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Tennisgame Physio: A tool for amputees physiotherapy based on gamification

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Abstract

The present work aims to develop a computational solution in hardware and software that uses gamification methodologies to help physiotherapy professionals in the rehabilitation sessions of upper and lower limb amputees, who are in the pre-prosthetic and prosthetic stages. Thus, a table tennis match simulator is developed to instigate patients to reach the flow state during the session. Thus, a mobile program is developed to collect data from the smartphone's gyroscope sensor and, through Bluetooth communication with the Arduino prototyping board, this information is forwarded to the simulator. The data received is used to move the virtual racket in the game. Furthermore, physiotherapists have a tool integrated with the tennis match simulator, to monitor the progress of patients during the sessions. In short, this solution turns out to be effective in helping both patients and physical therapists in physical rehabilitation sessions.

Keywords: *Challenge, Motivation, Rehabilitation, Performance, Low cost technology.*

1 Introduction

The lower and upper limbs are one of the main limbs of the human body, Kapandji (2000). These limbs are essential elements for executing several trivial activities, such as locomotion, feeding, and physical activity, among other tasks. However, on different occasions, these limbs can suffer from problems, like the main ones are limb malformations, accidents that cause trauma to the joints, and severe infections. In addition, there are also diseases such as diabetes mellitus that make it impossible to heal wounds, causing inflammation, and thrombosis, among others, Ferreira et al. (2017).

Considering these scenarios, in most cases, the only alternative in the treatment is the amputation of one of the limbs, either lower or upper, given the degree of the disease. Nevertheless, on the other hand, amputation is a delicate procedure that affects both the patient's psychological and physical aspects, given the limb removal scenario and, possibly, the patient's inability to perform daily tasks. In this way, health professionals such as psychologists and physiotherapists are essential in the rehabilitation process.

Physiotherapy is a therapeutic process that aims to reduce distress and the gradual return of the patient to his daily life, thus providing a better quality of life for the individual. According to Marques and Kondo (1998), physiotherapy uses many kinds of therapeutic exercises, like passive and active mobilization, stretching, isometric, isotonic, and other activities. Additionally, computing has become an essential tool with a growing acceptance in the medical field. Numerous studies and works use computational solutions to watch health professionals in new treatments. This area of development of computational solutions applied to health is called medical informatics.

Medical informatics is an area that has numerous ramifications, and it is possible to act both in the development of technologies to withstand decision-making processes and in the development of instruments/devices that enable better efficiency in medical procedures. For example, virtual reality (VR) and gamification methodology could assist in the physical rehabilitation process.

The gamification methodologies used to assist patients in physical rehabilitation has good therapeutic potential. It is due to the development of the applied computing area in the construction of solutions that make the sessions more fun. In addition, the method of rehabilitation uses the games allows the patient to overcome challenges to achieve better results in the game, leading to more significant cognitive involvement Grande et al. (2011).

However, there are still gaps and research opportunities regarding the development of computational solutions to help physical therapists in the physical rehabilitation of amputees. Therefore, the present work shows the extended version of previous work Pinheiro et al. (2021), which aims to develop the prototype of a computational solution based on gamification for the physical rehabilitation process. This solution uses the gyroscope sensor of a Smartphone and, through Bluetooth communication, sends the collected data to a sensor node composed of a microcontroller and serial communication with a computer.

The captured information is processed and sent to a software that will run on a computer, which will contain the implementation of a table tennis match simulator. The information captured by the Smartphone will perform the avatar movement in the game according to the registered coordinates through the mobile application developed on the Smartphone. The solution aims to help physiotherapists in the upper and lower limb amputees in rehabilitation sessions. This way, it makes physiotherapy sessions more fun and motivating. In addition, the solution aims to capture information about sessions to create performance and effectiveness indicators, making patient assessments less subjective.

The present work is organized as follows: section two presents the theoretical foundation with the main concepts to understand the work better. Section three presents the proposed solution developed for both the sensor node and the smartphone application, and the game. Section four presents the results of the experiments carried out with the patient and the physiotherapists' considerations. Finally, sections five and six present the conclusions of the work and the references.

2 Theoretical foundation

This section presents the main concepts for a better understanding of the proposal, such as physical rehabilitation and gamification, and discusses related works found in the literature.

2.1 Physical rehabilitation of amputees

The physical rehabilitation process of amputees involves seve-ral stages, starting from pre-amputation, postoperative, pre-prosthetic, and prosthetic stages. The last step is the stage where the patient receives a prosthesis and where the process of monitoring and long-term follow-up of the patient begins Kovač et al. (2015). This process is of essential importance since the amputee needs to receive professional help. This help allows adapting to a new tool that will help him return to his pre-amputation daily activities. In the rehabilitation process, the limits imposed by the amputation must be accepted by the individual and faced realistically, De Benedetto et al. (2002).

The physical rehabilitation procedure for amputees involves about five main phases. The first stage is the pre-amputation or preoperative period, which consists of the stage of psychological preparation of the patient and their families when the scheduled procedure is due. The second phase is the postoperative period, where there is the monitoring of wound healing and, also, an assessment of the patient's potential for the use of a prosthesis or not is carried out, de Lima and Mejia (2013).

The third stage is pre-prosthetic, which includes preparing the patient to receive the prosthesis since the wound has already healed completely. Physical rehabilitation in this stage aims to prepare the stump for acceptance of the prosthesis and, also, the process of physical conditioning of the patient, Kovač et al. (2015). The fourth stage is the prosthetic, which is the phase of the patient's adaptation to his new limb. The last stage, the fifth, is the process of monitoring and long-term follow-up. The computational solution developed in the present work aims to apply to patients in phases three and four, that is, in the rehabilitation and prosthetic phases.

2.2 Gamification

Gamification is a methodology that lists game mechanisms and Techniques applied to achieve a goal in a given activity. The reason for using this technique is to motivate users to perform activities without needing to generate much effort, that is, to "feel" driven to perform a task that they would not otherwise be so attracted to perform Domingues (2018).

