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IFAC PapersOnLine 58-24 (2024) 199–204

Development of Assistive Technology Using Gametherapy for Congenital Clubfoot Treatment

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Abstract: This paper introduces a novel approach to treat Congenital Clubfoot (CC), a condition impairing the mobility and quality of life in young children. Despite the effectiveness of the Ponseti method for the treatment of CC, there are practical challenges, particularly in Brazil. Our study proposes a game-based therapeutic system that integrates an embedded system for motion detection and pressure measurement, targeting the specific rehabilitation needs of children with CC. The system includes an MPU6050 accelerometer/gyroscope sensor and a custom-made Velostat pressure sensor matrix. These components communicate via Bluetooth and I2C protocols to facilitate therapeutic exercises such as eversion and dorsiflexion of the feet. The project also features the Hofeet Portal, a Flask-based web interface for healthcare professionals to manage patient data efficiently. The gaming aspect involves "Bam-boo!", a 2D Unity game designed for children aged 3 to 7. This game incorporates activities for the correction of CC, engaging children in a fun and interactive manner. The remote control for the game uses a rotary joint connected to a slipper-shaped controller, allowing natural foot movement. Economic considerations, especially in public healthcare networks, guided the selection of cost-effective and accessible technologies such as Arduino and Unity. This interdisciplinary approach aims to improve compliance with CC treatment, reduce discomfort, and improve results. The project exemplifies the potential to integrate technology, healthcare and gaming in pediatric physiotherapy, potentially serving as a model for patient-centered care innovations.

Keywords: Gametherapy, congenital clubfoot, Ponseti method, embedded systems, mechatronics, physiotherapy, orthopedics.

1. INTRODUCTION

Congenital clubfoot (CC) is one of the most common musculoskeletal deformities at birth, occurring in about 1 to 2 per 1.000 live births (Nogueira et al., 2011). It is a developmental anomaly of the foot induced by a disfunction that occurs in the posterior and medial aspects of the lower leg, ankle, and foot. It starts in the middle third of pregnancy and lasts up to the fourth year of life (Ponseti, 2002; Changulani et al., 2006). This disfunction originates from a three-dimensional foot deformity in which four elements are present: cavus, forefoot adduction, hindfoot varus, and equinus. The foot is positioned inward and downward, affecting the child's ability to walk normally (Feldbrin et al., 1995). The widely accepted treatment to correct CC deformities is serial manipulation and casting using the Ponseti method, including a percutaneous Aquiles tenotomy, followed by a post-correction foot abduction brace (FAB) until four years of age, that is, when the factors that trigger the deformities become inactive. The extensive surgical interventions to correct clubfoot have become almost obsolete due to the success of the Ponseti method (Lourenço and Morcuende, 2007).

However, CC has a strong tendency to relapse up to four years of age because the factors that induce the deformity are still active even after the primary correction has been achieved (Little et al., 2019; Gelfer et al., 2020). After successful primary correction with the Ponseti method, recurrence has been reported to affect up to 40% of the children. The FAB has been the standard of care for preventing recurrence, but even with excellent compliance, recurrences still occur. Prevention of recurrence is one of the main challenges during the treatment of patients with

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10.1016/j.ifacol.2024.11.036

CC initially treated with the method. Evidence points to a congenital neuromuscular imbalance that comprises the deforming forces present in the clubfoot.

Several challenges hinder wider adoption of the Ponseti method. These include the financial burden of acquiring well-fitted orthoses, children's negative attitudes towards orthoses resulting in complaints and persuading family members to discontinue their use, and the overall effectiveness of orthopedic device usage. Therefore, this study aims to address these obstacles by introducing game therapy. Specifically, a game will be developed to encourage dorsiflexion and reversion movements in feet affected by the condition. This interactive game will be responsive to the patients' foot movements and will require a remote control connected to an embedded system that incorporates sensors and microcontrollers.

Game therapy, often integrated into physiotherapy programs, utilizes interactive and engaging games to improve treatment outcomes. This approach, especially beneficial for pediatric patients, such as those with CC, uses technology-driven activities to promote physical movement and correct musculoskeletal conditions. The use of game therapy in this process provides many advantages such as: increased adherence by arousing interest in children, the exercises can be carried out at home without the need to travel to rehabilitation clinics, the sessions and the evolution of patients can be monitored remotely by the treatment team, and still constitutes a viable alternative to be implemented in locations where there is no hospital network available to carry out surgical procedures.

