

Development of a serious game for ankle dorsiflexion rehabilitation

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RESUMO

Disfunções motoras afetam muitos indivíduos devido a psicopatologias ou acidentes. O tratamento geralmente envolve exercícios fisioterapêuticos, que podem ser demorados e desmotivadores, especialmente se o progresso for lento. Para lidar com isso, o projeto visa desenvolver um jogo sério para a reabilitação da dorsiflexão do tornozelo. O sistema utiliza um sensor que captura o movimento do tornozelo do paciente no pedal e comunica o movimento ao computador por meio do joystick. Os resultados obtidos são apenas técnicos e baseados em dados simulados. A reabilitação da dorsiflexão do tornozelo foi desenvolvida, o sistema para capturar com eficiência os movimentos de dorsiflexão, oferecendo ajustes de dificuldade e adaptabilidade às necessidades do paciente.

Palavras-chave: Reabilitação física, Reabilitação de dorsiflexão do tornozelo, Jogos sérios.

ABSTRACT

Motor dysfunctions affect many individuals due to psychopathologies or accidents. Treatment typically involves physiotherapeutic exercises, which can be lengthy and demotivating, especially if progress is slow. To address this, the project aims to develop a serious game for ankle dorsiflexion rehabilitation. The system uses a sensor that captures the movement of the patient's ankle on the pedal and communicates the movement with the computer through the Joystick. The results obtained are only technical and based on simulated data. Ankle dorsiflexion

rehabilitation was developed, the system to efficiently capture dorsiflexion movements, offering difficulty adjustments and adaptability to the patient's needs. **Keywords:** Physical- rehabilitation, Ankle dorsiflexion rehabilitation , Serious games.

1. INTRODUCTION

The constant technological advances have completely changed how people live. For example, long-distance communications took months to be carried out in the past, whereas, in the modern world, they occur in just milliseconds. Such advances have been applied in all areas of society, including communication, transportation, medicine, education, and the economy (IBANGA 2024).

However, an inherent aspect of human nature is the affinity for entertainment. Human history indicates that games are played in all societies, with records of board games over 5,000 years old (DEPAULIS 2020). Balls, dice, and cards have been used for centuries as game tools for entertainment purposes (HARGRAVE 2000). With the emergence of the first computers and demonstrations of their capabilities, it became evident that they could also be used as tools for games (DORNER *et al.* 2016).

As mentioned, board games are primarily aimed at entertainment. However, there are also several traditional games that are educational. That is, the main objective of these games is to entertain the players and provide some learning (TRAJKOVIK *et al.*). With the popularization of digital games (ERHEL; JAMET, 2013), they too began to fit into this category of games with a serious purpose, called serious games. A serious game, characterized by its educational or therapeutic purposes, emerges as a promising tool in physiotherapy. It provides a playful environment that motivates patients to participate in the rehabilitation process actively (WIEMEYER; KLIEM, 2012).

The first concept of a serious game was conceived by (ABT 1987), who stated: “We are concerned with serious games in the sense that these games have an explicit and carefully planned educational purpose, and are not intended to be played primarily for entertainment.”

The use of games in physiotherapy is known as game therapy. According to (COSTA; SANTOS, 2021), this approach enables the representation of everyday life situations through technology, eliciting a motor response from the patient. Engaging in a moment of entertainment, the patient unwittingly complies with the activities prescribed for their treatment.

Games can offer a secure and enjoyable environment for patients to concentrate on their tasks, diverting their attention from any discomfort or pain they may experience during rehabilitation (LING *et al.* 2017). Furthermore,

games can offer immediate feedback on the patient's performance, enabling the physiotherapist to tailor the treatment and modify the difficulty level as the patient advances (DE JESUS *et al.* 2018).

Incorporating games into physiotherapy treatments can also boost motivation and adherence to treatment, especially since the rehabilitation process can often feel monotonous. By integrating game elements into the treatment, patients may find increased motivation to persist with the rehabilitation process and attain their treatment goals (COSTA; SANTOS, 2021).