When the user is exclusively involved in a game story or any activity that induces immersion, he is flow state. The flow state was characterized by satisfaction and success feeling during the activity. To reach the state of flow, according to Csikszentmihalyi and Isabella Selega (1988), it happens under specific conditions, when attention is focused on an activity, there is no space in consciousness for conflicts and contradictions, and when feelings, desires, and thoughts are entirely aligned. The present work aims to awaken with the gamification activity the state of flow in the patient in rehabilitation.

2.3 Related works

Concerning related works, there are several solutions to the subject of games that help the physical rehabilitation of amputees. For example, the Motion Rehab AVE 3D game developed by Vergouwen et al. (2020) is a solution that proposes several activities to support conventional rehabilitation processes. The application was developed using the Game Engine Unity 3D. The user's movements are captured with the Kinect sensor and the use of Rift Virtual Reality glasses to emerge in the solution.

The solution developed by Akbulut et al. (2019) is a game that aims to help improve phantom pain that affects amputees. In this work, the sEMG sensor is used to collect patient data, in addition to the Kinect sensor and Rift Virtual reality glasses. The game is developed using the Game Engine Unity 3D and has four mini-games to help reduce phantom pain in patients with upper or lower limb amputees.

Therefore, based on the solutions described above, there are common aspects among the works presented with the solution proposed by the present work. The first point refers to the development tool, in which both Vergouwen et al. (2020) and Akbulut et al. (2019) use the Game Engine Unity 3D. The tool will also be used to develop the TennisGame Physio proposal.

In addition, another particularity between the works is the use of the Kinect sensor and the Rift Virtual Reality glasses. However, TennisGame Physio's solution employs the gyroscope sensor present in most smartphones.

Finally, the solutions have the possibility of configuring the activities that the patient will perform, and also, it is possible to verify the performance of the patient. In the case of the proposed solution, TennisGame Physio is still possible to collect the patient's physical data before and after the match and compare the patient's physical performance. Another hand, the proposed solution aims too at a low cost, without requiring specific sensor components, using only the Smartphone's sensors and an Arduino development board, and the HC-05 sensor as a sensor node. The proposal for this work will be presented below.

3 TennisGame Physio

The proposal of this work was from the demand of the Physical Rehabilitation Service (SRF) of the Bagé/RS city, which has a deficit of support tools in the amputee's sessions of upper and lower limbs for professional physical therapists. In this way, this proposal aims to elaborate a prototype of a system in hardware and software that uses gamification methodologies and that is low cost. A game was developed that allows the simulation of a table tennis match, which aims to collaborate with tools for physical therapists to monitor patients' performance in rehabilitation sessions. Furthermore, it tries to create alternatives that instigate patients to reach the flow state during the session. In addition, the proposed computational system allows physical therapists to obtain statistical information about the sessions, allowing performance and effectiveness indicators. These indicators will provide a less subjective assessment of patients' performance between sessions.

In this sense, when reaching the flow state, it is expected to stimulate the patient to improve the range of motion to improve their physical conditioning and consequently reduce pain and suffering, which may make it imperceptible. The solution can be used both in the pre-prosthetic stage, which involves preparing the patient's stump to receive the prosthesis, and in the prosthetic stage, the patient's adaptation phase to his new limb.

The system architecture and the demonstration of the communication between hardware and software are presented in Fig. 1. In this way, the proposal was executed in the following way: firstly, patient physical data are collected by a physical therapist so that information prior to the session can be compared with later data; Soon after, the Smartphone is positioned next to the patient, starting the game. For this, the mobile device's gyroscope sensor is used, and the data collected from the sensor concerning the movement of the patient's stump or arm. Then, the data obtained was transmitted through Bluetooth communication between the developed mobile application and the sensor node. The sensor node contains a microcontroller and a Bluetooth module for communication. Finally, they are forwarded to the tennis match simulator with the data collection completed. The game was developed using the Unity environment and will be played on a computer.

In this game, the data obtained via Bluetooth communication moved the virtual racket, moving only to the right and the left. Different levels of difficulty were defined in the game as the patient progressed in the score, starting at low complexity levels to guide the individual in the session, for example, low ball speed and high racket sensitivity. The information collected before, during, and after the dynamics is saved in a local database on the computer. The patient's history and projections between sessions can be searched in the application.

The waterfall model's software development process was selected as a development methodology Sommerville (2011). Its approach is directed to plans, where all process activities are planned and programmed before starting work.

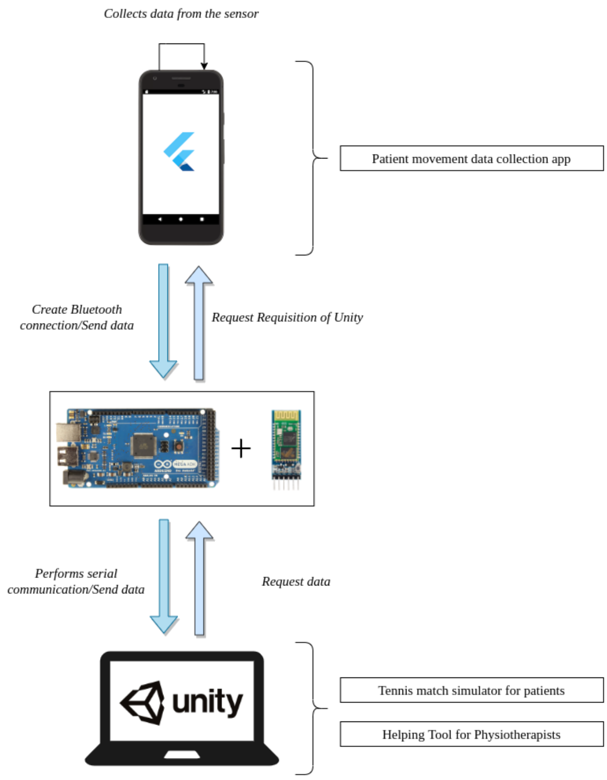

Figure 1. Solution architecture. Source: Author (2022).