This paper has the following structure. Section 2 describes the CC. Section 3 has a brief introduction to game therapy. Section 4 has the requirements. Section 5 describes the methodology used, and Section 6 has the development of the three components: the device with the embedded system, the game developed for a cell phone, and the web interface to follow the evolution of treatment. Section 8 provides conclusions and future work.

2. CONGENITAL CLUBFOOT

CC is a medical problem for several reasons. CC, also known as talipes equinovarus, is a deformity that is present at birth, characterized by the inward and downward rotation of one or both feet. The severity of CC can vary, but if left untreated, it can result in significant physical disability. The atypical shape and position of the foot can create difficulties or even make walking impossible, affecting mobility and independence. Untreated CC induces physical limitations that can have a substantial effect on the individual's quality of life. Children with CC may find it difficult to participate in regular play or physical activities, which can influence their social interactions and psychological development. As the child grows, the deformity can cause discomfort and pain, particularly when walking or standing. This discomfort can also be intensified by the appearance of secondary problems, such as calluses or sores, caused by an abnormal position of the foot (Smythe et al., 2023).

The association of shortening of the muscles and tendons of the posteromedial aspect of the foot (triceps surae, Achilles tendon, posterior tibialis, and toe flexors) and weakness of the evertor muscles of the lateral aspect of the foot (peroneus longus, peroneus brevis, and peroneus tertius) promotes an imbalance that induces the return of the downward (equinus) and inward (varus) position of the foot. Recent studies suggest that when poor evertor muscle activity is identified in infants with clubfoot, there is a greater likelihood of recurrence and additional intervention for correction (Isaacs et al., 1977; Cordeiro et al., 2022).

Although CC is a condition that can be treated, the treatment process can be long and can involve multiple interventions. The standard approach to treatment, known as the Ponseti method, typically includes a series of manipulations and castings. After this, patients often need to wear a brace for several years to prevent the condition from recurring (Radler, 2013; Agarwal, 2022). In some cases, surgery may be necessary (Li and Myerson, 2022). The treatment process can place a significant emotional and financial burden on families Walter et al. (2020). In regions with limited access to healthcare, children with untreated clubfoot may face social stigma and have limited opportunities for education and employment in the future. This not only impacts the individual, but also has broader social and economic implications. If CC is not adequately or fully treated, it can lead to long-term complications such as chronic pain, arthritis, and difficulty walking. Consequently, further medical intervention may be required, which can affect an individual's ability to work and perform daily activities (Hopwood et al., 2023).

To summarize, CC poses a significant issue as it has the potential to result in physical disability, discomfort, and social and economic difficulties. It is of utmost importance to provide prompt and efficient treatment to achieve optimal outcomes and reduce the risk of long-term complications.

3. GAME THERAPY

Game therapy, also known as therapeutic gaming or game-based therapy, is a therapeutic approach that integrates video games or elements of the game into the therapeutic process. This novel method has gained popularity and improved usage for several reasons. Game therapy utilizes the captivating and immersive nature of games to inspire patients, especially children and adolescents, who may not respond as well to traditional therapy techniques. Games can be designed to promote the development of particular skills such as problem solving, decision making, memory, fine motor skills, and emotional regulation. Games provide a secure and controlled environment in which individuals can experiment with different behaviors and strategies. Many games offer immediate feedback and monitor progress over time, which can serve as motivation and allow both therapists and patients to assess improvement. Games can be customized to address specific therapeutic objectives or to accommodate individual preferences, thus improving the personalization and effectiveness of therapy (Gradi et al., 2024).