Physical rehabilitation constitutes a fundamental pillar in the recovery process from musculoskeletal injuries and restoring full functionality to the human body (TODHUNTER-BROWN *et al.* 2014). Patients experiencing ankle movement limitations, such as dorsiflexion, are affected in this extensive field due to the limited availability of treatment approaches.

Dorsiflexion is essential for daily activities like walking, climbing stairs, and maintaining balance, thus emphasizing the imperative search for the complete reintegration of patients into their daily routines and achieving the desired quality of life (ALMANSOOF *et al.* 2023). Nonetheless, the effectiveness of traditional rehabilitation methods for ankle dorsiflexion often faces specific challenges related to motivation and patient engagement in treatment. Implementing innovative technologies is a promising way to improve therapeutic outcomes (LOHSE *et al.* 2013).

In this context, and to address the aforementioned challenges, the main contribution of this work is the development of a novel system for ankle dorsiflexion rehabilitation, which integrates a serious game with electronically instrumented control.

Furthermore, the ongoing progress monitoring within the game yields valuable data for healthcare professionals and empowers patients by enabling them to visualize their development over time. This immediate feedback fosters a positive cycle, strengthening the patient's commitment and involvement in the rehabilitation process.

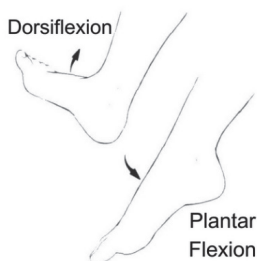
The general objective of this study is the development of a prototype of a serious game associated with an instrumented pedal for ankle dorsiflexion rehabilitation, achieving stable and real-time communication between the game and the controller. The system effectively captured dorsiflexion movements, offering difficulty adjustments and adaptability to patients' needs.

2. MATERIALS AND METHODS

The system was designed to assist patients in improving deficits in ankle dorsiflexion. Dorsiflexion is the biomechanical action that reduces the angle

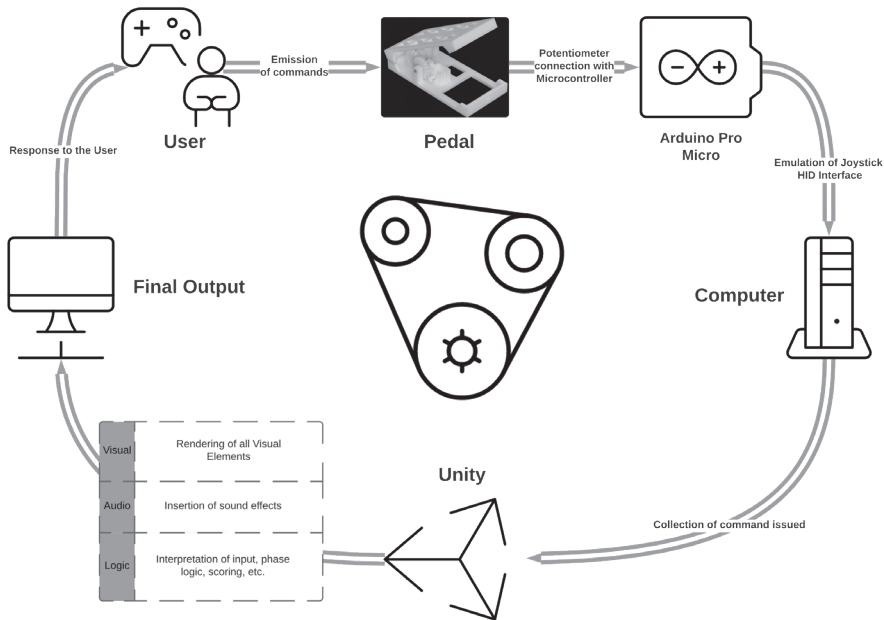
between the dorsum of the foot and the anterior surface of the lower leg, as shown in Figure 1. Dorsiflexion is a movement that involves the flexing of the ankle joint, which decreases the angle between the foot and the leg, as presented in Figure 1. This movement is essential for daily activities such as walking, running, climbing stairs, and driving. Being able to control and move the muscles responsible for dorsiflexion precisely is crucial for maintaining good posture and how you move around. (KENDALL *et al.* 2010).