The specification, development, validation, and evolution process activities in this model are fundamental. Therefore, each of the processes is designated as a distinct phase, being as follows: requirements specification, software design, implementation, testing, and maintenance.

Thus, the choice of this development methodology is because the present research is similar in several aspects to the waterfall model. The requirements listed for the development of the solution are understood clearly and objectively. In addition, the development stages are methodical since there are a series of stages that evolve during the solution.

3.1 Modeling

For the proposal's development, the solution's modeling was created first. Then, based on the stages of the waterfall model, the first step was to perform the analysis and definition of the requirements through an open interview with the physical therapist of the SRF. The main essential functional requirements collected included/excluding patients from re-gistration, including/excluding physical therapists, and match configuration. In addition, the requirements classified as important are capturing patient physical data, capturing patient performance data during start-up, and consulting patient performance history. Finally, there is only one desirable requirement: patient performance report generation.

After completing the first stage, the information obtained was analyzed based on the definition of functional and non-functional requirements. From this, it was possible to carry out the planning of the application prototype and the creation of diagrams of use cases of the game using the Unified Modeling Language (UML). The solution actors are the sensor node that comprises the Smartphone, the Arduino prototyping platform and the Bluetooth module, the user that includes the patient and the physical therapist, and the system that is the game developed in Unity 3D that will be executed in a desktop.

Therefore, the actions performed by the system are to initialize a session, create a record, collect data, store data and generate reports. On the other hand, the actions defined for the sensor node are the connection between the Smartphone and the Bluetooth module, collecting the data generated by the Smartphone's movement, processing the data and sending them, and, finally, performing the movement of the game's element. The user's actions (physiotherapist or patient) are: to create a connection with a Bluetooth module, register physiotherapist, log into in system like physiotherapist to register patients, log into in system like patients, collect patient physical data, access patient history, configure game mode, start the game, move game elements and, finally, end game.

In addition, the architecture modeling is built through the Arduino prototyping board and HC-05 module that receives data via Bluetooth communication from the Smartphone and forwards the values via Serial communication to the game developed in Unity 3D. The Smartphone captures movement data through the gyroscope sensor through an application developed using the Flutter framework. In Fig. 2 the Bluetooth connection screen of the sensor data collection application is represented.

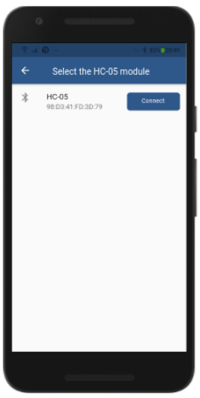

Figure 2. Sensor data collection application - Connection screen. Source: Author (2022).

Finally, the modeling of the software can be subdivided into tennis match simulation for patients and a tool for managing patients' information during sessions. In Fig. 3 and Fig. 4, the example of two screens of the solution can be visualized. Fig. 3 presents the patient's physical data registration screen, and Fig. 4 presents the game screen is displayed. The game's dynamics are to move the avatar on the x-axis and hit the ball against the bot opponent. The physical therapist is responsible for configuring the game for the patient, and it is possible to select the following game modes: demo, being a game for the patient to adapt to the movement of the racket; by time, which the physical therapist can configure how many minutes he wants the patient to play; and, by difficulty modes, being, easy, medium and hard.

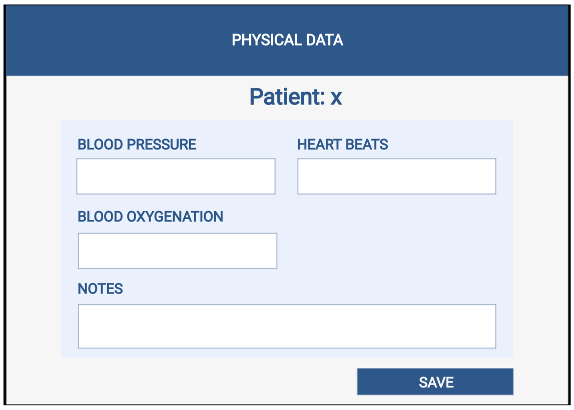

Figure 3. Physical data registration screen. Source: Author (2022).

To understand the actions and flow of the solution, in Fig. 5 the sequence diagram of the solution is represented, which demonstrates the flow of system actions. Therefore, after the physical therapist positions the Smartphone and collects the patient's physical data, the patient starts calibrating the sensor. After the completed calibration process, the physical therapist sets up the game, and the patient starts the game by generating the movement of the stump. When carrying out the mobility, the sensor node collects and sends the data through Bluetooth communication to the Arduino prototyping board, which receives and processes the information and forwards it via serial communication to the system. The system, in turn, receives and validates the data. In addition, it performs the calculation of the displacement and, finally, gene-rates the movement of the virtual racket in the simulator.

Figure 4. Game screen. Source: Author (2022).

At the end of the session, the data collected during the game are presented, being captured: the score of the game between patient and bot, game mode configured by the physiotherapist, elapsed time of the game, number of hits and errors of the patient, number of hits made by the bot and the coefficients of effectiveness and patient performance. Fig. 6 demonstrates the feedback scene returned at the end of the game.

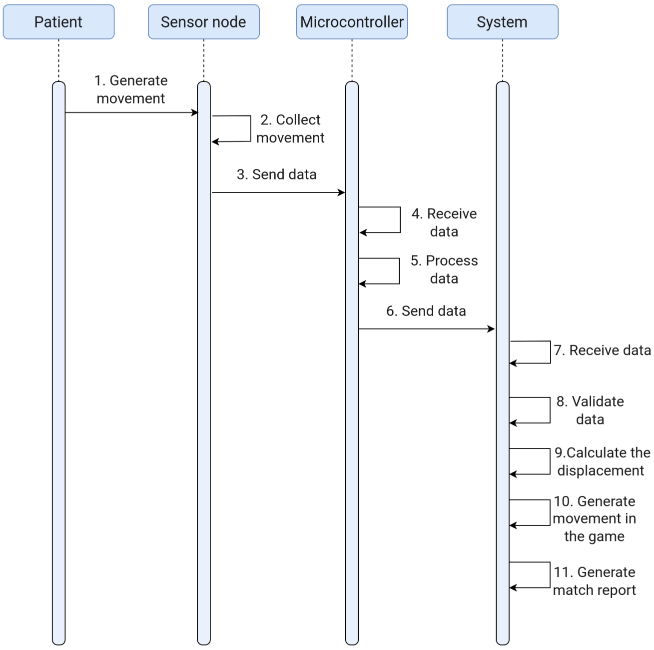

Figure 5. Solution sequence diagram. Source: Author (2022).