Advancements in technology have improved the accessibility and effectiveness of game therapy. For example, virtual reality provides immersive experiences that facilitate exposure therapy and skill development. The prevalence of digital technology has made younger generations more

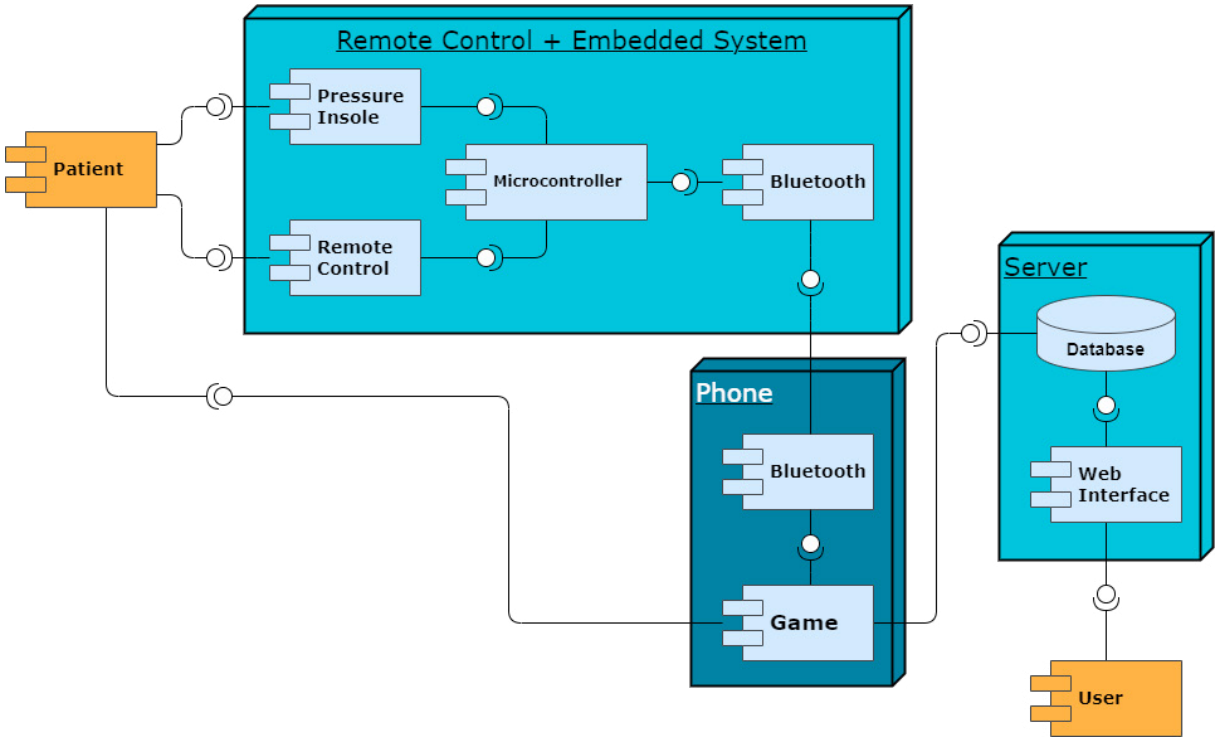

Fig. 1. Project's diagram of components. The patient acts directly to the embedded system which remote control the game. The cell phone has the game. The cell phone sends information to the server with the database. The user can access the web interface and the database.

inclined to engage with digital platforms, making game therapy an attractive option for them. Additionally, online and digital games can be accessed remotely, allowing therapeutic interventions for people who cannot attend in-person sessions, which has become particularly significant during events such as the COVID-19 pandemic. As gaming becomes more widely accepted and its potential benefits are increasingly recognized, there is a reduction in stigma and greater acceptance of incorporating games into therapeutic practices. Game therapy often integrates elements of physical and mental therapy, appealing to a more comprehensive approach to health and well-being (Tolks et al., 2024).

In summary, game therapy is a field that is constantly changing and connecting technology with mental health care (Wu et al., 2024). Its popularity is driven by advances in technology, a growing body of evidence showing its effectiveness, higher levels of engagement and accessibility, and a wider cultural recognition of the game as a valuable therapeutic tool (Shahmoradi et al., 2022).

4. METHODOLOGY

This section describes the requirements of the interactive game and the selection of its components.

4.1 Requirements

At the University Hospital of USP, the orthopedic team has identified a need for physiotherapy sessions with children. These sessions involve training the children to perform exercises that focus on external rotation of their feet. The exercises specifically target eversion and dorsiflexion movements. The main objectives of these exercises are to improve muscle and ligament strength, minimize adduction tendencies, reduce cavus and equinus conditions, and correct calcaneal varus.

