EMG Based Serious Game
For Use in Stroke Rehabilitation

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Abstract. *This paper introduces a proof-of-concept for a serious game that uses electromyography (EMG) signals as input, with the aim of improving rehabilitation treatment for patients experiencing stroke sequelae. The prototype, developed with the Unity game engine, incorporates a low-cost hardware device for reading and processing EMG signals. Communication between software and sensor is enabled through Bluetooth using an ESP32 microcontroller. The prototype includes a secondary monitor with a virtual hand to emulate Mirror Therapy. The positive evaluation of a physiotherapist validates the project for future development.*
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1. Introduction

A research published by The Lancet [Feigin et al. 2021] shows that cerebrovascular accidents, better known as strokes, remain the second largest cause of death globally (11,6% in 2019) and the third place when considering disability-adjusted life years (DALY). The sequelae can vary among various motor, cognitive, and sensory impairments, with hemiplegia and hemiparesis being common clinical manifestations [Silva et al. 2021].

As part of physiotherapy, serious games have been used since the early 2000s as complements to more traditional treatments, as they can shift focus away from pain in an interactive way, which contributes to stroke rehabilitation [Latorre et al. 2020]. Studies also show that mirror therapy (where typically a mirror is used to reflect the image of the healthy limb instead of the affected one, to trick the brain into thinking movement has occurred without pain) can be used as another effective method in the treatment of post-stroke upper limb functionality [Silva et al. 2021].

One frequently used technology, by itself or within serious games, is electromyography (EMG) biofeedback. In treatments using EMG, muscle contraction activity is measured by sensors and provides some form of feedback to the patient, such as visual signals, allowing self-regulation. This method has been proven to be effective in stroke patients [Kim 2017]. However, the reality is that many studies in this field utilize expensive or limited-use equipment that only functions in specific situations.

This work shows the development of a proof-of-concept game that uses EMG biofeedback and elements of mirror therapy with the goal of contributing to the rehabilitation of post-stroke upper limb hemiparesis. The resulting prototype was tested by a physiotherapist to validate and guide future development of this project.

2. Related Works

There have been many works dedicated to better implement game-therapy and biofeedback for post-stroke rehabilitation. A group of researchers [Latorre et al. 2020] did an extensive review of such methods, showing the widespread use of regular video game consoles such as the Nintendo Wii and Xbox 360 for this kind of treatment, where they are effective even if not designed for this specific application.

The work of [Cyrino et al. 2019] shows an advanced serious game that uses the Myo armband and virtual reality with the goal of aiding in post-stroke paresis of the upper extremities, much like this project. Their work also suggests a high degree of customizable settings for game sessions, as treatment requirements and the level of impairment can vary between patients.

The Myo armband used by [Cyrino et al. 2019], and various other researches in this field, was also considered for this project. Unfortunately, the device was discontinued in 2018 and is no longer commercially available [Di Donato et al. 2019], which leads to alternative EMG solutions. One such solution is the MyoWare muscle sensor, a relatively inexpensive EMG sensor that can be used with a microcontroller such as the popular Arduino or the ESP32.

The paper by [Müller et al. 2020] studied the viability of the MyoWare sensor as an input method for serious games, concluding that it can achieve satisfactory results, given that the game does not require fast reflexes or precise movement, which aligns with the goals of the present work. Another article [Follmann 2019] makes use of the same sensor, applied in a serious game, to be used as part of the rehabilitation from upper extremity amputation. While this is not the same ailment as the one dealt with here, it is a similar application and suggests the same device could be used.

Another research [Ferreira de Lima et al. 2021] reviewed the use of virtual reality (VR) in post-stroke treatments, reaching the conclusion that it may significantly aid in the functional capacity of the affected limb, when paired with physical therapy. The study also shows that this benefit can be achieved both in immersive VR, as achieved by VR goggles, or non-immersive VR, achieved by the integration of a virtual environment and real elements with the use of a screen as in the present work.

3. Materials and Methods

The serious game here proposed has the goal of utilizing EMG biofeedback and elements of mirror therapy to aid in the rehabilitation of post-stroke upper limb hemiparesis.

To better understand how to achieve this goal, a physiotherapist was consulted for professional insight. She had ample experience in this field, and she already used commercial serious games with similar operating principles and application.

Hemiparesis often causes the patient to lose the ability to open his or her hand, resulting in a permanently clenched fist [Ou et al. 2020]. To address this, the game was designed to stimulate the user to engage the muscles responsible for this action.

The game presents the user with a fish character that goes up when the hand extensor muscles are contracted (in the attempt of opening the hand) and goes down as they relax. The hardware used to achieve this is described in Section 3.1, while the mechanics and development are described in Section 3.2. Also, a short questionnaire was created in order to collect the physiotherapist's impressions at the end of the project.

3.1. Hardware Devices

The EMG sensor chosen for this work was a MyoWare, a device made by Advancer Technologies, which can be seen in Figure 1. This sensor measures the electrical signals generated by muscles as they contract, via two surface electrodes to be positioned along a given muscle (the middle finger extensors in this project), while a third electrode is placed in a non-adjacent muscle or bony area, to provide reference.

