Proposal of an Augmented Reality Telerehabilitation System for Powered Wheelchair User's Training

Daniel Caetano , Caroline Valentini, Fernando Mattioli , Paulo Camargos , Thiago Sá , Alexandre Cardoso , Edgard Lamounier and Eduardo Naves

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 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. The 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. Also, a questionary was used to evaluate system features. Preliminary results demonstrated the specific needs of individuals using a PW thanks to adopted metrics (qualitative and emotional). Results have shown the need for a 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. This system architecture allows further studies on telerehabilitation of PW users training.**

Index Terms—**Mobility, Powered Wheelchair Training, Augmented Reality, Telerehabilitation, Power Mobility Road Test, Biosignals**

I. Introduction

IN Brazil, more than 45 million people have some motor limitation among which 2.33 percent (1 million people) have a severe motor disability, according to the 2010 census [1]. Among them, 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 [2]–[4]. 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 [5]. 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 and mobility in daily activities [4]. However, not everybody has conditions to acquire such device [2], [3], [6].

The Unified Health System in Brazil is responsible for providing a PW for users, attending criteria established by Ordinance n. 1272 through rehabilitation centers Brazil [7], [8]. Although users get a simple training on the PW, it is not enough to prepare them, leading to misuse and eventual accidents [7], [8]. Nevertheless, many users face different problems to overcome their displacement of rehabilitation center like financial resources, time available and others [9].

Authors have been exploring Virtual Reality (VR) in many protocols and several situations safely [5], [6], [10], [11]. A Virtual Reality Environment (VRE) for PW driving training, which is focused only on indoor challenges are shown by John et al.[5], Kamaraj et al. [10] and Mahajan et al. [11]. A VRE with indoor and outdoor scenarios, but not yet focused in training is shown by Vailland et al.[6]. 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 [5], [6], [10]. Notwithstanding, these VRE's have some limitations such as were 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 is needed [12].

On the other hand, Augmented Reality (AR) can provide the user with better control, where user interaction can be achieved in a more realistic and intuitive way and safely [13]–[17].

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In doing so, the system augments the real world with digital information (e.g., pictures, videos, instructions, clinical data) enhancing the user's experience [14]. 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 [14].

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. [5]. The PMRT was chosen by Kamaraj et al.[10], Mahajan et al. [11] and Massengale et al. [18] as a standard and reliable methodology (training protocol and assessment) applied for each user distinctly. 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 hallway or avoiding a therapy ball in the way[18]. All tasks evaluated on PMRT are based on visual perception. 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 [19]–[22].

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[23] has among others, the goal of extending and improving user care [23], [24].

In light of the aforementioned, in this paper, the authors presents a telerehabilitation architecture developed to be used as a complementary tool for PW users training, based on the PMRT [10], [18]. This architecture allows a remote support by the therapist 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 [19]–[22].

This paper is organized as follows. We introduce the telerehabilitation system architecture designed including the environments description in Section II-A, while the system modeling detail to support the architecture is shown in Section II-B. Biosignal data acquisition and processing is presented in Section II-C. Preliminary test scope is presented in Section II-D to evaluate user experience and their training with the system. The results are presented and discussed in Section III and IV. Finally, in Section V we draw our conclusions and highlight some potential future studies.

II. Material and Methods

A. Architecture Designed

Based on three main modules of computational system used by Burdea et al. [25], he authors present the solution outline on Figure 1, composed by [26]:

- A training site, where the exercises protocols will be executed;
- A patient site, where the user remotely controls the wheelchair;
- A therapist site in which a health professional can customize, follow and evaluate trials executed by the user and access performance data;

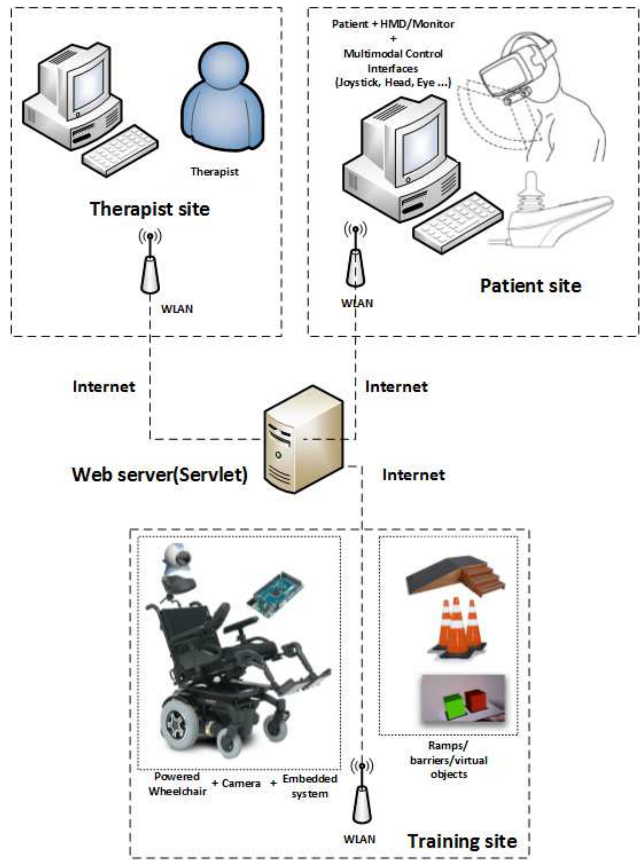


Fig. 1: AR Telerehabilitation System Architecture

1) Training site: The controlled environment where each structural part was built based on 60 surveys filled out by PW users with different disabilities. The area presented in Figure 2 is 14.76x7.16 m and is currently located in a classroom at Federal University of Uberlândia and can be previewed in 360° image[1].