To perform these exercises, an interactive game is proposed. As explained above, games are known to be engaging and immersive, making them an effective tool for game therapy. They help maintain motivation, prevent boredom, and offer ongoing challenges to overcome.

In cases of CC, it is essential for children to participate in activities that involve their affected feet. Consequently, the use of a remote control activated by foot movements becomes imperative. To facilitate this, an electronic system needs to be implemented that allows communication with the game via wired or wireless methods. Creating a mobile game appears to be the most feasible choice, as it offers greater accessibility, requiring only a smartphone instead of a computer or laptop. Lastly, it is crucial to store game data for future analysis and visualization by healthcare professionals who monitor patient progress.

Essential components for the project include:

- The mobile game;
- Enable wifi and/or Bluetooth technology for communication purposes.
- A database and web platform designed to store and visualize data that enables healthcare professionals to track the progress of therapy.

In addition, there is an ongoing initiative to create a pressure sensor matrix that can depict the advancement of weight distribution during the use of the assistive device. The enhancement of the evertor muscles and the correction

of CC contribute to an improved walking gait and the interaction between the foot and the ground.

Taking into account economic factors, particularly in public healthcare networks with limited distribution of orthosis, the production costs are significantly higher. Inclusion of an additional device in treatment unavoidably increases the costs of correction. Hence, the objective of the project is to implement a system that is both cost-effective and capable of fulfilling the intended functionalities.

4.2 Selection of Components

After understanding the requirements and specifications, the next step is to evaluate the existing models in the market for each type of solution. It is important to consider the scope of prototyping and find the most cost-effective, accessible, and time-efficient alternatives. In this case, the Arduino Rapid Prototyping ecosystem is found to be the most appropriate choice as it provides all the essential components for the embedded system. There is a diverse selection of commercial software available for game development in the electronic gaming industry. Unity software is the preferred choice because of its user-friendly interfaces, a variety of pre-designed objects that can be bought, and a thriving online community that makes the learning process easier.

There are many affordable and simple alternatives available for the database and web platform. In terms of the database, a SQL server was chosen to store patient data, registration information, future visit dates, and progress data from the game and pressure matrix. For the web platform, Flask, a modular framework for website development in Python, was used. Flask allows for the definition of address routes and determines which HTML pages will be displayed, as well as the allowed HTTP commands. The component diagram in Fig. 1 shows the interactions between the sets and when there is user interaction.

5. HARDWARE AND SOFTWARE

In this section, the development of a remote control and game-based therapeutic system is described that aims to enhance physical therapy for children with CC. The system integrates an MPU6050 accelerometer/gyroscope to detect motion and a custom-made pressure sensor matrix that utilizes Velostat to measure pressure. These components communicate through Bluetooth and I2C protocols to transmit data to computing devices. The design of the system includes a rotary joint and a slipper-shaped remote control, which facilitate physical therapeutic exercises such as eversion and dorsiflexion of the feet. In addition, a web interface called Hofeet Portal was created using Flask, providing healthcare professionals with a tool to manage patient data. To complement the hardware, a 2D Unity game called “Bam-boo!” was specifically designed for children. This game incorporates therapeutic activities that help correct CC, engaging the patient in a fun and beneficial way.

5.1 Embedded System

The remote control will be equipped with an MPU6050 accelerometer/gyroscope sensor. This sensor is capable