The first stage of development was the creation of the mobile application in Flutter Framework, which collects data from the sensors present in the Smartphone. With this, the development of the sensor node followed with the help of the Arduino prototyping platform, which connected the HC-05 module to enable communication via Bluetooth. Because of this, it was necessary to create an initial phase of the game so that there was a communication test between the sensor node and software through serial communication. Therefore, the sensor node captured the virtual racket commands movements, which processes and submitted to the game executed on the computer. The next section will present the different experiments and modifications in the solution for validation.

Figure 6. Feedback at the end of the game. Source: Author (2022).

4 Results and discussions

The first test performed has the goal of verifying data collection in the application. This way, data was captured in a predetermined time of about 5 seconds. The values x, y, and z captured by the Smartphone's accelerometer are shown on the application screen. Thus, it is worth noting that only the device's acceleration on the effects of gravity is considered at this moment. The capture of the gyroscope can be added to this, which has also already verified the possibility of collection. In addition, it is also possible to collect data from the accelerometer sensor, which suffers the user's activity on the Smartphone, disregarding the acceleration of gravity.

Soon after the data collection tests, the Bluetooth communication functionality was added. Therefore, the next test was the communication via Bluetooth with the HC-05 module contained in the Arduino board. After the sensor node tests, functional tests of the serial communication between the game on the Unity 3D platform and the sensor node were performed. Accordingly, the data received via serial communication was printed on the Unity console. After this step, an algorithm was created that performs the racket's movement on the x-axis from the values received via serial communication from the sensor node.

After concluding the initial testing stage described above, the solution underwent a remodeling, from the application to the tennis match simulator, aiming at the version of experiments with patients of the solution. In this way, the baud rate of the Bluetooth module was changed to support the demand of the data stream sent by the Smartphone, and the baud rate of 9,600 bits per second was modified to 115,200 bits per second. Therefore, after changing the module, the sensor data reading and processing function was changed so that the information could be instantly captured, discarding the delay inserted in the initial test.

The processing verifies which axis of movement the sensor is directed to and forwards an indication flag via Bluetooth communication to the Arduino. The Arduino receives it and forwards it via serial communication to Unity. The received data is used to indicate which direction the virtual racket should be moved.

The physical therapist has a tracker for each patient integrated into the tennis match simulator, with physical data collected before and after the match and feedback with data resulting from the sessions performed by the patients.

After the remodeling process was completed, the solution underwent a first physiotherapy session at the SRF for a functionality test. The patient performing the game was in the fitting phase, and the game was used in the balance training session. The patient has an amputation of the left lower limb. In Fig. 7, the execution of the experiment can be visualized.

During the session, the physical therapist monitored the patient at departure. Then, he carried out the configuration by the level of difficulty, the easy mode was chosen, which consists of hitting the ball, and when five hits are reached, the match is completed.

Figure 7. Test session of the solution. Source: Author (2022).

In the execution of the simulator, some problems were identified in the solution. In this way, the main errors verified are: failure in the sensor data capture axis, delays in processing the captured information, no collision detection, racket movement during the game with failure, delays, and loss of location in the screen domain.

After listing the problems of the proposed solution, its reformulation was performed. Initially, it removed the serial communication from the Arduino with the simulator to improve the physics game and detect collisions. Also, to solve the problems was the removal of all elements built in the game scene and its refactoring. After that, the game elements were remodeled, and side barriers were inserted on the game table to detect the collision of the virtual racket. Thus, the racket does not go out off the screen when rendering the movement.

After finishing this step, there was an improvement in the processing of data captured from the sensor and also the creation of a new handshake protocol, as shown in the Table 1. The table shows which value is emitted, its sender and respective receiver, and the description of the action performed upon receipt of the flag.

In the handshake protocol, packets with information are of string type and each message sent has a specific purpose. For example, when it is necessary for the sensor to be calibrated, either to the right or left, the game software issues either zero or one through serial communication to the Arduino board, communicating that a calibration process will be carried out. Thus, when the Arduino receives the information, this message is validated and forwarded via Bluetooth communication to the Smartphone. The data, when received, is validated, and, if the information is correct, the Smartphone forwards the packet, with flag seven, that the calibration will be initiated.

Suppose the valid value was collected during the calibration process. In that case, Smartphone sends a message with the value “A” via Bluetooth communication for the software to emit a notice to the player. In order to notify that player to wait for the calibration to finish in the current position. Otherwise, if it is not possible to collect a valid value, the value nine is output, which means that there was an error during the calibration. Therefore, the software will need to ask the patient to re-calibrate.

In addition, flag two is used, which is responsible for requesting movement data at the game starts. In this case, the game will request the data from the node sensor. Then, via serial communication, it requests that the movement data be sent. This communication rule is essential for the proposed solution because it was possible to improve data communication and improve the movement of the virtual racket.

