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Victus Exergame: An Approach to Rehabilitation of Amputees Based in Serious Game

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Abstract: This article describes a solution that aims to make the process of physical rehabilitation more attractive for amputees through a solution based on medical informatics and gamification through a serious game. Addressing the challenges faced by individuals with lower limb amputations during physiotherapy — such as trauma, pain, and lack of motivation — this work introduces a serious game that incorporates an embedded sensor system with microcontrollers to a stationary bike. That system serves as both the game controller and a set of biological monitors, alongside a physiotherapy tool that displays the data obtained during sessions for the therapists to track patient progress. Developed through a participatory design approach involving patients and therapists, the system collects data on user engagement, physiological responses, and performance metrics via sensors and feedback forms. By fostering a relaxed and immersive treatment environment, the approach seeks to improve the effectiveness of physiotherapy. Initial experiments demonstrated that this solution holds promise in creating a more playful and motivating physical rehabilitation environment.

Keywords: Physical Rehabilitation, Embedded Systems, Serious Game, Game Health, Exergame

1 Introduction

According to Cieza *et al*. [2020], there are 180 million people around the world who have some amputation, whether caused by congenital malformation, trauma, vascular diseases, cancer, serious infections, or complications of chronic diseases. Amputation accounts for 36% of years lived with disability worldwide. Although the amputation mortality rate decreased, the prevalence of the condition increased by 52% between 1990 and 2019. These data highlight the importance of physical rehabilitation to improve the quality of life of people with amputation and reduce its impact on the global burden of diseases [Cieza *et al*., 2020].

Within the field of physical rehabilitation of amputees, during physiotherapy, patients need to overcome several obstacles to perform a successful treatment. Due to the proximity in which the amputation occurred, the pain during the rehabilitation process, the lack of acceptance of the event, and even phantom pains of the amputated limb are some challenges faced by the patient and, consequently, by professionals in the area in aid of these patients. As much as it is a time to get around the patient's difficulties, it is not always easy to keep him motivated to engage with the adaptive treatment Matos *et al*. [2014]. In this sense, technology has been a great ally in helping this process, primarily through gamification.

Even with the advancement of technology, there are still few low-cost solutions to assist physical rehabilitation. On the other hand, the leading solutions to make the physiotherapy process more attractive involve hardware devices with peripherals capable of capturing information and user movements, such as video game consoles. However, performing an analysis based on the patient's vital signs is impossible through these devices. Due to this lack of data, the analysis of the physiotherapist about the evolution presented by the patient is often subjective because it is supported by human observation and patient descriptions [Mousavi Hondori and Khademi, 2014].

In this context, this work proposes a system to transform physical rehabilitation sessions into a more playful and motivating activity through a serious game. We focus on patients with lower limb amputation who undergo exercises on a stationary bike to adapt to their prosthesis. Due to the demand observed by the Serviço de Reabilitação Física de Bagé (SRF), activity is monitored using sensors to capture physiological data, bringing more significant detail to the patient's evolution from the aid in its evaluation by the physiotherapist in the different sessions. The following sensors are used in this solution: heart rate sensor, muscle strength sensor, and Hall effect sensor (which, together with a magnet fixed on the wheel of the exercise bike, allows measuring speed and displacement during the session).

The first version of the system was developed. After some initial experiments, a new version was proposed, considering new challenges and points system and making available a new phase with a new scenario and architectural modifications. This proposal was called Victus Exergame, and the new architecture used a new system based on a web application to present the data sessions. This way, from databases developed on the Firebase, it is possible to present the results for the physiotherapists with a more suitable tool. Thus, after new functional experiments were performed, it was possible to verify that the new solution was more interesting for physiotherapists and patients than the initial version.

This work is organized as follows: Section 2 provides the theoretical basis on the subject of the project; Section 3 describes the exploration of the project space and presents the developed solution; in Section 4 presents outlines the research methodology employed in this study, detailing the procedures, settings, artifacts used, and ethical considerations; in Section 5 are presented the results of the experiments performed; finally, Section 6 contains the conclusions of the work and the bibliographical references.

2 Theoretical Background

2.1 Amputation Process

The amputation process is necessary in cases of accident or illness where there is no option to save or improve the patient's quality of life [Matos *et al.*, 2020]. The levels of lower limb amputation vary significantly, each presenting unique challenges and rehabilitation needs. From the extensive hemipelvectomy to the precise partial foot amputation, the spectrum encompasses many surgical procedures[Krajbich *et al.*, 2023]. However, amputation is not solely about removing the limb; post-surgery, patients embark on a journey of physical rehabilitation. This process involves learning to cope with their new condition and readapting to daily activities.

The amputation process is necessary in cases of accident or illness where there is no option to save or improve the patient's quality of life [Matos *et al.*, 2020]. Amputation is not only about removing the limb because, after the surgical procedure, the patient also begins the process of physical rehabilitation to learn how to deal with his new condition and readapt to daily activities.

Lower limb amputations can vary significantly in their levels, each presenting unique challenges and rehabilitation needs. Hemipelvectomy, involving the removal of half of the pelvis, is an extremely rare procedure. Hip disarticulation removes the entire lower limb at the hip joint, requiring substantial rehabilitation efforts. Transfemoral amputation, commonly performed above the knee, removes part of the thigh and necessitates the use of a knee prosthesis. Knee disarticulation preserves the thigh but removes the lower leg at the knee joint. Transtibial amputation below the knee involves removing part of the leg below the knee, allowing for greater mobility with a prosthesis. Ankle disarticulation removes the foot at the ankle joint while preserving the heel pad. Syme amputation is akin to ankle disarticulation but involves the complete removal of the foot, including the heel pad. Partial foot amputation entails removing part of the foot, such as the toes or the forefoot, significantly affecting balance and walking ability.

This process involves several health professionals (such as physiotherapists, occupational therapists, and psychologists) to recover the patient's mobility, independence, and self-esteem. The process involves adapting to prostheses, improving balance and motor coordination, and exercises to strengthen muscles and improve mobility. Finally, post-amputation involves psychological and emotional care through therapy Matos *et al.* [2020].