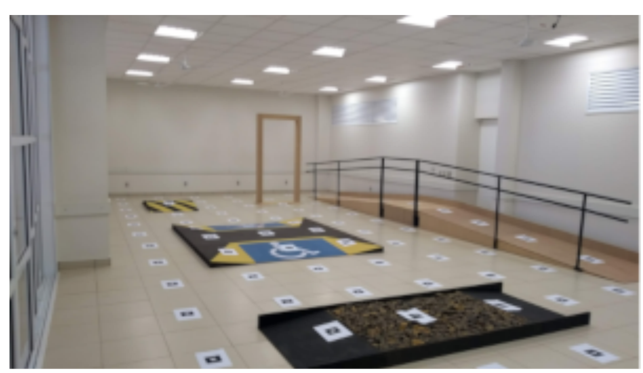


Fig. 2: Remote training site

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

The room is composed by physical objects such as curb and a high access ramp, uneven surface area, spine, portal and a PW (Figure 3a) without diagonal movements.

(a) SMB SM2 wheelchair (b) Adapted USB Joystick VR2 P&G [27]

Fig. 3: Training and Patient environment components

2) Patient site: From a remote place, the user controls the PW using different interfaces such as a keyboard, joystick (Figure 3b) and others. From traditional monitors the patient has an augmented preview in a semi-immersive level.

3) Therapist site: As in the patient environment from a remote place, the health professional is able to aid the user on performing the tasks described in Section II-A and also interacts with the PW using the arrow keys to move or space key to stop.

B. Implementation details

The web server application[2] was implemented using Java™ Servlets technology that provides a consistent mechanism and makes possible the development of an architecture with video streams (Multi-WebRTC) and different channels to receive/redirect data. Thus, an independent system platform was designed to keep different sites connected over Internet. The development is based on the MVC (Model - View - Control) which is very useful for building interactive software [28]. The MVC is divided into Model (Java class), Controller (Java Servlet) and View (JSP pages). This makes it easy to incorporate different libraries (JSArtoolkit, Boostrap and WebGL) and features with a reliable web application. 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 (UDP). In this system, there are two basic actors' roles: therapist and patient.

1) Training environment: The training environment has a PW connected to a microcontroller responsible for receiving user's commands, activate the PW and collect its speed. The data transfer between the web server and this environment was made possible through UDP socket connection using a 4G router modem. Also, a smartphone was coupled to the PW, responsible to provide a pure video streaming data to the therapist and patient environment. An emergency stop was implemented in order to avoid possible crashes in case of data interruptions in data transmission greater than 3 seconds [9]. The patient permission to interact and visualize the environment is given by the therapist after starting the video streaming.

2) Therapist role: One of the most important actions in the Therapist role is **"create a new protocol"**. Other available actions are register a new user (therapist or patient), setup, begin, tracking, evaluate, take notes of a training session and follow the training session. In Figure 4, the therapist is able to insert or clear activities, make a protocol description and define an empty fiducial AR markers map.

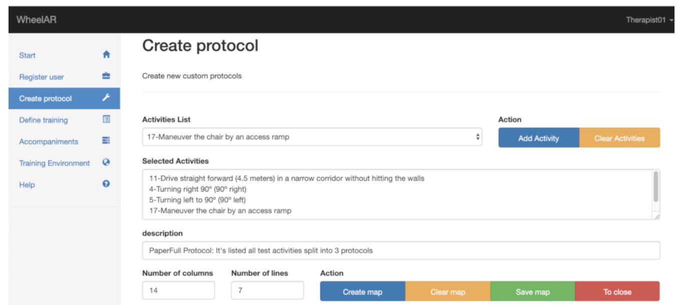


Fig. 4: Defining the activities for each protocol

All red buttons shown in Figure 5 represent physical objects inside the room that can be used by the therapist on training protocol.

Fig. 5: Customized protocol through AR techniques

Virtual objects can be used as a guidance (green arrows) or avoidance. From the list presented in Figure 6 it is possible to add a static or animated object to compose each activity of the training protocol as presented in Figure 5.

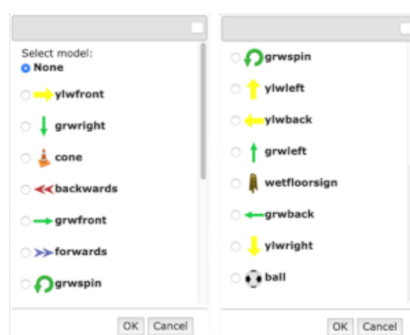


Fig. 6: Virtual objects (animated/statics) list

Yellow arrows are used to signalize the end of an activity proposed by the therapist. This adaptation was implemented based on PMRT in order to allow the therapist to customize the protocols activities (structural or non-structural) providing the user with their needs.

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

The training workflow consists of receiving the patient request and defining the protocol, initiating stream, tracking session, evaluate training and saving notes (therapist role). After the training request, the patient is redirected to a **"Waiting page"** as presented in Figure 7. In this page the patient is instructed to read all information of existing virtual objects and which action to perform.

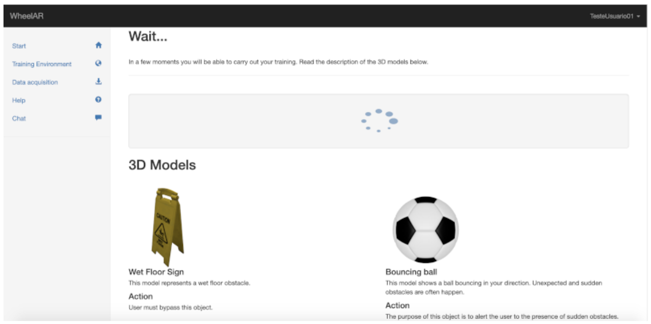


Fig. 7: Waiting page: Virtual objects information

Figure 8 present the training sessions requested by the patients and possible actions and also realize the training environment status.