Table 1. Handshake Protocol

Flag	Sender/Receiver	Description
0	Unity/Arduino/Smartphone	Right calibration
1	Unity/Arduino/Smartphone	Left calibration
2	Unity/Arduino/Smartphone	Movement
3	Smartphone/Arduino	Connection established
4	Arduino/Smartphone	Connection established ok
5	Unity/Arduino/Smartphone	Restart
6	Smartphone/Arduino/Unity	Calibration will start
7	Smartphone/Arduino/Unity	Calibration completed
8	Unity/Arduino/Smartphone	Stop reading motion data
9	Smartphone/Arduino/Unity	Calibration error
A	Smartphone/Arduino/Unity	Wait

In the first experiment, the sensor calibration function was not have been implemented, so it was necessary to create it. Therefore, the function to calibrate was produced as follows: the patient is asked, before the start of the match, to move the stump, first to the right and, after that, return to the starting point as reference is the middle. Soon after, the patient is asked to move to the left. The values are collected within 15 seconds for each side and are the thresholds that will be used to identify the movements.

This information captured during calibration serves to identify a valid movement generated by the patient. Therefore, the accelerometer sensor function reformulation started from the calibration function conception. In the same way, the choice to capture only the acceleration integers, disregarding floating-point values. The action described was because when using two floating-point houses, a processing overhead was noticed, which resulted in a delay in the racket’s movement. In addition, there was no possibility of capturing the zero value (which defines the positioning of the racket without movement), as it is not possible to obtain an exact value, but with noise due to the high sensitivity of the accelerometer capture. This problem makes it more difficult for the movement logic implementation.

Therefore, after making the modifications for solving the problems found during the experiment, unit tests were performed for each module solved separately. In this way, it was possible to notice that the solution was still not meeting satisfactorily during this step. Because the data collected from the accelerometer sensor have noise and, therefore, generate anomalies in the movement. Therefore, it was necessary to investigate the second alternative sensor, which is the gyroscope. The data collected from the gyroscope is the smartphone rotation values on the reference axis.

The first action to change the sensors was the investigation of which of the axes (x, y, z) would perform the best data collection to prevent the problem with noise that occurred with the accelerometer from being repeated. Given this, it was delimited in which positions the Smartphone should be positioned, and this location is exemplified in Fig. 8.

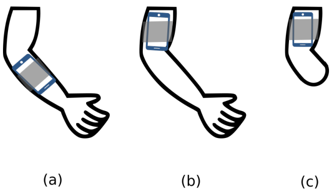

Figure 8. Smartphone Positioning. Source: Author (2022).

After creating the sensor positioning configuration, tests were performed to collect data from the gyro sensor. Initially, it was investigated on the x-axis, which did not return data congruent with the configured positions. Later, the data on the collection y-axis was examined, which, in the same way, returned incongruent values. Finally, the test was performed with the collection of data from the gyroscope sensor on the z-axis, which demonstrated good efficiency in capturing and also presented very little noise in order to be able to verify when the patient was immobile. In Fig. 9, the smartphone coordinates axis is represented, in which the red line represents the values of the axis in Fig. 9.

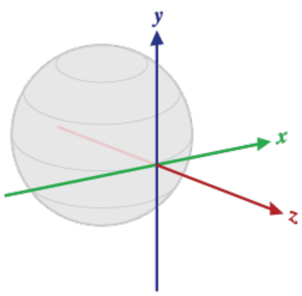

Figure 9. Smartphone sensor coordinate axes. Source: Android Developers (2021).

Similarly, it was also necessary to reformulate how the movement performed by the patient was captured to determine which points the virtual racket should move. Therefore, it was necessary to create a new method of tracking the positions of the sensor in the game table. This way, the insertion of the scale factor calculation was followed. It operates with the values collected from the calibration for the right and left and with the maximum values that the virtual racket can move on the match table.

Hence, the equation (1) demonstrates how the calculation of the scale factor of right is performed, “FS_RIGHT” where the numerator describes the top value possible to the right and the denominator is the module of the calibration value to the right. Likewise, the equation (2) describes the calculation of the scale factor of the left, “FS_LEFT” being the numerator of the top-left position on the game table.

$$FS\_RIGHT = \frac{8}{|right\_calibration|} \tag{1}$$

$$FS\_LEFT = \frac{-8}{|left\_calibration|} \tag{2}$$

The scale factor aims to map the value collected through the patient’s movement with the gyroscope sensor in a valid movement of the racket in the game. In this way, the values of the right and left scale factors are used to calculate the position to which the virtual racket must move.

Therefore, the equation (3) describes how the position operation takes place, where “FS” is the right or left scale factor, depending on which side the sensor moved. To understand how the verification and validation of the movement are performed by the sensor node, Fig. 10 shows the flowchart of the implemented logic.

$$position = FS * CurrentGyroscopeValue \tag{3}$$

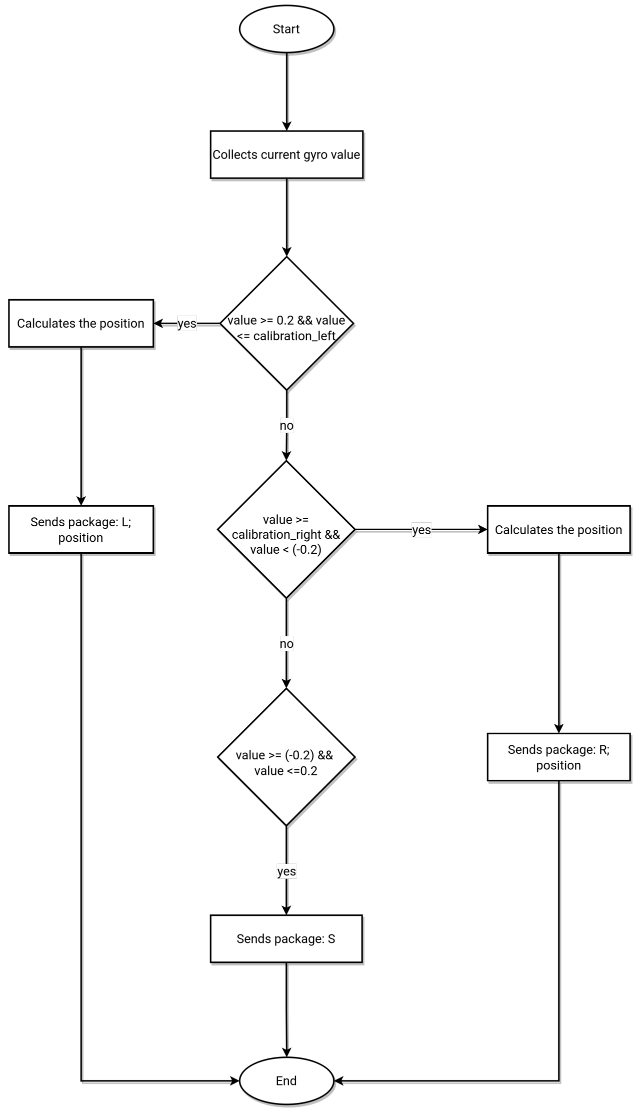

Figure 10. Flowchart of the move validation function. Source: Author (2022).