The physical rehabilitation process can be optimized through sensing devices that collect real-time patient data and send information to medical monitoring systems. Embedded systems, such as those intended for sensing, are widely used in medicine, such as vital sign monitors, diagnostic devices (electrocardiograms, electroencephalograms, and tomography), and life support devices. These devices control the patient's vital functions, such as mechanical ventilation, medication administration, and blood oxygenation monitoring, ensuring patient survival in emergencies [Arandia *et al.*, 2022]. The use of computational resources in medicine, such as sensors and virtual games as the solution described here, belongs to Medical Informatics. From the perspective of computer science, this is the field of study that ranges from the collection, treatment, and presentation of data to the health professional to more hardware-oriented tools, such as the development of measuring instruments and robotic prostheses, among others [Gray and Sockolow, 2016].

The sensors in this system have two purposes: monitoring physiological data for a greater understanding of the state of evolution of the patient and controlling the simulation game to unwind the activity through gamification, which, despite being a separate concept, is present in this context. *Gamification* is a technique that uses elements of games in nonludic environments in order to improve the involvement in solving a given problem [Altarriba Bertran, 2014]. This approach aims to stimulate the participation of patients through the use of resources such as scores and rewards for these activities and make the treatment environment more enjoyable, in addition to allowing visualization of the progress of each of them.

2.2 Related Work

In recent years, interest in using serious games exergames that promote physical activity) in physical rehabilitation has grown, particularly for patients with motor difficulties [Van Diest *et al.*, 2013]. As in amputees, in order to make rehabilitation more engaging.

Nascimento *et al.* [2023] presents a relevant solution in physical rehabilitation for patients with motor difficulties. The work presents an innovative approach to assistance in telerehabilitation sessions (domestic physical rehabilitation sessions, where the patient and physiotherapist are in different environments and interaction is mediated by communication technologies). It is demonstrated in the exergame "CicloExergame", a game genre Endless Runner (style similar to the game Subway Surfers), which aims to keep as long as possible, avoiding obstacles and collecting coins to add to the score. The system consists of a Cicloergometer, an oximeter, a numeric keypad (for controlling the lateral movement of the character in the game), and an Arduino to perform the connection and analysis of the data obtained in the Cicloergometer (number of pedals) and the oximeter (heartbeat per minute - BPM - and blood saturation - spo2) [Nascimento *et al.*, 2023].

Prahm *et al.* [2017] also uses an exergame, in this case, to adapt myoelectric prostheses (prostheses controlled by muscular electrical signals) in people with amputation below the shoulder. Three games were presented: the supertuxkart racing against time and computer-controlled opponents, Step Mania 5, which is a rhythm game (genre similar to games like Guitar Hero and Just Dance) whose goal is to activate the "notes" in order and at the right time, making the virtual character dance without errors. Each game has its particularity in the controls. However, they are generally sent via an electromyography sensor (EMG) fixed in the muscles where you want to apply rehabilitation [Prahm *et al.*, 2017]. The study results show that individuals who used the mentioned games performed better in myoelectric prosthesis control tests than those who received only traditional rehabilitation training. Although myoelectric prostheses are not the focus of this study, the participants of the tool mentioned above reported that the game was more fun and engaging than the classic exercise.

Games that promote physical activities in patients during the telerehabilitation process are also aimed. "ExerCam" is a serious game that uses the technology of "Human Pose Estimation" to detect the position of the player's body via a standard camera tracing lines highlighting the joints - the result of which resembles a stick figure drawing. Using a standard camera, the player interacts with the tool, can visualize on the screen, and can perform the challenges proposed by the four games available in the system. Crazy Targets is a game where players must hit the circular targets on the screen. Boxing is a game that stimulates the patient's upper body through boxing movements to hit the targets that appear on the screen. The third game is Football, in which the patient must kick a virtual ball to exercise the lower body. Finally, the last game is called Bars. Also, to exercise the lower limbs, the player has a goal to dodge bars that will appear on the screen of the patient getting up or sitting. To account for a higher score, aspects such as accuracy and speed of movements are crucial [Rosique *et al.*, 2021]. The games present in this application have varied levels, providing different challenges depending on the stage where the patient is, an interesting aspect to be based on and bring to the present study, considering that amputee patients react in very different ways to the process of physical rehabilitation, varied challenges are essentially crucial in this context.

In summary, the studies show promising results about the use of serious games in physical rehabilitation activities in patients with motor difficulties, both in improving the control of myoelectric prostheses and, in the second work, physical activities in distance physiotherapy sessions (telerehabilitation sessions), offering greater engagement, immediate feedback, and removal of monotony during recovery. However, although the applications presented are low-cost, these works seek to reach a different target audience of the system described here (people who go through the amputation process).

3 Victus Exergame

The proposed work aims to create a low-cost system that unites an exergame to a monitoring structure for physiotherapy sessions. The patients targeted for this application are those with lower limb amputations who perform exercises on the exercise bike. Therefore, this work can be divided into the physiotherapist interface with patient data obtained by the sensors and reporting for each session. Another uses the same sensors, but their data controls the bike in the simulation game, where the patient must travel and avoid obstacles on the track of the virtual environment in order to maximize their score.

The development of this monitoring system was a collaborative effort driven by the insights and needs identified by physiotherapy professionals actively serving in the Serviço de Reabilitação Física de Bagé/RS (SRF). Through empirical analysis of patient progress, it was clear that tools were needed to assist in professional diagnosis and treatment monitoring. Each patient's progress is meticulously recorded and then evaluated, forming a crucial part of this collaborative process.