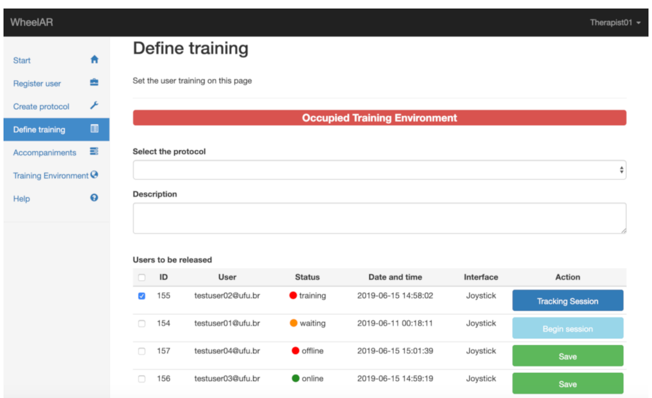


Fig. 8: Training protocols request status and actions

After the therapist has started a new training session his is able to track it and mark each activity finished by the patient from the viewport presented in Figure 9.

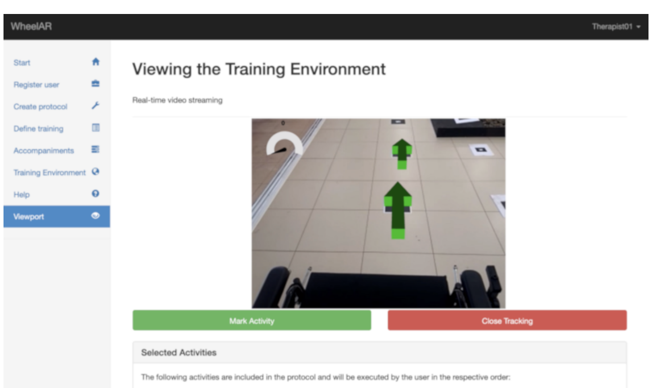


Fig. 9: Tracking session and Therapist ViewPort page

Once the training protocol is finished, the therapist is able to evaluate the training session by the adaptation realized in a PMRT Assessment form as presented by Figure 10. After the workflow fulfillment he can also use the bar chart to follow the patient evolution after each protocol.

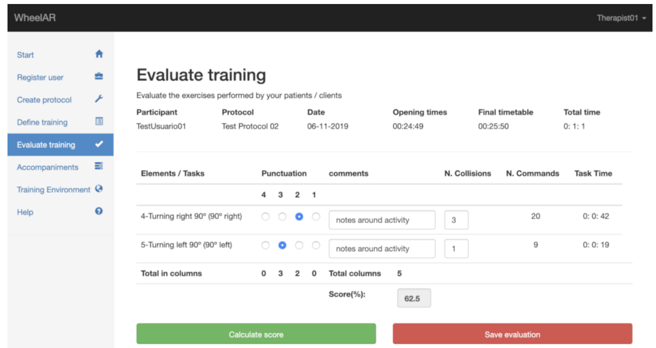
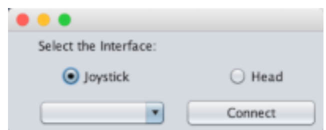
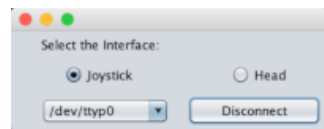


Fig. 10: Adapted PMRT Evaluation Form

3) Patient role: A cross-platform Java™ application shown in Figure 11a and Figure 11b must be downloaded from the patients home page presented in Figure 12.



(a) Starting dataflow



(b) Close dataflow

Fig. 11: Data acquisition GUI

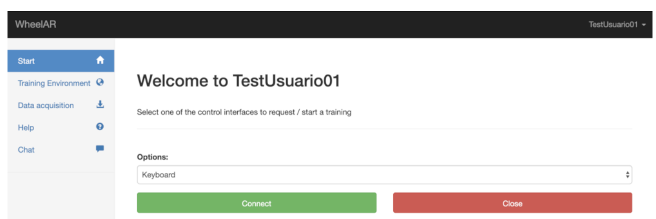


Fig. 12: Patient's page

This application is responsible for establishing a connection with the system server and relay commands produced by the patient in a joystick [29]. Requesting a new training session, the patient must select the control interface. After the therapist released the training the patient is able to interact and preview the augmented training environment shown in Figure 13.

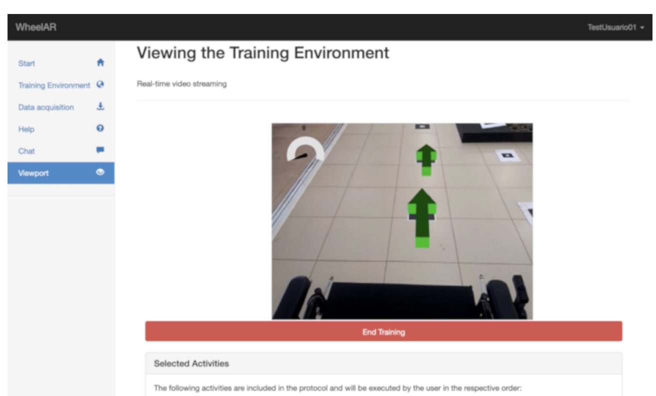


Fig. 13: Real-time streaming preview page

C. Biosignal data acquisition and processing

Biosignal data acquisition was performed using the E4 wristband (Figure 14), manufactured by Empatica®. The instrument is an easy to wear wristband that can measure various biosignals, among them EDA and BVP.