Figura 01 - Ankle joint movement, exemplifying the dorsiflexion.



The diagram shown in Figure 2 synthesizes the general operation of the project, presenting the main elements that will be detailed later in the section. Briefly, the game takes place in a space scenario where the goal is moving a spaceship controlled by the pedal, avoiding obstacles. A sensor (rotary potentiometer) captures the ankle's movement on the pedal, which communicates with the computer through the Joystick.h library. The patient constantly receives visual, auditory, and logical feedback, encouraging better performance in the game and consequently exercising the ankle.

Figura 02 - Logical diagram of the game process.

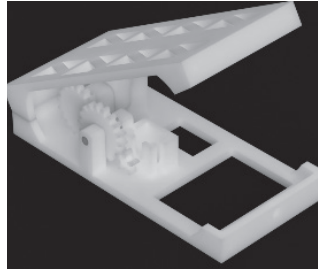


The pedal was modeled using the CAD software Fusion 360. This software allows for precise and efficient design, making creating a model that meets the project's specific needs easier. The pedal was designed to be ergonomic and functional, providing an intuitive interface for the user as shown in Figures 3 and 4.

The sensor used in the pedal is a linear potentiometer, which captures the movement of the ankle. As the pedal is pressed, the angle of inclination of the ankle changes the resistance of the potentiometer, thereby varying the electrical signal sent to the microcontroller. This variation allows the physical movement to be translated into a measurable electrical signal.

PETG (polyethylene terephthalate glycol), a type of thermoplastic commonly used in 3D printing, was used to construct the pedal. This material is known for its high mechanical, chemical, and thermal resistance, offering durability and robustness compared to other 3D printing materials. The use of PETG allows the device to endure continuous operation without compromising performance.

Figura 03 - Rendered model of the designed pedal.



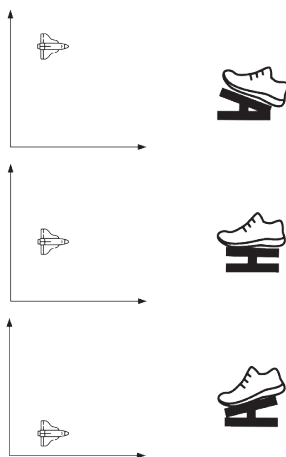
Data acquisition and processing occur on the Arduino Pro Micro microcontroller. The microcontroller is based on the ATmega32U4 and was chosen for its ability to emulate HID (Human Interface Device) devices. The analog reading of the potentiometer is done through an analog port of the Arduino, which provides a resolution of 10 bits, allowing for the capture of variations of 4.9 mV per unit.

Communication between the pedal and the computer uses the Joystick.h library, which allows the microcontroller to be recognized as a video game controller by the operating system. The data processed by the Arduino are sent to the computer through a USB interface using the HID protocol. This approach ensures efficient and low-latency communication, which is essential for interactive applications such as games.

The game features a spaceship as the main character and is set in a space scenario. The main mechanic involves controlling the spaceship's position based on the pressure exerted on the pedal. This control is crucial for avoiding obstacles and completing the stages. The game is divided into six stages, each presenting a unique pattern of obstacles that the player must navigate. All stages have configurable parameters to accommodate individual player preferences, with stage six being considered a custom stage, allowing users to define the obstacle pattern.

The pedal is essential for controlling the spaceship within the game. The pedal position is mapped to the position of the spaceship. This mechanic enables the game's obstacle patterns to require the player to make corresponding movements to dodge obstacles and avoid losing points. These movement stimuli align with existing treatment patterns, wherein the amplitude, speed, and control of dorsiflexion movements are practiced.