From this, a system was developed with node sensors connected to a microcontroller that processes the collected data in a more understandable format for the physiotherapist and performs the necessary calculations to capture the heartbeat and the speed calculation achieved by the exercise bike. This data is then sent via serial communication to a computer that has a database for storing information in a structured way. This information is accessed through software developed to elaborate graphs about the session time for a more detailed analysis of the patient's performance during the exercise. Finally, through this same software, it is possible to generate documents (reports in PDF format) containing data referring to the history of sessions of a particular patient, including partial data and charts. The solution based on a serious game approach derives from the tests carried out in the first part of the project, which only involved data capture and reporting. It was noted that the lack of tools that solve the low motivation in amputees during physical rehabilitation sessions.

Then, delimited this problem, this game adapts the information obtained and sent by the sensors to the physiotherapist monitoring software for a 3D game developed in Unity that aims to simulate a bike route to be performed by the patient, allowing a more relaxed and engaging moment. It then uses the speed of the exercise bike to control the speed of the game, displayed on the screen along with the data obtained from beats per minute (BPM) and electromyography (EMG) in order to give a visual perception of the effort committed by the patient during the activity.

3.1 Solution Modeling

For the implementation step of the system that captures information about the rehabilitation exercise, which is already elucidated, it was necessary to seek sensors to adapt the stationary bike to obtain the speed achieved in real-time and to analyze the physiological data of patients. Similarly, it was also necessary to seek essential concepts for creating games and modeling the session management software, finally obtaining a solution architecture as shown in Figure 1.

In Figure 1, it is possible to see that the information about the sensors is sent to the microcontroller and then used by the game, which, at the end of a session, sends the obtained data to the Firebase online database. Also, the data session is sent to the physiotherapist tool for analysis. The modeling process of the solution is presented hereafter.

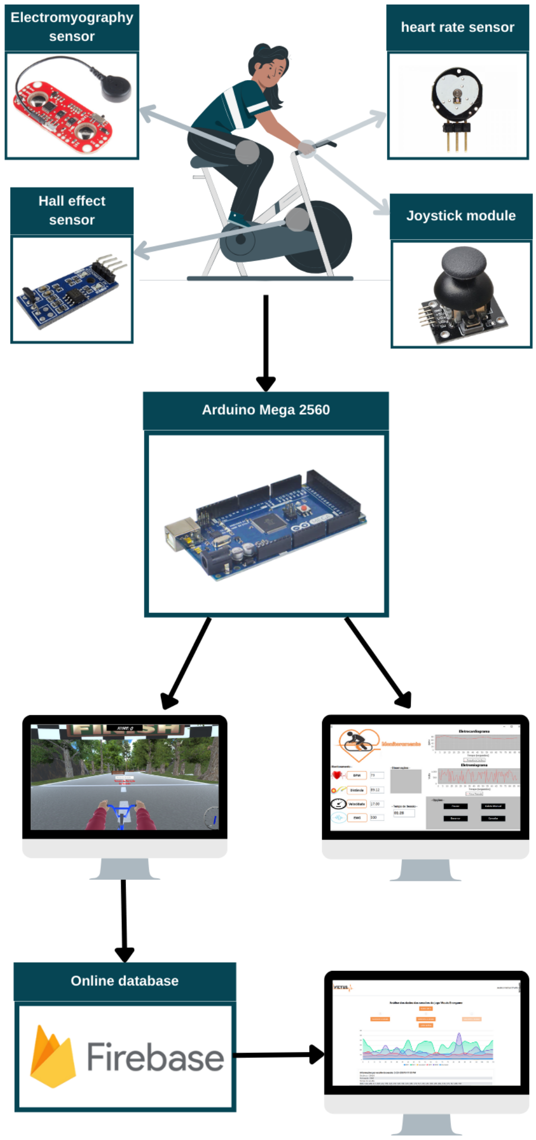


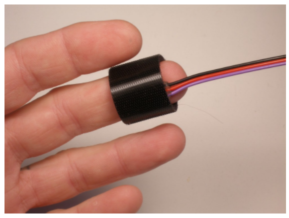
Figure 1. Conceptual Diagram of the Tool and Positioning of the Sensors.

3.2 Sensors Modeling

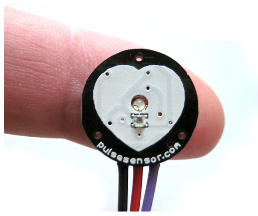
The modeling of the sensor node is one of the fundamental steps in developing electronic devices for monitoring physiological signals in clinical and sports environments. This subsection will present the four sensors used to monitor and control the game during rehabilitation. These are intermediated by the Arduino Mega 2560 hardware prototyping platform, attached to the patient's body and exercise bike: the Amped sensor, the hall effect sensor, the electromyography sensor, and the joystick module. The project's low-cost goal was to consider simpler and cheaper sensors to build the solution.

3.2.1 Pulse Amped Sensor

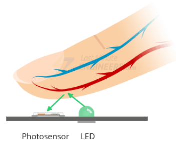
The Pulse Amped sensor is an electronic device for a microcontroller capable of measuring the heartbeat rate through photoplethysmography (PPG) technology [llc., 2015]. It consists of a small module attached to the finger that emits light and measures the amount of reflected light to determine changes in blood flow, as shown in Figure 2.



(a) Sensor position.



(b) Pulse Amped Sensor.

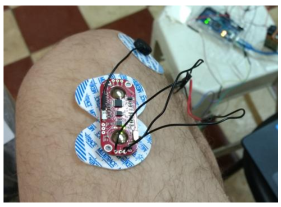


(c) Amped operation.

Figure 2. Pulse Amped Sensor, positioning and its operation.

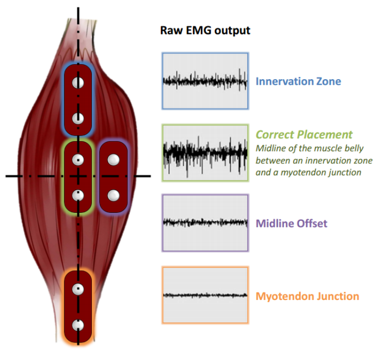
3.2.2 Electromyography sensor

The MyoWare Muscle Sensor, chosen to monitor muscle strength, measures electrical signals through the skin surface that the muscle emits when it contracts or relaxes through electromyography. The sensor and its arrangement in the area to be evaluated and its mode of operation are shown in Figure 3.