Fig. 14: The E4 wristband for biosignal data acquisition

EDA data processing was conducted using [30], as shown in Figure 15, to decompose the signal in two components: phasic and tonic. For evaluation of the event related skin conductance responses (each command given by the participant is considered an event in this preliminary study), the phasic component was used, considering an event response window starting 1s after each event and finishing 4s after this same event. The Continuous Decomposition Analysis (CDA) method was used, given its robustness on decomposing EDA biosignals in continuous tonic and phasic data [31].

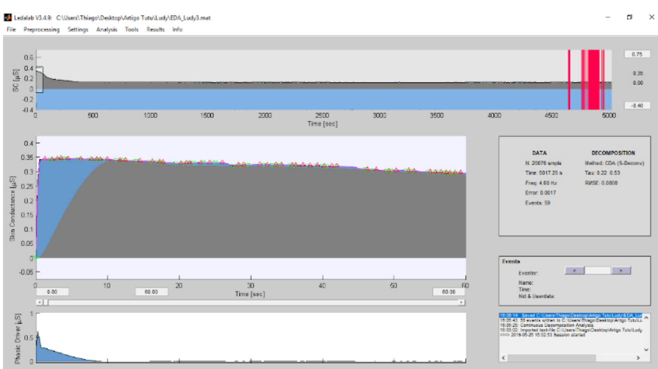


Fig. 15: Ledalab software used for EDA decomposition into phasic and tonic components

Amongst output variables extracted from Ledalab to evaluate individuals responses, the Integrated Skin Conductance Response (ISCR) was 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 was 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 was z scored to reduce subject variability.

Data processing of BVP was performed using Kubios [32], a software used to analyze Heart Rate Variability. It utilizes Inter Beat Interval (IBI), extracted from BVP measured by the E4 wristband [33] for each participant on each protocol. It returns several output variables, among them the stress index (SI) calculated as the square root of Baevsky's stress index [34].

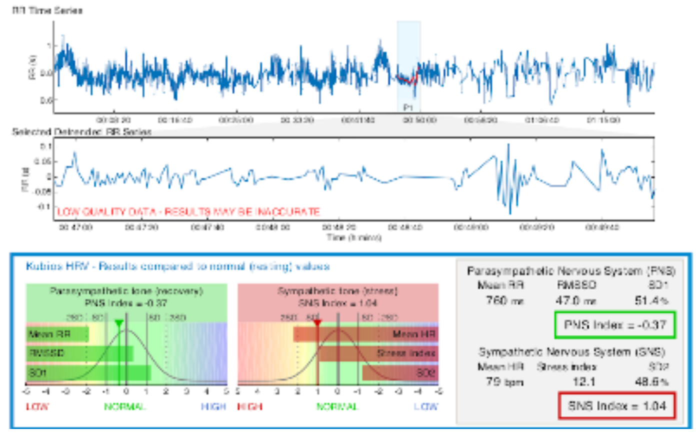


Fig. 16: A section of a report generated by the Kubios software for HRV

D. Preliminary test

1) Participants: General and Clinical information about the participants in this research is detailed in Table II and I.

TABLE I: Participants general information

No.	Description	Detail
1	Participants	Consist of 3 adults aged 22 to 57 years;
2	Gender	1 woman and 2 men with spinal cord injury [35], [36];
3	Location	Collection was made in a rehabilitation center 10 kilometers far from the training site;
4	Consent form	All participants were asked to fill a consent form;
5	Ethical Committee	The approval to conduct this research was obtained from the Federal University (377566140.0000.5152).

TABLE II: Participants clinical information

Participant	Detail
01	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), have transportation (not adapted), house adapted to move around and needs joystick adaptation;
02	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 (SI), have adapted transportation, house fully adapted and requested a joystick position adaptation;
03	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 Activities of Daily Living (ADL) / Instrumental Activities of Daily Life (AIVD) performance is semi independent (SI) and SI, 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;

2) Procedure and process: The initial process steps followed for each participant every first time, instructed and supported by a therapist, is described in Table III.

The survey questionnaire is shown in Tables IV and V.

TABLE III: Procedure and Processes

Step	Procedure/Process
1	Ensure that the environment temperature is conditioned at 25°C for good quality of biosignals [20];
2	Participants will be registered into the system by the therapist as a patient. Participants had the project explained again for purposes of clarification and for a chance to withdraw the study;
3	Participants will be instructed about how to log into the system;
4	Participants 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 participants in 360° and explained how he/she must proceed to interact with;
6	Explain to the patient how to request a training session;
7	Participants will be instructed about how to request a training session;
8	Let the patient rest by 7 minutes before starting each training session to ensure a good emotional state and relax [20];
9	Wearing the“E4 wristband” wearable device as shown in Figure 14;
10	Request the training sessions;
11	While the therapist is selecting one of the preliminaries training protocols(Figure 5) splitted in: 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 patient read all information about how to proceed in from of each virtual object;
12	At the end of each protocol, participants 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;
13	Participants have to rest for 5 minutes to ensure comfort and absence of side effects before request a new training session [20];
14	After the last protocol, participants are invited to fill out other questions related to his/her own individual profile and system requisites;
15	The study ended.