After the verification, validation, and execution of the position calculation, the package containing which direction is the movement and which position is sent via Bluetooth communication from the Smartphone to the Arduino board. In the next step, authentication on the data to detect possible failures in the communication was performed. Finally, upon completion of the verification, the packet data is sent via serial communication to the game in Unity.

When Unity receives the packet, it is read and processed to collect the direction in which the virtual racket should move and the desired position. Subsequently, the request for new data is sent via serial communication, issuing flag 2, through the handshake protocol developed previously.

There is a reverification of the data received so that it does not perform wrong calculations, harming the avatar's movement in the game. If the information received is correct, the displacement calculation begins. Therefore, first, the racket's current position is collected to verify if the position to which the racket is to be moved is valid. If yes, the displacement calculation is performed, which can be of three types depending on the values, in the following way:

1. Current position of the virtual racket is equal to zero or is in the range between one and minus one: the displacement calculation is given by the sum of the current position of the racket and the position coming from the sensor node.
2. Position captured by the sensor node is greater than the current position of the racket: the displacement calculation is given by the difference between the position of the sensor node and the current position of the virtual racket.
3. Current racket position is greater than the position collected by the sensor node: the displacement operation is given by the difference between the current position of the racket and the position collected by the sensor node.

Therefore, among the methodologies created and tested, the scale factor and the calibration functionality, and the handshake protocol were the methods that obtained the best performance. The problems with rendering the racket movement and the difficulty faced in racket controlling have been fixed.

In order to patient analyze fewer data subjective during the match, the individual's effectiveness and performance coefficients were created. The created analyzes are one of the main contributions of the present solution, considering that this analysis did not exist before. The effectiveness coefficient is described as the patient's performance concerning the score obtained, and the equation describes the calculation (4). This effectiveness is related to the number of points it mana-ged to achieve, i. e., the greater the number of points, the greater the effectiveness in winning the match. On the other hand, the performance coefficient, described by the equation (5), concerning the patient's performance in the match, i. e, is the value related to how much the match was played.

$$Effectiveness = \frac{Scoreboard\ patient}{(Scoreboard\ patient + Scoreboard\ bot)} \quad (4)$$

$$Performance = \frac{(N.\ of\ hits - Scoreboard\ patient)}{(N.\ of\ batting - Scoreboard\ bot)} \quad (5)$$

The patient may have won the game and achieved high effectiveness, but his performance may be below. He may have also lost the match and achieved a high performance during the session. In Fig. 11 the generation of the patient performance graph is demonstrated.

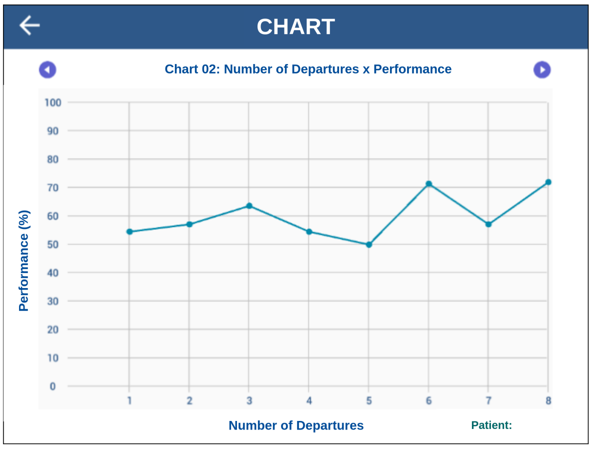

Figure 11. Scene of the performance coefficient graph generation. Source: Author (2022).

When viewing the data from the match sessions and generating the graphics, it is possible to export the data and graphics to a pdf file. In this way, the physical therapist will be able to print the report of his patients and have control of the sessions that the patient practiced.

New unit tests were carried out for each TennisGame Physio component with the new changes. In addition, tests were carried out to verify the functioning of the sensor data collection, communication between the hardware components, and the joint evaluation of the system.

Considering that the primary goal of this work was to create a solution that helps physiotherapists in the amputee's rehabilitation sessions, it was necessary evaluation the solution in a realistic scenario. Thus, some patients were selected to participate in the initial tests of the developed solution. The SRF physiotherapists chose according to their degree of physical fitness and the ability to perform the required movements during the session.

For health reasons imposed by the spread of the coronavirus, two patients were selected who performed the TennisGame Physio sessions with the follow-up of physical therapists. Thus, Table 2 presents the characteristics of the patients, concerning the information of sex, age, level of amputation, and the stage of rehabilitation in the patient.

Table 2. Profile of the patients selected for the solution validation.

	Patient 1	**Patient 2**
Genre	Male	Male
Age	28	56
Amputation Level	Lower	Lower
Rehabilitation stage	pre-prosthetic	prosthetic

Patient one, who was in the pre-prosthetic phase, used the solution to assist in the session that works on the patient's balance. Because during the session, he was balancing himself without using crutches and a walker for the first time. The demonstration of test execution can be seen in Fig. 12. This individual performed two sessions, totaling 14 games played, with at least two executions of each difficulty category.

Figure 12. Validation of the solution with the patient 1. Source: Author (2022).