Figura 04 - Functioning of the pedal in the game



The game's visual elements, including sound effects, 3D models, and images, were obtained from online platforms by authors who make them available for free use. The visual design is focused on providing an immersive and engaging experience for the player while the interface is intuitive, ensuring fluid gameplay.

3. RESULTS

The timeline of the final game works as follows: first, there is a main menu where the user can access options for audio adjustments and control calibration or go to the stage menu to choose one. When selecting a stage, the specific options of the chosen stage are displayed, allowing the configuration of the session variables before entering the stage. During this stage, it is possible to observe the percentage of errors in real-time, and at the end, the pattern of the movement graph is displayed, allowing it to be exported in CSV format. This flow can be observed visually in Figure 5.

Figura 05 - Example of movement graph of the third stage



The development of the serious game and the instrumented pedal was successful, resulting in a functional prototype. The pedal, equipped with a potentiometer, integrates efficiently with the game, allowing user interaction through dorsiflexion movements. This device transmits movements without delays, providing an effective interface for performing the actions required to progress through the game's stages.

The serious game can stimulate dorsiflexion movements, assisting in treatment and providing an interactive interface. As the player advances through the stages, the stimuli and difficulty levels increase, featuring different formats and varieties of obstacles. The stage configuration interface allows for specific adjustments for each level. Additionally, the game offers auditory and visual feedback, such as a sound indication of errors and a visual indication with the character blinking in red when colliding with an obstacle. Performance evaluation methods include two scoring methodologies: one playful to motivate the patient and another technical for health professionals, including a standard movement graph and the possibility of exporting data in CSV format for pattern analysis and subsequent progress tracking.

4. DISCUSSION

The choice to develop a serious game for ankle dorsiflexion rehabilitation, in addition to being driven by interest from professionals in the field, was based on the search for an innovative and motivating approach to the recovery process. Integrating an interactive virtual environment offers an effective means to engage patients in rehabilitation. The interactivity stimulates active patient participation, while real-time feedback allows instant adjustments, optimizing progress in rehabilitation.

No interventions have yet been carried out with patients using serious games as a form of treatment. Therefore, a physiotherapist advised and monitored the development of this game to be a potential tool in ankle rehabilitation, given the existing needs and demands.

A relevant work in developing serious games for rehabilitation is that of (ANDRADE DE OLIVEIRA 2011), who designed games aimed at recovering ankle movements. Using an active orthosis, the games offered different stimuli for dorsiflexion and plantar flexion. Four specific games were created, two for each type of movement, where patients needed to apply a specific force to complete the actions in the game. The results of the experiments showed greater adherence of patients thanks to visual and motor feedback, indicating that these games are effective in rehabilitating ankle movements.