TABLE IV: Survey Questionaire

N.o	Questions Asked				
6	How was it to lean to use the system?				
	5	4	3	2	1
	Very Easy	Easy	Relatively Easy	Difficult	Very Difficult
7	How do you evaluate the graphical interface of the system?				
	5	4	3	2	1
	Great	Very good	Good	Median	Bad
8	How was it to use the system?				
	5	4	3	2	1
	Very easy	Easy	Relatively easy	Difficult	Very difficult
9	Did the system meet the navigation needs?				
	5	4	3	2	1
	Excellent	Great	Good	Median	Bad
10	How do you consider the quality of the image presented?				
	5	4	3	2	1
	Excelent	Great	Good	Median	Bad
11	Do you consider that the AR (virtual objects) help to carrying out the training?				
	5	4	3	2	1
	Very	Moderate	Medium	Little	None
12	How was the processing time (response time)?				
	5	4	3	2	1
	Very fast	Fast	Moderate	Slow	Very slow
13	How much do you consider this tool assists in the development of driving skills?				
	5	4	3	2	1
	Intensily	Very	Moderately	Little	Nothing
14	How do you evaluate your well-being after training?				
	5	4	3	2	1
	Relaxed	Little tired	Tired	Very tired	Exhausted
15	Are you satisfied with the system features?				
	5	4	3	2	1
	Very Satisfied	Satisfied	Indifferent	Dissatisfied	Very dissatisfied

TABLE V: Survey Questionaire

N.o	Questions Asked				
16	Does the system do the right thing?				
	5	4	3	2	1
	Extremely well	Very well	Well	Relatively well	Nothing

3) Data collection and analysis: The data information extracted during the trials is shown in Table VI and the analysis performed in this data is described in Table VII.

TABLE VI: Data collection information

N.o	Description
1	Parameters like the number of input controls, elapsed time, collisions number were measured in order to evaluate the participants trials performance;
2	A survey questionnaire was also used to provide qualitative information about the system from the participants point of view as well the therapist's comments about each activity performed;
3	Participants biosignals were also collected to analyze protocols impacts during the trials

TABLE VII: Data analysis information

N.o	Description
1	The PMRT Methodology is used for trials performance evaluation;
2	Bar charts shown the participants questions evaluation and Word clouds [37] represent the most relevant reasons for the patient's evaluations based on participants and therapist's comments/notes;
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-software^{TM} [38]. The Shapiro-Wilk test was used, and the data distribution was found to be non-normal [39]; 2) Stress Index Analysis, using the IBI time series(Inter-Beat Interval - Time between individual heart beats) was used to obtain the Stress Index for each protocol individually using the software Kubios [40];

III. RESULTS

A. Trials performance evaluation information

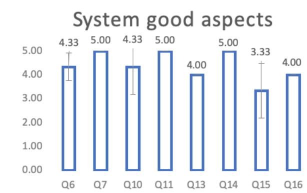
Table VIII presents the performance evaluation realized by therapist.

TABLE VIII: PMRT Evaluation Summary

Participant	Prt	Command	Collision	Time(s)	Score(%)
01	1	38	2	199	50
	2.1	37	1	328	50
	2.2	7	0	57	
	3	54	0	354	75
02	1	27	0	282	75
	2.1	17	0	127	75
	2.2	21	0	67	
	3	66	0	178	75
03	1	14	0	227	75
	2.1	9	0	98	50
	2.2	13	0	51	
	3	34	0	236	75

B. System requirements information

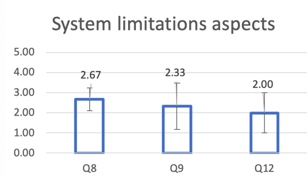
Figure 17a and Figure 18a represent the participants' survey questionnaire evaluation. Figure 17b and Figure 18b represents visual qualitative information about advantages, disadvantages and comments.



(a) System Good Aspects

(b) WordClouds Advantages

Fig. 17: Good evaluations



(a) System Limitations Aspects

(b) WordClouds Limitations

Fig. 18: System limitations evaluations

C. Protocols evaluation

1) EDA Analysis: The ISCR (obtained after processing EDA) Descriptive Statistics is presented in Table IX. It is possible to observe that Skin Conductance Responses are skewed and can produce non-normal distributions [41], as observed in the difference between ISCR average and ISCR median.

TABLE IX: 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
- 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 [42]. 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.

2) Stress Index Analysis: In order to obtain the stress index for each protocol and each participant, we used the IBI time series prepared for processing using Kubios.

TABLE X: Stress zone boundaries

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

TABLE XI: Stress zone participants comparison

User	SI Protocol 1	SI Protocol 2	SI Protocol 3
Participant 01	12.0769	11.4139	09.9194
Participant 02	17.5959	14.8135	16.9240
Participant 03	06.0430	05.2265	08.0705

Table X present the Stress Zone and corresponding SI (Stress Index) band values [40].

Participants comparison results are presented in Table XI:

Finally, data presented on Table XI is translated to stress zones in Table XII:

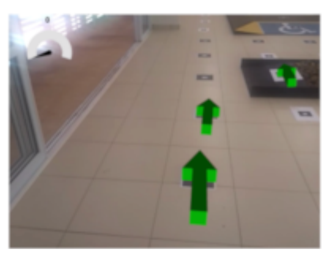
TABLE XII: Stress zone participants translation

User	SI Protocol 1	SI Protocol 2	SI Protocol 3
Participant 01	Normal	Normal	Normal
Participant 02	Elevated	Elevated	Elevated
Participant 03	Low	Low	Normal

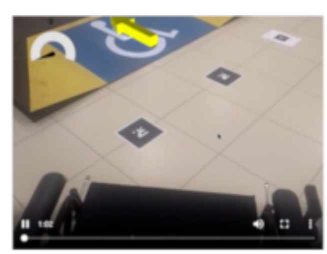
IV. Discussion

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

Questions 6, 7 (Figure 17a) and 8 (Figure 18a) 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 - Q12[Figure 18a]) and failure to render virtual objects (Figure 18b) shown in Figure 19.



