models information (description and action) that might be chosen for his training. Then, his status will be updated to "waiting".

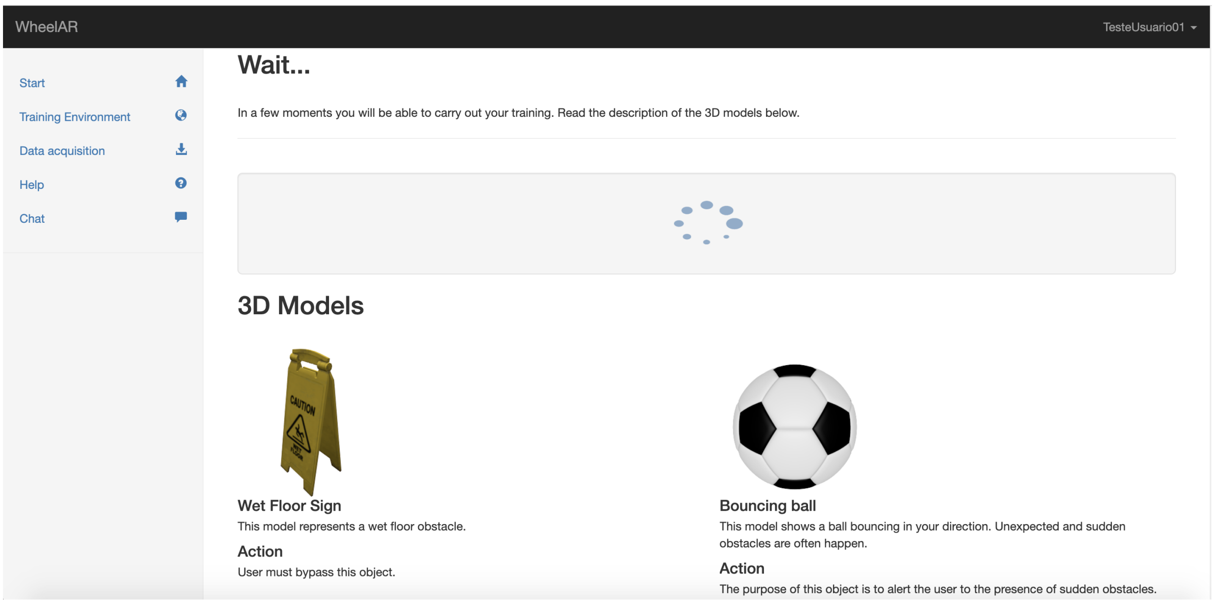

Figure 124 – Waiting release training page

D.2.3.1 Data acquisition

Since a web browser is a sandbox application, to issue commands inputs to a remote PW, the user has to download the cross-platform JavaŮ application shown in Figure 125 and 126. From this application, a data connection with the command servlet is established. This servlet is responsible for forwarding all control input to the training environment. However, when a keyboard is used as an interface control, this application is not requested, because the browser recognizes the keyboard as basic input. To start the data-flow, the user has to select an option If it is "joystick" then select the port and then press the button "Connect" or "Disconnect" to close data-flow and application.

Figure 125 – Starting dataflow

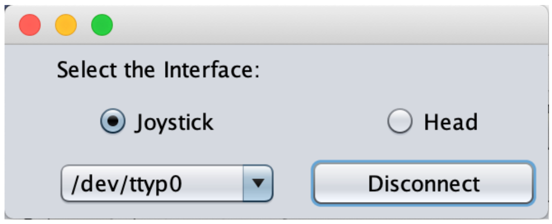

Figure 126 – Close dataflow

D.2.3.2 ViewPort

When the training session is released, the user status is changed to "training" and redirected to this page shown in Figure 127, which provides a first-person experience view.

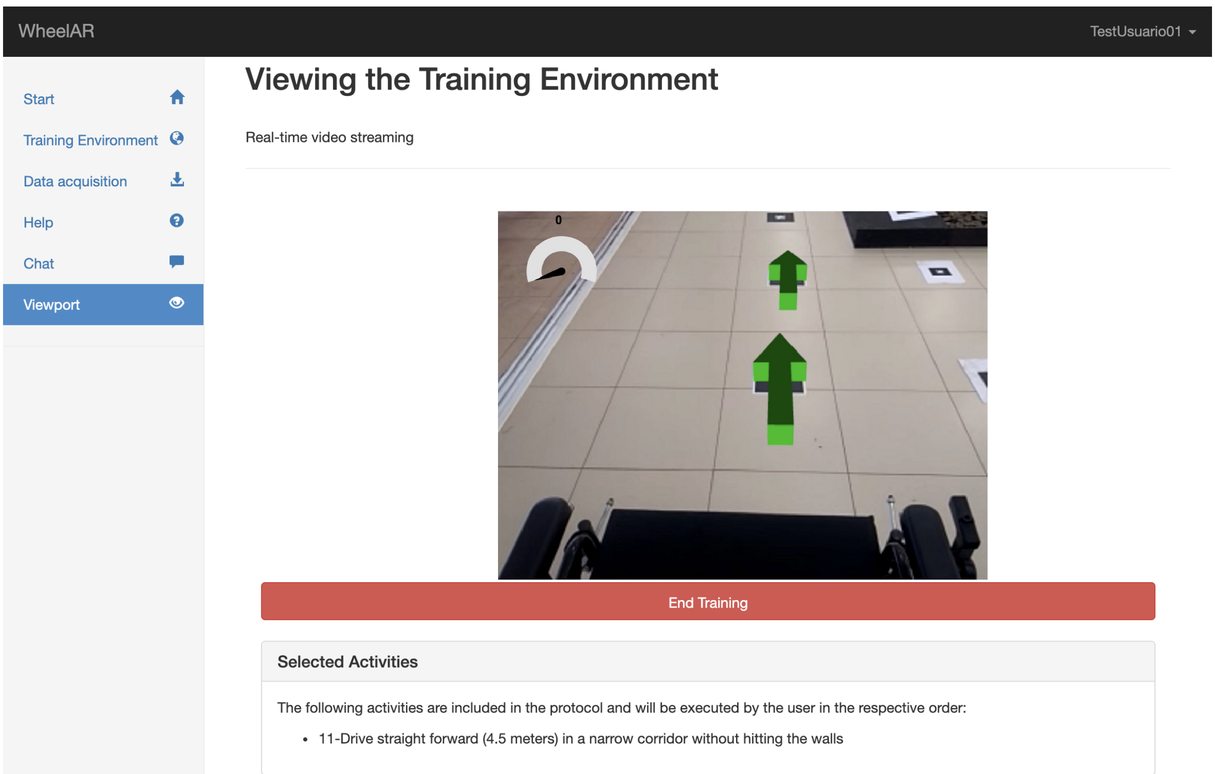

Figure 127 – Real-time video streaming preview page

The exercises prepared for each training protocol is listed on page bottom. The "End training" button has to be pressed when the training session has been concluded redirecting to the main users' page presented in Figure 123, updating the user status to "on-line".

D.3 Final considerations

This chapter described all implementation details. In the next chapter, preliminaries results will be presented and discussed.