The patient in Fig. 13 in the first test performed was at the beginning of the prosthetic stage, and he had recently received the prosthesis and was familiarizing himself with the new limb. He was instrumental in capturing the issues described above as he performed an initial test match. This individual performed two sessions, totaling about seven games played, except for the initial test, which had no data collection. There was the execution of at least two games for each difficulty level.

Therefore, when finalizing the tests with the patients and the physical therapists. Some questions were asked about the experience of using TennisGame Physio during physiotherapy sessions. For this, two closed questionnaires were created, one for patients and another for physical therapists, to investigate the solution's performance.

Patients were asked nine questions regarding the table tennis match simulator. The evaluation was performed using the Likert Scale, presenting five possible answers, including the extremes "Strongly Disagree" and "Strongly Agree".

On the other hand, the physical therapists were asked about the support tool and the patient's analysis during the game. The physical therapists' questioning includes nine questions using the Likert Scale, ranging from one to five, with one being the "Worst Evaluation" and five being the "Best Evaluation", and two descriptive questions.

Figure 13. Validation of the solution with the patient 2. Source: Author (2022).

4.1 Patient assessment

First, how the patient described the solution would be described. It is important to stress that the group of patients who validated the solution is small, but new tests will be performed with other groups of people. Therefore, question one was intended to check whether the patient felt challenged by the game's complexity and trusted his or her skills to meet the challenge. The questions is presented on the Table 3, thus the patient's results is showed at Fig. 14.

In this way, the patients return to question *Id* number one that they mark entirely agree. This answer represents that they strongly agree with the question. In this way, it can be seen that the game challenges the patient in his limitations. The question *Id* number two only 50% strongly agrees, demonstrating that the solution returns information to the patients, however, not entirely satisfactorily.

Table 3. Patient's Questions.

Id	**Question**
1	"Did you feel challenged by the game's complexity, but do you believe that your capabilities allowed you to face the challenge?"
2	"Was it clear to you how your performance was during the game?"
3	"Did you feel that you were in full control of the activity?"
4	"Do you feel comfortable performing the activity?"
5	"Do you feel disconnected from the notion of time?"
6	"Did you not have to make an effort to stay focused on the activity?"
7	"If you are not concerned about the considerations of the people around you?"
8	"Did you find the experience rewarding?"
9	"Would you like to repeat the game experience?"

In the same case, the question *Id* number three, only 50% agree, portraying that patients feel in command of the game, however, not in its entirety. For the fourth question, all patients consider staying comfortable with the activity. It indicates that the movements required to perform the game's dynamics are not exhaustive. The fifth and sixth questions focus on the flow approach. Both questions returned that the patient agreed. It shows that the patient is induced to lose perception of the time around him and remains focused on performing the activity. The seventh question corroborates the inference that the patient can achieve the flow state during the game because every patient strongly agrees.

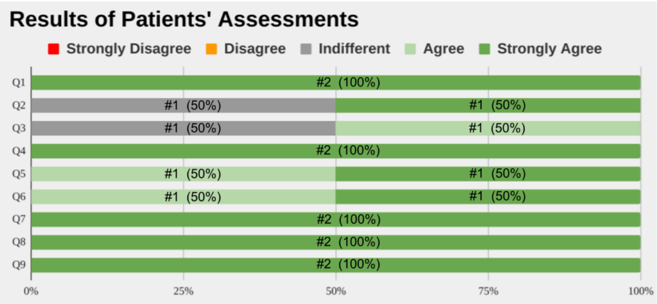

Figure 14. The patient's results summarized. Source: Author (2022).

4.2 Evaluation of physical therapists

The feedback from the SRF professional physical therapists is essential to the work. After monitoring the patients during the session, the physical therapists answered the TennisGame Physio evaluation instrument. The questions below were answered by a focus group of three professional physical therapists. For, it was this group that monitored the patients' sessions. The physical therapist's questions is presented in Table 4, and the questions results is showed at Fig. 15

Therefore, for the question about the first impression of the system, whether it would be helpful for amputees' sessions, every answer of physical therapists is that yes, the solution is valid. Regarding the layout of the tool, it is intuitive and easy to access. In addition, the information collected by the solution is of paramount importance for evaluating the patient's rehabilitation.

Likewise, when asked about the data returned at the end of the game and the patient's history, it is clear that the solution satisfactorily returns the information. Subsequently, when asked about the performance of TennisGame Physio and if it is reliable, the physiotherapists returned that the solution presents good performance and reliability.

When questioning the physical therapists regarding the tool being motivational for the patient, TennisGame Physio obtained a high evaluation. Being considered highly motivational to the patient, instigating him to practice the session without realizing the efforts he will perform during the game. The next question corroborates the statement because the physical therapists noticed the real motivation of the patient during the execution of the table tennis match simulator.

Table 4. Physical Therapist's Questions.

Id	Question
1	"The first time you used the system, did you have the impression that it would be really useful in upper or lower limb amputees sessions?"
2	"Does the system have an intuitive, pleasant, and user-friendly interface?"
3	"Is the information collected by the solution relevant to assessing the patient's physical rehabilitation?"
4	"Does the system collect the data presented satisfactorily through the fields at the end of the match screen and in the session history?"
5	"Does the system perform reliably without lag, slowness, or correctly?"
6	"Is the tool capable of motivating the amputee patient?"
7	"Does excellent the patient's motivation when using the tool?"
8	"Does the system provide the functionality to track the patient's progress throughout the physical rehabilitation treatment?"
9	"In general, did you enjoy using the system?"

Finally, it is verified whether the data provided for patient follow-up are valid. Regarding the return of physical therapists, they consider the information extremely important for tracking the patient's progress throughout rehabilitation. In addition, the professionals evaluated the use of the solution with the maximum value.