(a) Rendering failure-01



(b) Rendering failure-02

(c) Rendering failure-03

Fig. 19: Virtual objects rendering failure

In Figure 19a the guidance arrow is rendered at a wrong place, in Figure 19b and 19c the guidance and final activity arrows was 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 Q9 (Figure 18a) and, adjustments from the participant (Figure 18b).

On the other hand, questions 10, 11, 13, 15 and 16 (Figure 17a) confirm that the application of telerehabilitation techniques fused with the AR techniques presents itself as a great tool to elevate the driving skills of the patients without leaving their home(Figure 17b). 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 realization of the protocol, as shown in Figure 20 .

(a) End first activity (b) Spin the PW

Fig. 20: Virtual objects static and animated

During the execution of each training protocol, the therapist is able to monitor the participants' performance in the proposed activities in real time. Upon completion of the training process, the therapist must complete the adapted PMRT assessment form. Information such as number of commands and up 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 note to the activity. After the activity notes are applied, the final score of the protocol is calculated. The participant is considered approved in a protocol when he/she reaches a score higher than or equal to 95% [18], as the summary presented by Table VIII. Through the comparative bar charts shown in Figure 21, the therapist can follow the evolution in the development of the participant's abilities. Therefore, it 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 that 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, and it is important to understand, whenever these issues arise, if 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.

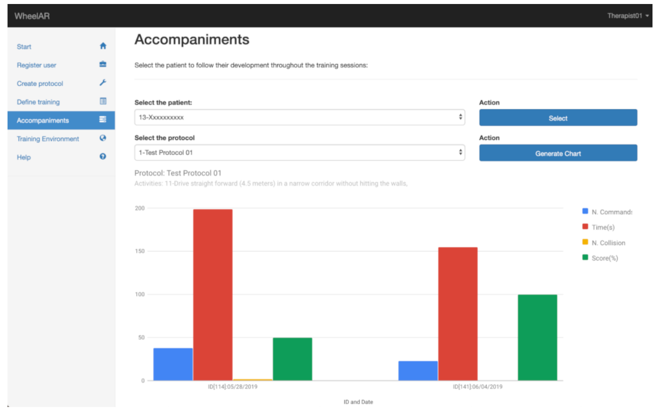


Fig. 21: Patient training protocol comparison

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 protocol duration is considered short - longer protocols might present different results. The intention of this preliminary test is to showcase 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.

V. Conclusion

Based on the participants' survey answers, we believe that the purpose of the system architecture was achieved. In this preliminary study, all tests were conducted in a rehabilitation center. 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 patient conditions. Since the beginning of the system architecture development, we opted to use only open-source tools and libraries because we hope in the future to incorporate this system on the rehabilitation centers connected with Brazilian Unified Health System and share[3] this project with the community as open-source for non-commercial license use.

From these results we conclude that the protocols did not show difference on the participants analyzed. Participant 3 was the only one changing stress zones. However, we believe it represents a normal variation towards a resting state on the normal stress zone, not caused by the protocols.

Different subject segmentation based on injury type, severity, age and experience using assistive technologies can be implemented to evaluate the learning curve connected to participant biosignals evolution during time and to identify roadblocks on each protocol. Patient's stress monitoring is also important not only to address learning but also to assure safety during normal use. Also, further studies could be done in this direction to classify patient's stress better and provide a risk

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

assessment in order to develop improved strategies to prevent accidents.

Future work can be divided into two strands: increase users' experience and scientific contributions. In order to correct the rendering failure of the augmented objects, the fiducial markers will be removed and replaced by rendering based on the Cartesian position of the PW [43]. By implementing a proximity sensor, all virtual objects within range are rendered, as in the Poke-mon GO game [44]. Otherwise, the use of deep learning techniques can be investigated in order to reduce rendering failure [45]. 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 [46]. Finally, replace the model of PW used by one with less time of breaking of inertia and also with diagonal movements.

Although the results were satisfactory, there are limitations in this research-study, such as the small number of volunteers and the need to have more sessions and training during the experiment. However, due to latency during the trials in many different moments was not possible to complete the sessions. As mentioned before, the participants have many restrictions, as described in Table II and also their displacement to the rehabilitation center. The majority of works cited did not make evaluations using eligible participants, only healthy users.

REFERENCES

[1] d. c. Cartilha, "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)[Portuguese version], 2012, p. 17.

[2] S. Arlati, V. Colombo, G. Ferrigno, R. Sacchetti, and M. Sacco, "Virtual reality-based wheelchair simulators: A scoping review," Assistive Technology, 2019, pp. 1–12, doi: 10.1080/10400435.2018.1553079.

[3] C. C. Caro, J. D. Costa, and D. M. C. Cruz, "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," vol. 26, no. 3. [Portuguese version], 2018, doi: 10.4322/2526-8910.ctoAO1117.

[4] M. J. Scherer and S. Federici, "Why people use and don't use technologies: Introduction to the special issue on assistive technologies for cognition/cognitive support technologies," NeuroRehabilitation, vol. 37, no. 3, 2015, pp. 315–319, doi: 10.3233/NRE-151264.

[5] N. W. John, S. R. Pop, T. W. Day, P. D. Ritsos, and C. J. Headleand, "The implementation and validation of a virtual environment for training powered wheelchair manoeuvres," IEEE transactions on visualization and computer graphics, vol. 24, no. 5, 2018, pp. 1867–1878, doi: 10.1109/TVCG.2017.2700273.