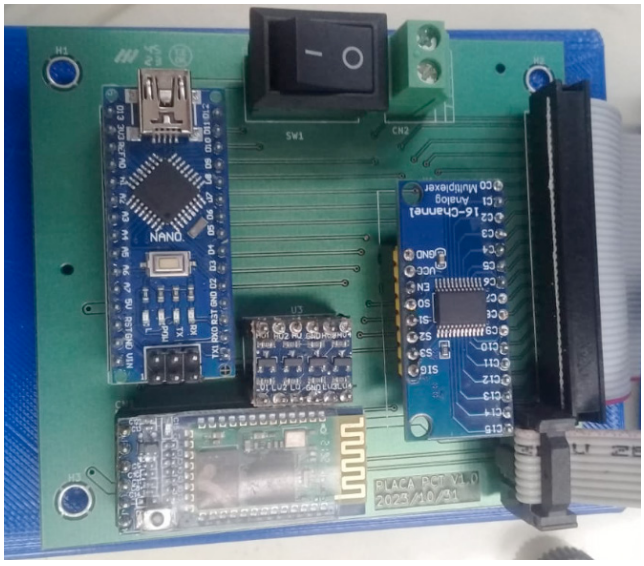

Fig. 2. The printed circuit board (PCB) has Arduino components connected to it. The Arduino, Bluetooth, and other components can be seen on the PCB. There are two cables coming out of the PCB, one wider cable for connecting to the pressure sensor matrix and another narrower cable for connecting to the accelerometer.

of measuring the acceleration of an object, allowing determination of both the direction and magnitude of the acceleration. The MPU6050 has its own calibration setup and communicates using the I2C protocol, which uses two channels. In addition, a Bluetooth communication module will be incorporated into the remote control to enable wireless transmission and reception of data. This module will be utilized to transmit data from the accelerometer, the gyroscope, and the pressure sensor matrix to a computer or mobile device. The printed circuit board (PCB) with Arduino components attached is shown in Fig. 2.

There are various models of pressure sensor matrices available in the market, but their fixed sizes pose challenges in fitting them into the inner sole of the orthosis, making their implementation complicated. Another option is to use individual point pressure sensors that operate on the same physical principle. However, this approach would limit the number of connections that can be accommodated by the Arduino prototyping board. Given this situation, it was decided to construct a pressure sensor matrix using the principle of piezoresistivity. Velostat, a material composed of carbon embedded in a layer of elastomeric polyester, proves to be a suitable alternative as a piezoresistive material. It is commonly used as a pressure-sensitive layer where the carbon layers come into contact and alter the electrical resistance of the material, enabling pressure detection.

In order to construct the sensor, it is essential to utilize copper tape or uninsulated wires to arrange in rows and columns, as illustrated in Fig. 3. The Velostat sheet is positioned at the intersection of these terminals, creating a matrix of contact points, resembling three layers between a terminal, the Velostat layer, and another terminal. By connecting all the pins to the Arduino, it becomes feasible to apply a voltage of 5V to a row or column. When

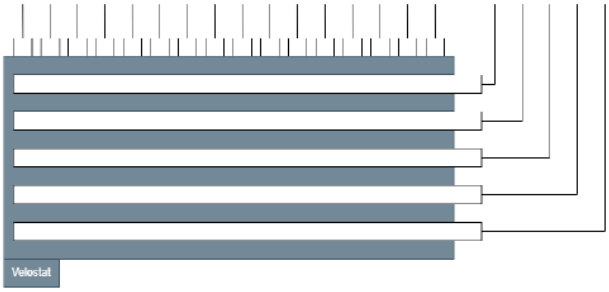

Fig. 3. The pressure sensor matrix is illustrated in the schematics. A sweep is conducted across the vertical and horizontal lines to establish the points of contact between them.