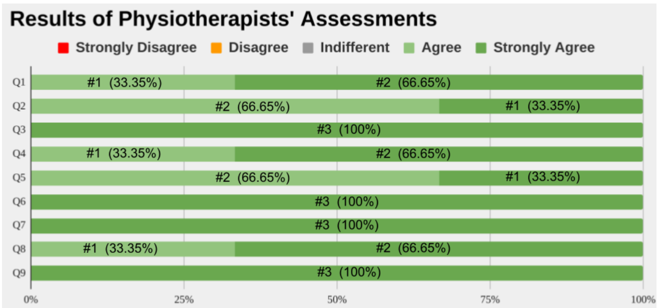

Figure 15. The physical therapist's results summarized. Source: Author (2022).

4.3 Final considerations

Based on the evaluations performed by patients and physiotherapists, it is possible to verify that the present solution meets the objectives proposed at the beginning of development. In this way, with the results obtained by questioning the patient, it was observed that it is presumable that they when playing the table tennis match, reach the state of flow. This affirmative is justified by responded values on questions that ask how concentrated and disconnected from the notion of time the individual can achieve. Furthermore, in Fig. 16, it is possible to verify the trend line in the performance graph of one of the patients, which depicts how attentive and instigated he was during the session.

Fig. 16 also identifies, through the colors, in which difficulty modes the games were being executed. The interval between the first game and the eighth mode game was defined as easy. In the values between the ninth and eleventh, the individual was executed in medium mode. Finally, during the interval between the eleventh and thirteenth games, the patient was at the maximum level of difficulty, hard mode. In this way, it is possible to evidence that even with difficulty being high, the patient remained focused and motivated during the game. Therefore, the trend line of the graph collaborates to show that the patient reached the flow state during the session.

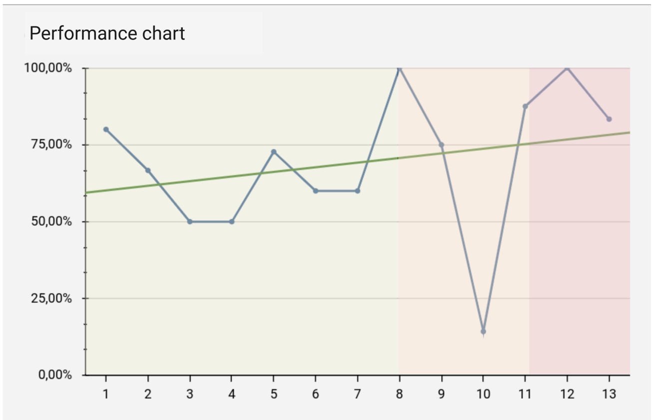

Figure 16. Performance graph with the patient trend line. Source: Author (2022).

Furthermore, physical therapists also contribute to this evidence since when asked if their patients show motivation, the answers are high. In addition, the tool for monitoring patients, which is made available to physical therapists, proves to be effective for the professional in tracking the patient's evolution.

In short, the solution meets the research problem that was the creation of a computer solution that applies gamification methodologies and also has a support tool for physical therapists. Besides that, the patient can achieve a flow state during the session.

Although the preliminary results demonstrate high potential for applicability, as the following steps are to be performed, it is expected to expand the experiments with a more representative group of patients and carry out the follow-up experiments in a control group format. These tests must be carried out initially within the SRF and later expanded to other partner institutions.

5 Conclusions

This work was a demand from the Physical Rehabilitation Service of Bagé/RS, which had a deficit of tools to support amputee's upper and lower limbs sessions. Therefore, the main goal of this work was to create a computational solution in hardware and software that used gamification methodologies to assist rehabilitation sessions in the pre-prosthetic and prosthetic stages.

Thus, the theoretical foundation was performed first to obtain more familiarity with the issues involved in the research. Thus, the studied related works were of total value in the foundation of this work. In addition, the requirements definition by together physical therapists at the SRF was essential to develop all the modeling described in this solution. Furthermore, the chosen development methodology, the waterfall method, was also essential for the effectiveness of the solution's progress.

Thus, the first stage of the solution was the creation of the system modeling, software, architecture, and the game. After that, tests are performed on the functionalities of the elements that constitute the solution. Initially, there was data collection from the accelerometer and gyroscope sensors. However, it was necessary to opt for using only the gyroscope during the development. The accelerometer sensor is unstable and does not detect when the patient was stopped, generating anomalies in the solution.

After executing the functional tests of the components, the integration between the sensor node and the game was performed. From that, several problems hindered the progress of the solution. The main problem faced was the correct movement and rendering of the game's virtual racket. After many studies and tests, it was determined that the choices that should be made were: Change the sensor from the accelerometer to the gyroscope. Reformulate the calibration logic. Change the x-axis of data collection to the z-axis and. Use the scale factor calculation methodology to track the movement of the sensor concerning the game avatar.

Finally, with the table tennis match simulator developed and the physiotherapists' support tool created and integrated into the solution, selecting the experimental group of patients was necessary to run the experiments. In this way, despite the health protocols imposed by the spread of the coronavirus, it was possible to perform the tests and validate the solution with a minimal group. Although the preliminary results demonstrate high potential for applicability, as the following steps are to be performed, it is expected to expand the experiments with a more representative group of patients and carry out the follow-up experiments in a control group format.

Concerning was reported by the physical therapists that evi-denced that the system is easy to install and handle, besides being motivating and providing patients with different levels of amputation with a way to entertain themselves during the sessions.

Thus, the implemented solution is effective and solves the research problem raised. Furthermore, based on the evaluations made by the physical therapists and patients, the solution has great potential to become a recurring tool in the physi-cal therapy processes of the Physical Rehabilitation Service of the city of Bagé/RS. They are considering that the physical therapists reported, through the descriptive answers in the questionnaires, that the solution is easy to use and helps patients perform the physical rehabilitation sessions to make the process more stimulating for the individuals.

However, there are aspects to be improved, such as improving the report generated for the physical therapist and inserting new sensors to collect information about the speed and distance traveled by the patient.

Finally, it is essential to highlight that the project developed was approved by the Research Ethics Committee of the Federal University of Pampa (UNIPAMPA) and registered at Plataforma Brasil under CAAE number 51777521.5.0000.5323.

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