[6] G. Vailland, F. Grzeskowiak, L. Devigne, Y. Gaffary, B. Fraudet, E. Leblong, F. Nouviale, F. Pasteau, R. Le Breton, S. Guegan et al., "User-centered design of a multisensory power wheelchair simulator: towards training and rehabilitation applications," 2019, doi: 10.1109/ICORR.2019.8779496.

[7] Brazil, "Includes wheelchair procedures and wheelchair postural adaptation in the unified health system table of procedures, drugs, orthotics, prosthetics and special materials (opm)," in Ordinance 1272. Accessed: 04/04/19, [Portuguese version], 2013. [Online]. Available: $http://bvsms.saude.gov.br/bvs/saudelegis/gm/2013/prt1272_25_06_2013.html$

[8] ——, "Supplementary info," in Ordinance No. 1272 - Annex I. Accessed: 04/04/19, [Portuguese version], 2013. [Online]. Available: $http://bvsms.saude.gov.br/bvs/saudelegis/gm/2013/anexo/anexo_prt1272_26_06_2013.pdf$

[9] S. Mitsumura, Y. Akimoto, E. Sato-Shimokawara, and T. Yamaguchi, "Development of remote controllable visiting robot considering local situation," in Micro-NanoMechatronics and Human Science (MHS), 2014 International Symposium on. IEEE, 2014, pp. 1–4, doi: 10.1109/MHS.2014.7006142.

[10] D. C. Kamaraj, B. E. Dicianno, H. P. Mahajan, A. M. Buhari, and R. A. Cooper, "Interrater reliability of the power mobility road test in the virtual reality–based simulator-2," Archives of physical medicine and rehabilitation, vol. 97, no. 7, 2016, pp. 1078–1084, doi: 10.1016/j.apmr.2016.02.005.

[11] H. P. Mahajan, B. E. Dicianno, R. A. Cooper, and D. Ding, "Assessment of wheelchair driving performance in a virtual reality-based simulator," The journal of spinal cord medicine, vol. 36, no. 4, 2013, pp. 322–332, doi: 10.1179/2045772313Y.0000000130.

[12] M. K. MacGillivray, B. J. Sawatzky, W. C. Miller, F. Routhier, and R. L. Kirby, "Goal satisfaction improves with individualized powered wheelchair skills training," Disability and Rehabilitation: Assistive Technology, vol. 13, no. 6, 2018, pp. 558–561, doi: 10.1080/17483107.2017.1353651.

[13] L. Manring, J. Pederson, D. Potts, B. Boardman, D. Mascarenas, T. Harden, and A. Cattaneo, "Augmented reality for interactive robot control," in Special Topics in Structural Dynamics & Experimental Techniques, Volume 5. Springer, 2020, pp. 11–18, doi: 10.1007/978-3-030-12243-0_2.

[14] A. Borresen, C. Wolfe, C.-K. Lin, Y. Tian, S. Raghuraman, K. Nahrstedt, B. Prabhakaran, and T. Annaswamy, "Usability of an immersive augmented reality based telerehabilitation system with haptics (artesh) for synchronous remote musculoskeletal examination," International Journal of Telerehabilitation, vol. 11, no. 1, 2019, pp. 23–32, doi: 10.5195/ijt.2019.6275.

[15] S. B. Abdallah, F. Ajmi, S. B. Othman, S. Vermandel, and S. Hammadi, "Augmented reality for real-time navigation assistance to wheelchair users with obstacles' management," in International Conference on Computational Science. Springer, 2019, pp. 528–534, doi: 10.1007/978-3-030-22750-0_47.

[16] M. D. Wiederhold, "Augmented reality: Poised for impact," 2019, doi: 10.1089/cyber.2019.29140.mdw.

[17] M. Eckert, J. Volmerg, and C. Friedrich, "Augmented reality in medicine: Systematic and bibliographic review. jmir mhealth and uhealth, 7 (4), e10967," 2019, doi: 10.2196/10967.

[18] S. Massengale, D. Folden, P. McConnell, L. Stratton, and V. Whitehead, "Effect of visual perception, visual function, cognition, and personality on power wheelchair use in adults," Assistive Technology, vol. 17, no. 2, 2005, pp. 108–121, doi: 10.1080/10400435.2005.10132101.

[19] A. Affanni, R. Bernardini, A. Piras, R. Rinaldo, and P. Zontone, "Driver's stress detection using skin potential response signals," Measurement, vol. 122, 2018, pp. 264–274, doi: 10.1016/j.measurement.2018.03.040.

[20] A. Lanatà, G. Valenza, A. Greco, C. Gentili, R. Bartolozzi, F. Bucchi, F. Frendo, and E. P. Scilingo, "How the autonomic nervous system and driving style change with incremental stressing conditions during simulated driving," IEEE Transactions on Intelligent Transportation Systems, vol. 16, no. 3, 2014, pp. 1505–1517, doi: 10.1109/TITS.2014.2365681.

[21] J. Hernandez, D. McDuff, X. Benavides, J. Amores, P. Maes, and R. Picard, "Autoemotive: bringing empathy to the driving experience to manage stress," in Proceedings of the 2014 companion publication on Designing interactive systems. ACM, 2014, pp. 53–56, doi: 10.1145/2598784.2602780.

[22] J. A. Healey and R. W. Picard, "Detecting stress during real-world driving tasks using physiological sensors," IEEE Transactions on intelligent transportation systems, vol. 6, no. 2, 2005, pp. 156–166, doi: 10.1109/TITS.2005.848368.