(a) EMG sensor on patient leg.

(b) MyoWare muscle sensor.



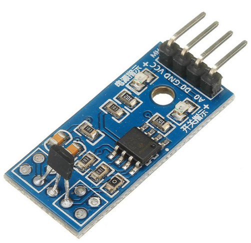
(c) MyoWare muscle position.

Figure 3. EMG sensor, its positioning in muscle extension and functioning.

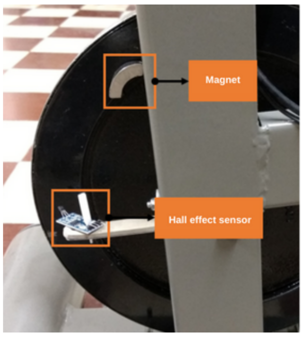
This sensor uses two silver electrodes to capture the electrical signals generated by the muscle and another to serve as a ground that must be attached away from the muscle it is planned to analyze. These signals are then amplified and filtered to remove unwanted noise, and the resulting signal is emitted as an analog voltage that can be picked up by the microcontroller [Technologies, 2015].

3.2.3 Hall effect sensor

The Hall 3144e Effect sensor (Figure 4) is an electronic device that detects the presence and strength of a magnetic field through the Hall Effect principle, which defines that when a conductor carrying a current is placed in a magnetic field, a voltage is generated perpendicularly to the current and magnetic field. It consists of a module containing a thin strip of semiconductor material sensitive to changes in magnetic fields. The strength of this current is proportional to the strength of the magnetic field, which can be measured and displayed by an Arduino board connected to the computer, for example. This sensor does not measure the physiological signs of the patient but rather the number of times a magnet attached to the wheel of the exercise bike passes through the sensor, as shown in Figure 4(b), returning the wheel rotation per minute of the equipment calculated in the Arduino for use in the session management software and for the game [MicroSystems, 2022].



(a) Hall Effect Sensor 3144e.



(b) Hall effect sensor on the exercise bike

Figure 4. Hall effect sensor and its position

3.2.4 Joystick module

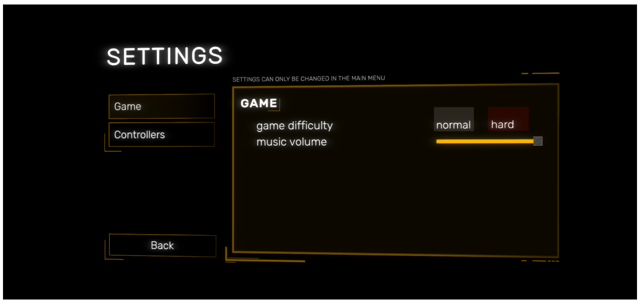
KY-023 is an electronic device that works with two potentiometers connected perpendicularly, one for horizontal movements and the other for vertical movements, in addition to a push button positioned at the center of the axes as illustrated in Figure 5 [Joy-IT, 2017].

Figure 5. Joystick module KY-023.

3.3 Serious Game

The game uses all the sensors mentioned above to control the app designed for the patient, making the sessions more playful. Thus, a game was developed through Unity software in addition to the information monitoring tool in the exercise. Whose interface is contained in Figure 6, in Figure 6(a), it is possible to see the main interface that allows two flows execution. The first selected play game, where the next step is to select the track play, time of session, and patient. On the second, which also has a menu of settings shown in Figure 6(b), to adjust the sound and difficulty of the game, it is possible to set whether the game will be controlled through the sensors or the keyboard (debug mode).

(a) Game main menu.



(b) Settings menu.

Figure 6. Game menu interface.

The game has a 3D scenario with a path to be fulfilled by the patient with visible obstacles to avoid, which will randomly spawn according to the difficulty selected by the physiotherapist on the previous menu (Figure 6(b)). The functions of accelerating the virtual bike are in charge of the Hall effect sensor, which, together with a magnet positioned on the bicycle wheel, allows calculating the speed of the patient in the game, which makes it possible to inform the distance traveled on the exercise bike.

The challenges in the game are shaping as the patient evolves, and these challenges are visible barriers ahead on the track to be avoided through the joystick module fixed on the bike's handlebars. With each barrier bypassed, the player adds points proportionally to their speed, and in case they collide with the barriers, the points will not be computed. On the game screen presented in Figure 7, it is also possible to see highlighted in different colors that the heart rate, the speed at which the bike reaches beyond the force affected by the patient's musculature (measured by the electromyography sensor) and, time session.

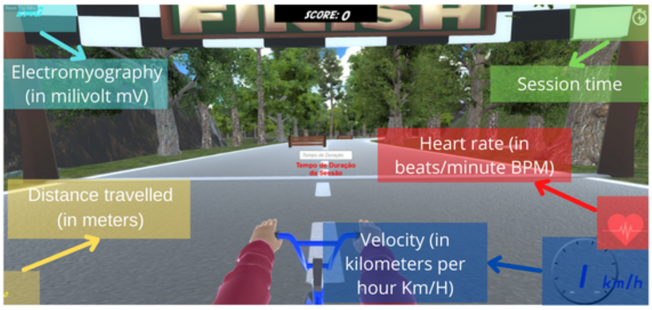
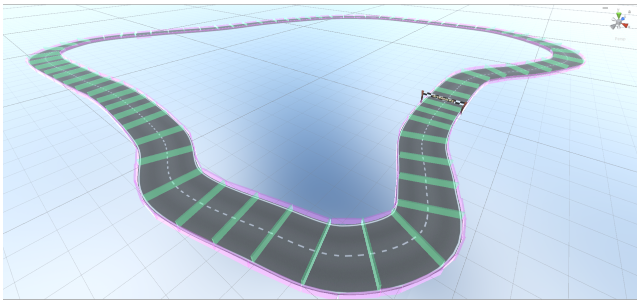
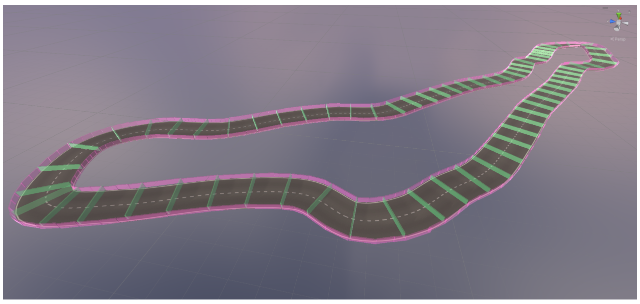


Figure 7. Game screen designed for the patient.