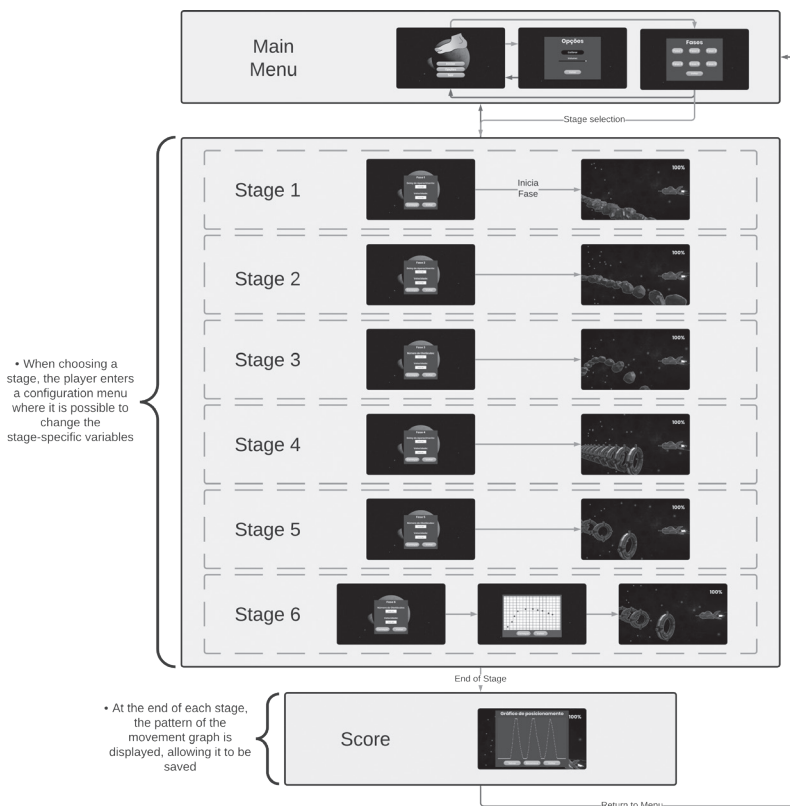
Another relevant study is that of (FERREIRA 2020), who developed a serious game for training dorsiflexion and plantar flexion of the feet, controlled by a wearable device with an accelerometer sensor. The tests carried out with children showed positive treatment performance and user satisfaction results. Based on the feedback received, improvements were suggested, such as adding different speed settings and obstacles and visual and sound feedback. These suggestions were incorporated into the game developed in this work, offering various methods to complete the phases and adjusting the difficulty based on the patient's level by controlling the speed, variability, and interval between obstacles, thereby increasing user interaction and immersion.

In this work, promising results were observed in improving the ankle's range of motion and adherence to the game. Simulations were carried out to evaluate the interaction between the game and the instrumented pedal. The results indicated a positive correlation between the dorsiflexion of the ankle measured by the pedal and the performance in the game. However, it is essential to emphasize that the results obtained are only technical and based on simulated data, not reflecting the responses of actual patients. There is no feedback available on patient satisfaction and adherence to the game. Therefore, while the results are exciting, they have not yet been proven in terms of effectiveness in a real clinical environment.

The discussion about the possible limitations of the work reveals important aspects to be considered in evaluating the serious game developed for ankle dorsiflexion rehabilitation.

Although the potentiometer is functional for measuring ankle dorsiflexion, it is necessary to improve its accuracy to capture ankle movements with greater sensitivity. The need for a mechanical interface, like the pedal, is also a consideration, as it introduces elements that can affect the accuracy of the measurement. Additionally, using wires in the connection between the sensor and the system can limit the patient's mobility during rehabilitation.

Figura 06 - General game flowchart



Another limitation is the minimum range of motion required to operate the game, which can represent a challenge for patients with more severe motor limitations. Although the phases of the game have been set up with the guidance of professionals, it is necessary to emphasize the need for tests and the collection of patient feedback. This aspect is crucial for the evolution of the serious game, especially in adapting the phases to meet the specific rehabilitation needs of different patients. Figure 6 shows the general flowchart of the game.

5. CONCLUSION

The work focused on developing a serious game associated with an instrumented pedal for ankle dorsiflexion rehabilitation, achieving stable and real-time communication between the game and the controller. The system effectively captured dorsiflexion movements, offering difficulty adjustments and adaptability to patients' needs.

Despite the innovative potential of the system in integrating interactive technologies for a personalized approach to rehabilitation, some limitations were

identified, such as the precision of the potentiometer and wired communication, which can impact patient mobility. The lack of clinical validation in a real environment also represents a challenge to be overcome.

For future work, it is suggested that real clinical studies be conducted to validate the system's effectiveness, in addition to direct feedback collection from patients for continuous refinements. The review of the control interface, considering wireless options and more advanced sensors, is pointed out as a promising strategy to consolidate the serious game as an effective tool in ankle rehabilitation, contributing to the advancement of the integration of interactive technologies in the rehabilitation area.

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