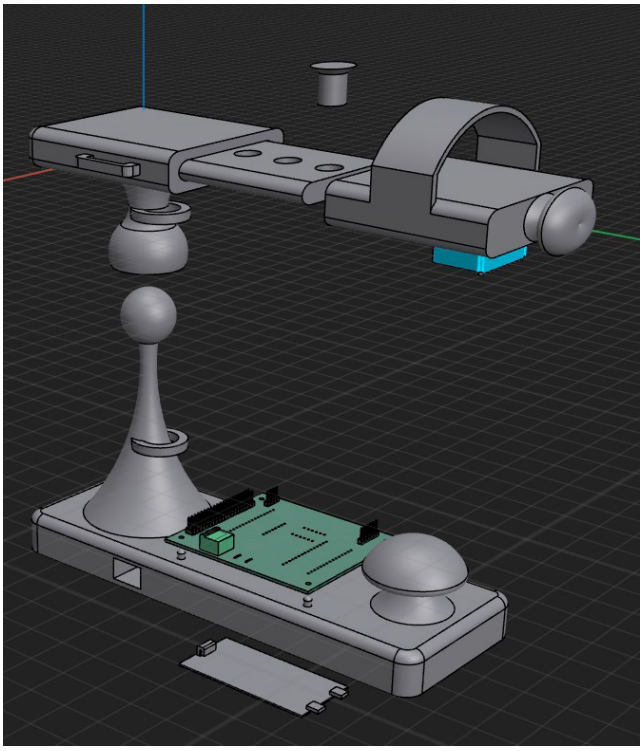

Fig. 4. The 3D model displays the remote control. The PCB is highlighted in green, and the MPU6050 sensor is shown in blue. Foot movements are executed using the upper part of the remote control, which are then detected by the MPU6050 sensor.

conducting analog reading on the same pin, the resistance value or the measured mechanical load at a specific point can be obtained. Consequently, to measure this value across the entire matrix, a multiplexer is employed to automatically scan all the columns. It activates one row at a time, resulting in the distribution of weight across the entire matrix.

Therefore, a concept was developed to utilize a rotary joint connected to a base that would be connected to the slipper-shaped remote control. This arrangement enables the patient to conveniently wear the orthosis boot. To provide mechanical resistance for the desired movement during interaction with the game, an elastic band will be fastened to the front end. The elastic coefficient of the elastic band can be evaluated. This will facilitate the proper execution of physical activity. The design was performed in the CAD system Shapr3D and then manufactured using the PLA+ additive manufacturing (see Fig. 4).

5.2 Web Interface and Database

The Hofeet Portal is a web interface that was developed for the purpose of testing database query requests. It provides healthcare professionals with an organized presentation of information, allowing them to check, edit, or add patient data in their workplaces. The website was built using the Flask microframework in the Python programming language. By utilizing Flask, the project benefits from its architectural simplicity, enabling rapid development without requiring extensive configurations. Additionally, Flask offers customization options, enhancing the overall robustness of the portal.

By analyzing the data sent from the device, including the elastic coefficient of the band, the foot movement history recorded by the accelerometer, and the gyroscope data, it is possible to determine the amount of force exerted by the foot.

5.3 The Game

In the game, players control a panda that needs to eat the food prepared by its parents to grow strong and healthy. The player can move his foot up, down, left, and right to move the panda. However, the presence of ghosts and the fear of the panda make this task challenging. The game follows certain rules: the panda, named Bam, needs to move around the screen and collect the food that appears periodically. The level is considered complete when Bam's stomach bar is full. However, eating spoiled food will decrease the progress bar. Additionally, after a certain amount of time, a ghost will appear on the screen and chase Bam, trying to scare him. Bam has a limited number of lives, and if he loses them due to ghost scares, he will run away scared and the game will end.

6. CONCLUSIONS

This study introduces a novel game-based therapy system to improve CC treatment in children, improving their mobility and quality of life. Despite the effectiveness of the Ponseti method, it faces challenges, prompting the development of a system that combines an embedded system with motion detection and pressure measurement to motivate children's active participation through engaging games. Using an MPU6050 sensor and a Velostat-based pressure sensor matrix, this approach facilitates the precise monitoring of therapeutic exercises. The Hofeet Portal, built with Flask, allows healthcare professionals to efficiently manage patient data and tailor treatments. Focused on affordability, especially in public healthcare, the project uses Arduino and Unity to ensure accessible and efficient treatment, showing the potential for broader physiotherapeutic applications in pediatrics. This integration of game therapy and custom hardware aims to improve treatment compliance, reduce discomfort, and improve results, making the treatment process more positive

and interactive for children with CC, thus benefiting their physical and psychological well-being.

To summarize, this project that combines technology, healthcare, and gaming aims to tackle the intricate issues surrounding the treatment of CC. If successful, it could serve as a blueprint for incorporating technology into patient-focused care in the realm of pediatric physiotherapy.

A methodology for testing and validation was proposed to the Ethics Committee, including sample sizes, control groups, and statistical methods to ensure robust data that confirm system performance.

ACKNOWLEDGEMENTS

M. S. G. Tsuzuki is partially supported by CNPq (grant 306.123/2022–3).

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