Besides that, considering the patients' constraints, some features were built to help them. First, a side barrier system was developed to avoid wasting time returning to the road. At game time, this invisible system was placed around the track and can be recognized when the patient is off the road. Suppose the patient goes to the wrong side of the track. In that case, the game has a system of waypoints to avoid the incorrect path formed by invisible objects during the track to identify collisions, causing the player to return to the last Waypoint after 2 seconds of the detour. When it happens, the bike will be transported to the center of the road. This way, the patients will not be demotivated during the learning curve. After a time, the system can be turned off on challenging levels. This system of waypoints developed in Unity can be shown in Figure 8 (a, and b).



(a) Track 1.



(b) Track 2.

Figure 8. Side barrier and waypoints system.

Furthermore, the game features two distinct tracks, each offering a unique experience to the player. One of the tracks takes place in a forest setting, while the other takes the player on a pedal ride by the sea (exclusively developed for this work), with a sunny climate, a lighthouse, and the sound of breaking waves. Both tracks are designed with a clearly defined finish line, providing instant visual feedback to the patient about their progress on the track.

The two tracks can be seen in Figure 9 (c, and d), highlighting the diversity of environments and stimulating different visual experiences for players escaping the monotony of stationary exercise.

(a) Forest track.

(b) Beach track.

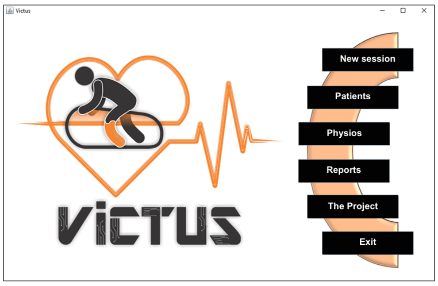
Figure 9. Tracks available in the game.

3.4 Tool for Physiotherapists Reports

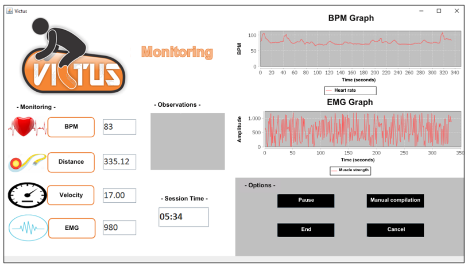
All sensors are connected to the Arduino Mega 2650, which is responsible for collecting data, processing it, and sending it via serial communication to a database on the computer. The data from the session can be viewed using software that displays the information through a graphical interface developed in Java.

In Figure 10, it is possible to observe the interface of the Java language physiotherapist's tool. Figure 10(b) shows the data obtained in real-time are presented on the monitoring screen, both numerically and with present data on BPMs, distance covered, speed, and force performed in millivolts (corresponding to 1/1000 of a volt or mV, obtained through EMG), as well as in a graph that demonstrates the variation of values over the session time.

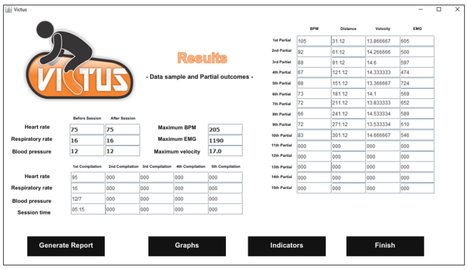
At the end of the session, the physiotherapist has some options about what to do with the data obtained, as shown in Figure 10(c). There can be a more detailed analysis of the partial results obtained during the session, a graphical analysis of the information obtained, or a report containing all partial data and the addition of physiological data obtained before the session, helping the professional to make decisions about patient advancement.



(a) Main menu screen.



(b) Real time info and charts interface.



(c) Partial results at finish of session.

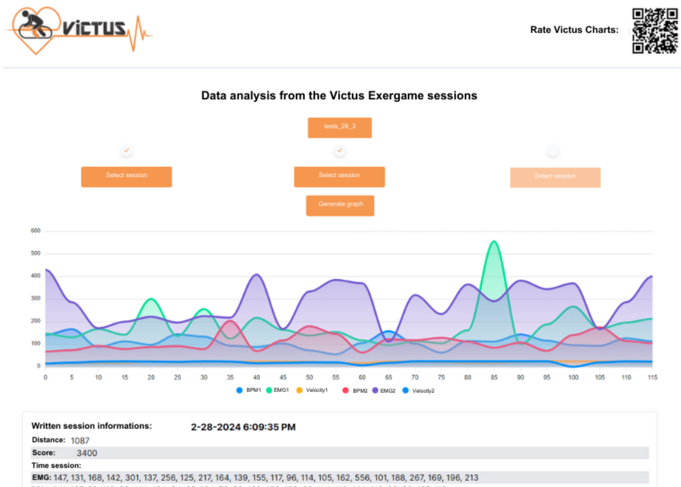
Figure 10. Monitoring tool in Java and its views.