[23] A. Barriga, J. M. Conejero, J. Hernández, E. Jurado, E. Moguel, and F. Sánchez-Figueroa, "A vision-based approach for building telecare and telerehabilitation services," Sensors, vol. 16, no. 10, 2016, p. 1724, doi: 10.3390/s16101724.

[24] Y. Lin, S. Song, and M. Q.-H. Meng, "The implementation of augmented reality in a robotic teleoperation system," in 2016 IEEE International Conference on Real-time Computing and Robotics (RCAR). IEEE, 2016, pp. 134–139, doi: 10.1109/RCAR.2016.7784014.

[25] G. C. Burdea, "Invited paper: Low-cost telerehabilitation," in Proceedings of Third International Workshop on Virtual Rehabilitation,, 2004, pp. 3297–3300.

[26] D. Caetano, F. Mattioli, E. Lamounier, and A. Cardoso, "[demo] on the use of augmented reality techniques in a telerehabilitation environment for wheelchair users' training," in Mixed and Augmented Reality

(ISMAR), 2014 IEEE International Symposium on. IEEE, 2014, pp. 329–330, doi: 10.1109/ISMAR.2014.6948473.

[27] J. PGVR2, "PG Drivers Technology - Wheelchair Control System." Accessed: 07/04/16, 2016. [Online]. Available: http://www.cw-industrialgroup.com/getattachment/439a3b95-d06f-4c98-bbd8-7f28cb9b1f71/vr2_brochure

[28] S. Hansen and T. V. Fossum, "Refactoring model-view-controller," Journal of Computing Sciences in Colleges, vol. 21, no. 1, 2005, pp. 120–129.

[29] D. Caetano, F. Mattioli, E. Lamounier, A. Cardoso, and E. Naves, "Adaptation of a usb interface for vr2 joystick applied to the training of wheelchair users," Assistive Technology: Development and Application, vol. 1, no. 1, 2018, pp. 261–267, Portuguese version.

[30] M. Benedek and C. Kaernbach, "Ledalab." Accessed: 16/06/19, 2016. [Online]. Available: http://www.ledalab.de/

[31] ——, "A continuous measure of phasic electrodermal activity," Journal of neuroscience methods, vol. 190, no. 1, 2010, pp. 80–91, doi: 10.1016/j.jneumeth.2010.04.028.

[32] "Heart rate variability - Kubios HRV," 2017. [Online]. Available: www.kubios.com

[33] "E4 data - IBI expected signal – Empatica Support." Accessed: 13/02/20, 2020. [Online]. Available: https://support.empatica.com/hc/en-us/articles/360030058011-E4-data-IBI-expected-signal

[34] R. Baevsky and A. Berseneva, "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.

[35] A. Rizzo, S. Thomas Koenig, and T. B. Talbot, "Clinical results using virtual reality," Journal of Technology in Human Services, 2019, pp. 1–24, doi: 10.1080/15228835.2019.1604292.

[36] J. Nunnerley, S. Gupta, D. Snell, and M. King, "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, vol. 12, no. 4, 2017, pp. 417–423, doi: 10.1080/17483107.2016.1176259.

[37] K. V. Bletzer, "Visualizing the qualitative: making sense of written comments from an evaluative satisfaction survey," Journal of educational evaluation for health professions, vol. 12, 2015, doi: 10.3352/jeehp.2015.12.12.

[38] J. Jurečková, J. Picek, and M. Schindler, Robust statistical methods with R. Chapman and Hall/CRC, 2019.

[39] T. U. Islam, "Ranking of normality tests: An appraisal through skewed alternative space," Symmetry, vol. 11, no. 7, 2019, p. 872, doi: 10.3390/sym11070872.

[40] hrvKubios, "Kubios hrv (ver. 3.1) user's guide," in Kubios Oy. Accessed: 11/07/19, 2018. [Online]. Available: https://www.kubios.com/downloads/Kubios_HRV_Users_Guide.pdf

[41] J. J. Braithwaite and D. G. Watson, "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.

[42] S. Bodkin, J. Hart, and B. C. Werner, "Common statistical tests," in Basic Methods Handbook for Clinical Orthopaedic Research. Springer, 2019, pp. 153–161, doi: 10.1007/978-3-662.

[43] R. Alves, C. R. Lopes, and M. Veloso, "Checkpoint coverage with wifi localization for indoor service robots," in JCAI 2016 WS Autonomous Mobile Service Robots, 2016, pp. 10–17. [Online]. Available: https://www.dropbox.com/sh/wp6abcswxstce3f/AADtfgehld7j0I9cNgZP2Zoua?dl=0

[44] Y. El Miedany, "Virtual reality and augmented reality," in Rheumatology Teaching. Springer, 2019, pp. 403–427.

[45] F. Mattioli, D. Caetano, A. Cardoso, E. Naves, and E. Lamounier, "An experiment on the use of genetic algorithms for topology selection in deep learning," Journal of Electrical and Computer Engineering, vol. 2019, 2019, doi: 10.1155/2019/3217542.

[46] S. Rashid and S. A. Razak, "Big data challenges in 5g networks," in 2019 Eleventh International Conference on Ubiquitous and Future Networks (ICUFN). IEEE, 2019, pp. 152–157, doi: 10.1109/ICUFN.2019.8806076.

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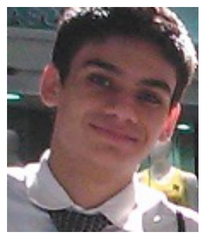

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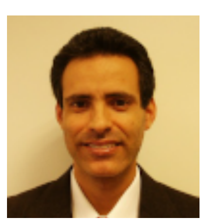

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