3.4.1 New Tool For Sessions Reports

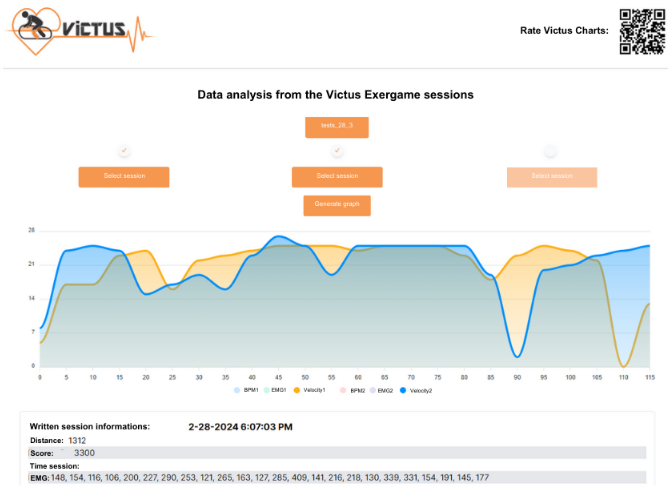
As much as the Java language approach is still valid and functional, due to problems such as the difficulty of introducing new features, global access to a tool, scalability, and portability, it was decided to take a different direction in the application of physiotherapists' use: a web interface. The new approach takes the game data to an online database that can be accessed and viewed from anywhere with more dynamism and the latest features for manipulating and presenting this data.

The web interface, integrated with the game and a Google Firebase database, offers a free solution for small projects (up to 1 GB of stored data). At the end of each session, the data collected during the exercise time defined by the physiotherapist is saved in 5-second intervals and sent to Firebase. This data is then accessible through the web interface, as shown in Figure 11.

Despite being an initial system (still being developed), a great advantage of the web tool is the dynamic visualization of the graphs, which allows comparisons between specific information from one or more sessions. An example is shown in Figure 11(a), where two sessions present every sensor's data. In Figure 11(b) it was select a comparison between the speed performed over time of the same sessions. This way, the web interface allows more portability and a friendly environment for physiotherapists; it is also possible to easily create new indicators and reports on the system.



(a) Comparison of data obtained in two sessions.



(b) Speed-only comparison case between two sessions.

Figure 11. Charts generated from session data.

4 Research Methodology

This section outlines the research methodology employed in this study, detailing the procedures, settings, artifacts used, and ethical considerations.

The study was conducted in partnership with the Serviço de Reabilitação Física de Bagé and involved three experimental phases, each aimed at evaluating different aspects of the Victus Exergame system. Experiments were performed in physiotherapy sessions at the SRF, providing a controlled environment for data collection and participant engagement. The study utilized a combination of sensors, including heart rate, muscle strength, and Hall effect sensors, connected to a microcontroller that processed and transmitted data to a web application for analysis.

Ethical approval for the research was granted by the Research Ethics Committee of the Federal University of Pampa (UNIPAMPA), registered in Plataforma Brasil, in the process of minor adjustment. The research was conducted with hadherence to ethical principles such as informed consent, confidentiality, and the right to withdraw from the study at any time. All participants were comprehensively informed about the study's objectives, procedures, and any potential risks before consenting to participate. All patients signed the informed consent form, which made the data and images available for research, since they hid their identities.

To gather qualitative data from participants during Experiments, a questionnaire was administered. The questionnaire employed a Likert scale to assess various aspects of the rehabilitation experience, including motivation, engagement, and perceived effectiveness of the Victus Exergame system. The complete set of questions used in the questionnaire can be accessed at link: https://figshare.com/s/cdde2bb111c37b0ed7e6.

5 Results and Discussion

After completing implementations, both versions of the Victus System performed experiments for all its functionalities. This experiment aims to elucidate the system's performance in registrations, session recording, analysis, and reports. Patients and physiotherapists were initially registered to test the solution's operation and perform session recording. The results from these tests were consistent, indicating the system's reliable performance.

In the current research stage, the experiments were performed in physiotherapy sessions through a partnership with the SRF of the city of Bagé-RS. This partnership added to the project's physiotherapy knowledge and provided the appropriate test facilities. The experiments will be reported as follows, performed in three moments.

The first experiment evaluated the Victus System without the patient's game, using only the sensors and the Java Physiotherapists tool (subsection 5.1). The second was performed to evaluate improvements in the Victus Exergames with only one track (forest) (subsection 5.2). The third experiment involved Victus Exergames with specific modifications developed for this work, including a new track (beach) to diversify the patient's experience, challenges, and waypoints systems to enhance engagement and a web application for physiotherapists to facilitate data management (subsection 5.3). This initial experiment evaluated the modifications proposed for the Victus Exergames Version.

5.1 Experiments of Java Physiotherapists Tool

The initial experiment was divided into two stages, considering the tool has two independent software components. The first stage was the evaluation of the accuracy of the sensor node, which was done by comparing each hardware component with the capture of manual data. In the case of the Amped pulse sensor, the captured values were compared with the readings of a digital oximeter. For the Hall sensor, the speed values obtained were compared with the speed displayed on the exercise bike display. At this stage of the EMG sensor experiments, MyoWare was not tested, as there was no base system for evaluating sensor accuracy. These individual tests of the sensors showed an equivalent operation to the reference devices and the ability to perform multiple collections in real-time, as shown in Table 1 that compares the accuracy averages per minute of the values measured by each piece of equipment. In the first minute, there was a low accuracy of the Amped sensor, which can be explained by its delay in stabilizing the reading of the luminosity signal, exposed by the sensor's documentation.

Table 1. Accuracy of sensor node.

Time	BPM	Distance	Velocity
1^{st} Minute	46.97%	98.60%	93.55%
2^{nd} Minute	84.18%	96.89%	96.16%
3^{rd} Minute	91.28%	96.21%	97.56%
4^{th} Minute	96.57%	94.72%	97.29%
5^{th} Minute	95.84%	96.84%	97.72%
Total	**82.96%**	**96.65%**	**96.45%**

In the second stage, tests were performed on integrating sensors with monitoring and session management (in Java Language), already applied in physiotherapy sessions. For this stage, the experiments have the participation of three patients selected by the professionals of the SRF, who participated in the exercises in the exercise bike monitored by the system, as shown in Figure 12. The data of patients was shown in Table 2. After using the tool, a multiple choice questionnaire was conducted for physiotherapists to obtain feedback on the system's usability. This step returned reasonable indications about the use of the tool, as well as ideas for possible improvements.

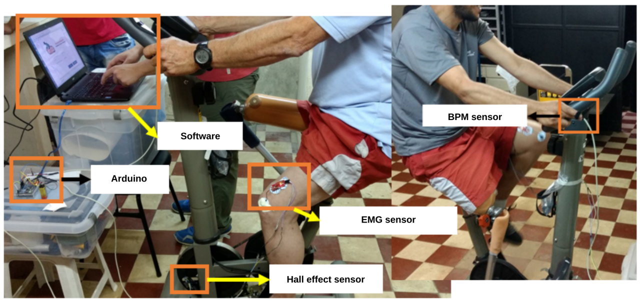


Figure 12. Test with patient system and only sensor node.

Table 2. Information of the Patients Tested in Fist Experiment

Patient	Sex	Age	Amputation
Patient A	male	34 years old	Right lower limb (transfemoral)
Patient B	male	78 years old	Right lower limb (transfemoral)
Patient C	male	52 years old	Right lower limb (transfemoral)

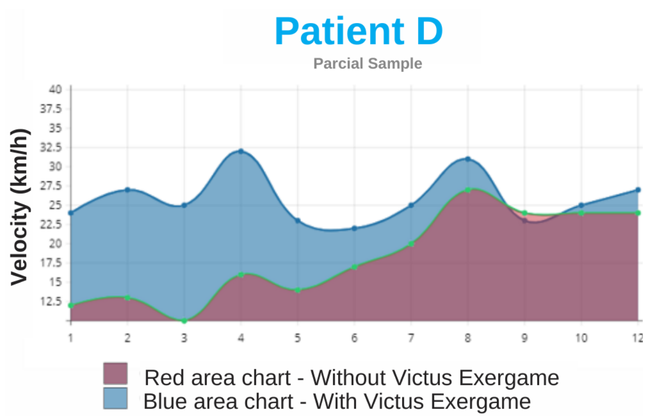
5.2 Experiments of First Version of Serious Game

The second experiment was directed to test the game's impact during physical rehabilitation activities. The tests used the game during the physiotherapy session, depicted in Figure 13 without using the modifications proposed in this work. There were two volunteer patients, and their data was shown in Table 3.

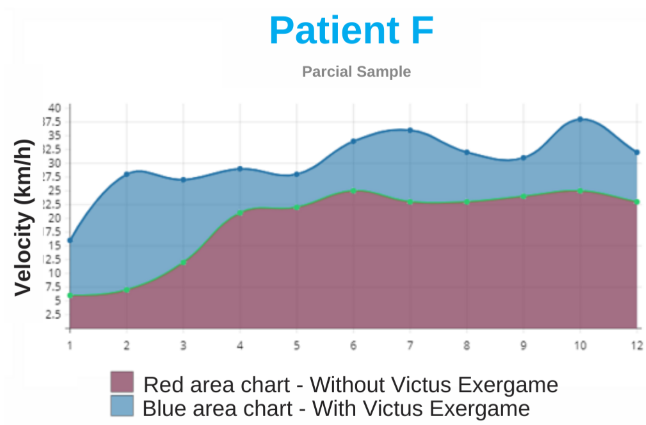
Figure 13. Patient test with the game.

Table 3. Information of the Patients Tested in Second Experiment

Patient	Sex	Age	Amputation
Patient D	Female	44 years old	Left lower limb (transfemoral)
Patient F	Male	38 years old	Right lower limb (transtibial)



(a) Graph of partial samples of speed patient D.



(b) Graph of partial samples of speed of patient F.

Figure 14. Graph of partial samples of speed.

In this experiment, there was also a questionnaire that, this time, was directed to both the physiotherapist and the patient based on the Likert scale to evaluate the motivational potential of the game from the perspective of both. The results on the efficiency and applicability of the tool in the real environment returned an average of results close to the maximum (grade 5). In addition, the partial speeds obtained with and without using the game were compared. With this, it was possible to observe a significant increase in speed when using the game, demonstrating greater patient involvement in rehabilitation. Figure 14 shows the chart of the comparative speeds of the sessions.

5.3 Experiments of Victus Exergames

Finally, the third experiment was directed to initial tests of modification proposed in this work, like a new track (beach), challenges and waypoints system, and a web application for physiotherapists, and had the participation of two volunteers, and their data was shown in Table 4. The tests consisted of the use of the game during the physiotherapy session, and both patients underwent amputation of the right lower limb. They were participating as volunteer patients in the process of adapting to prostheses.

In the same way, there was also a questionnaire that, this time, was directed to both physiotherapists on the Likert scale to evaluate the motivational potential of the game from the perspective of both. The results on the efficiency and applicability of the tool in the real environment returned an average of results close to the maximum (grade 5). Figure 15 presents the patients in the third experiment.

Table 4. Information of the Patients Tested on Victus Exergames

Patient	Sex	Age	Amputation
Patient G	Male	70 years old	Right lower limb (transfemoral)
Patient H	Male	62 years old	Right lower limb (transfemoral)

In this experiment, it is essential to note that the physiotherapists were enthusiastic and considered the tool promising. One of the individuals who tested the system in her second session with a prosthesis successfully played the game with great engagement (Figure 15(b)), demonstrating the high applicability of Victus Exergame. Additionally, the web application presented was considered more user-friendly by physiotherapists. Some interesting feedback was received, such as "*I suggest including a more sound stimulus in the game, which reflects the track the patient travels on, with a different sound when he bumps into something or leaves the track*". In the following versions, these improvements can be made.

Despite the promising results, it is essential to emphasize that this work aims to make several improvements for the following tests. Some of them are the assignment of steering controls by adapting the handlebars of the exercise bike and connecting the distant sensors wirelessly due to the difficulty of adjusting all sensors before the sessions and the ease of unplugging a jumper.

(a) Patient 1

(b) Patient 2

Figure 15. Patients testing Victus Exergames last version.

6 Conclusions

This work proposes a monitoring system for physiotherapy sessions on the exercise bike for amputees based on gamification. A sensor node was implemented that could measure physiological and exercise data to monitor patients' progress during treatment. Several experiments were performed, and the results demonstrated that it was possible to obtain a more significant commitment from the patients with the rehabilitation sessions, thus reducing the time of adaptation and demotivation in this stage of physiotherapy. In future work, the physiotherapist's application will be refined and migrated to progressive web application technology that is more suitable for any device (web or mobile). Besides that, it is considered to add a new way to control the direction of the virtual bike using a controllable handlebar to increase player immersion and especially the expansion of tests within a larger group of patients with a follow-up that evolves over the sessions with the use of the game.

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References

Altarriba Bertran, F. (2014). The revolution of fun: A study of applied games and fun in non-entertainment contexts. Master's thesis, Universitat Pompeu Fabra. `https://www.semanticscholar.org/paper/The-Revolution-of-Fun%3A-a-study-of-applied-games-and-Bertran/d4dd94c39b42a8fb04dca3a91d6a476c1a7ef797`, Accessed: 19 December 2024.

Arandia, N., Garate, J. I., and Mabe, J. (2022). Embedded sensor systems in medical devices: Requisites and challenges ahead. *Sensors*, 22(24). DOI: https://doi.org/10.3390/s22249917.

Cieza, A., Causey, K., Kamenov, K., Hanson, S. W., Chatterji, S., and Vos, T. (2020). Global estimates of the need for rehabilitation based on the global burden of disease study 2019: A systematic analysis for the global burden of disease study 2019. *The Lancet*, 396(10267):2006–2017. DOI: https://doi.org/10.1016/S0140-6736(20)32340-0.

Gray, K. and Sockolow, P. (2016). Conceptual models in health informatics research: A literature review and suggestions for development. *JMIR Medical Informatics*, 4(1):e7. DOI: https://doi.org/10.2196/medinform.5021.

Joy-IT (2017). *KY-023 Joystick Module (XY-Axis)*. `https://datasheet-pdf.com/PDF/KY-023-Datasheet-Joy-IT-1402034`, Accessed: 19 December 2024.

Krajbich, J. I., Pinzur, M. S., Potter, B. K., and Stevens, P. M. (2023). *Atlas of Amputations and Limb Deficiencies: Surgical, Prosthetic, and Rehabilitation Principles*. AAOS - American Academy of Orthopaedic Surgeons. Wolters Kluwer Health.

llc., W. F. E. (2015). *PulseSensor*. `https://cdn.shopify.com/s/files/1/0100/6632/files/Pulse_Sensor_Data_Sheet.pdf?14358792549038671331`, Accessed: 19 December 2024.

Matos, D. R., Naves, J. F., and Araujo, T. C. C. F. d. (2020). Quality of life of patients with lower limb amputation with prostheses. *Estudos de Psicologia (Campinas)*, 37. DOI: https://doi.org/10.1590/1982-0275202037e190047.

Matos, N., Santos, A., and Vasconcelos, A. (2014). Kinteract: A multi-sensor physical rehabilitation solution based on interactive games. In *Proceedings of the 8th International Conference on Pervasive Computing Technologies for Healthcare*. DOI: https://doi.org/10.4108/icst.pervasivehealth.2014.255325.

Melo, R., Mendes, D., Érico Marcelo Amaral, and Júnior, J. D. (2023). Gamificação na reabilitação física de amputados: Uma abordagem baseada em jogo sério. In *Anais Estendidos do XXII Simpósio Brasileiro de Jogos e Entretenimento Digital*, pages 1292–1302, Porto Alegre, RS, Brasil. SBC. DOI: https://doi.org/10.5753/sbgames_estendido.2023.234205.

MicroSystems, A. (2022). *Low-Noise Linear Hall-Effect Sensor ICs with Analog Output*. `https://www.allegromicro.com/~/media/files/datasheets/a1324-5-6-datasheet.ashx`, Accessed: 19 December 2024.

Mousavi Hondori, H. and Khademi, M. (2014). A review on technical and clinical impact of microsoft kinect on physical therapy and rehabilitation. *Journal of Medical Engineering*, 2014. DOI: https://doi.org/10.1155/2014/846514.

Nascimento, D., Souza, C., Berretta, L., and Carvalho, S. (2023). Avaliação de um exergame para a telerreabilitação de pacientes. In *Anais Estendidos do XXIII Simpósio Brasileiro de Computação Aplicada à Saúde*, pages 48–53, Porto Alegre, RS, Brasil. SBC. DOI: https://doi.org/10.5753/sbcas_estendido.2023.229818.

Prahm, C., Vujaklija, I., Kayali, F., Purgathofer, P., and Aszmann, O. C. (2017). Game-based rehabilitation for myoelectric prosthesis control. *JMIR Serious Games*, 5(1):e3. DOI: https://doi.org/10.2196/games.6026.

Rosique, F., Losilla, F., and Navarro, P. J. (2021). Applying vision-based pose estimation in a telerehabilitation application. *Applied Sciences*, 11(19). DOI: https://doi.org/10.3390/app11199132.

Technologies, A. (2015). *3-lead Muscle / Electromyography Sensor for Microcontroller Applications*. `https://cdn.sparkfun.com/datasheets/Sensors/Biometric/MyowareUserManualAT-04-001.pdf`, Accessed: 19 December 2024.

Van Diest, M., Lamoth, C. J., Stegenga, J., Verkerke, G. J., and Postema, K. (2013). Exergaming for balance training of elderly: State of the art and future developments. *Journal of NeuroEngineering and Rehabilitation*, 10(1):1–12. DOI: https://doi.org/10.1186/1743-0003-10-101.