Figure 1. The MyoWare muscle sensor, by Advancer Technologies

The sensor amplifies the muscle readings and treats them, modulating them in an analog voltage amplitude signal which can be easily read by another device, such as a microcontroller development board like Arduino or, the one used here, ESP32. The amplitude of the signal is defined by the supply voltage, recommended between 3.3V and 5.7V by the manufacturer.

The sensor presents the signal in two output modes: as a raw (though amplified) EMG signal or as an "EMG Envelope", where the signal is amplified, rectified and integrated, to work better with a microcontroller's analog-to-digital converter [Advancer Technologies 2015]. The difference between those signals is presented in the device datasheet, as seen in Figure 2.

The product's datasheet states that it can be powered directly from the microcontroller board while the board itself is grid powered, but this configuration may create a current loop. Testing shows this to be true, causing a situation where the microcontroller reads the signal constantly at the maximum value. This directed the authors to choose an ESP32 as the microcontroller board, as it includes Bluetooth, allowing for wireless communication with the computer game, while the hardware is powered by batteries, circumventing the current loop problem. Initial hardware prototyping can be seen in Figure 3 where a powerbank is used as the power source, with the sensor placed on the arm of one of the authors.

To hold all this hardware in a way that could be worn comfortably by the user, while positioning the electrodes in the correct place, a flexible bracer was designed and 3D printed in thermoplastic polyurethane (TPU), as can be seen in Figure 4.

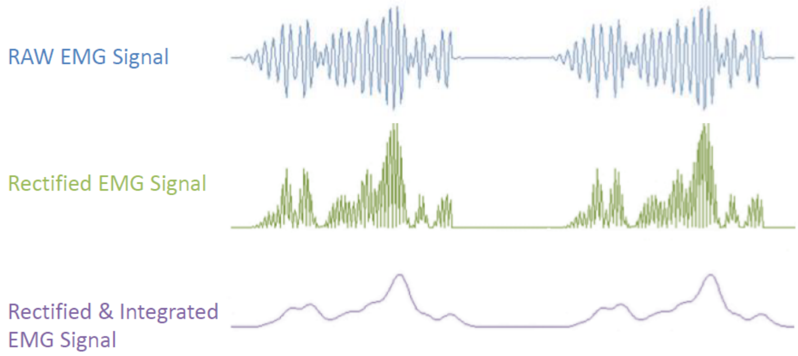

Figure 2. Representative EMG signal in different stages of treatment

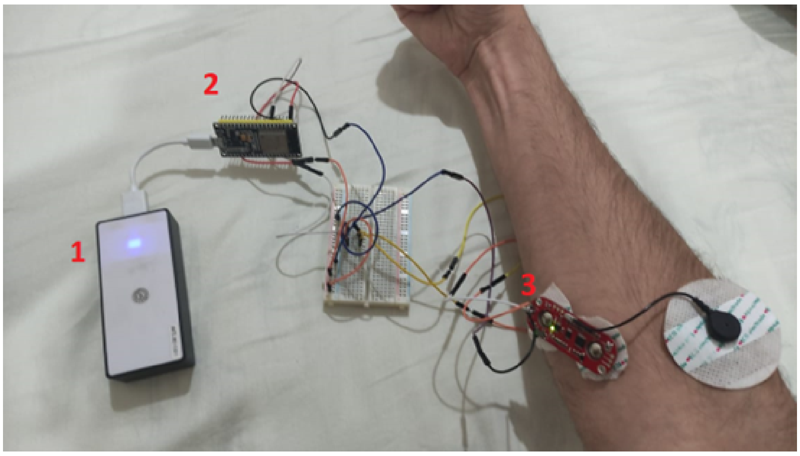

Figure 3. Initial hardware prototyping, where 1 is the powerbank, 2 is the ESP32 microcontroller and 3 is the MyoWare sensor

3.2. Game Development

In order to stimulate the user in engaging the muscles responsible for opening the hand, the serious game was designed to use EMG signal from this muscles as input. As this represents a single variable, the user controls the game's character (a fish) up, by trying to open their hand or down, by relaxing it. Meanwhile the scenario automatically scrolls from right to left. As a game goal, and to measure user accuracy, coins are spawned from the right side of the screen at random heights, and the player scores points when collecting them. The game at this stage is represented in Figure 5, inside the Unity game development engine.

The communication of the sensor's reading (described in Section 3.1) to the game itself is done via Bluetooth, through a plugin called "Arduino Bluetooth Plugin", available in Unity's Asset Store. The plugin's C# code connects the device's Bluetooth to the game and parses the serial transmission into discrete messages, converting them into variables that can be used by the game code.

As ESP32 uses 12 bit variables, the EMG readings are presented as an integer between 0 and 4095, a lower value when the muscle is relaxed and a higher value when contracted. The readings can be transmitted by the microcontroller as fast as its cycle speed, at 240MHz, while the game code is processed once per frame (usually between

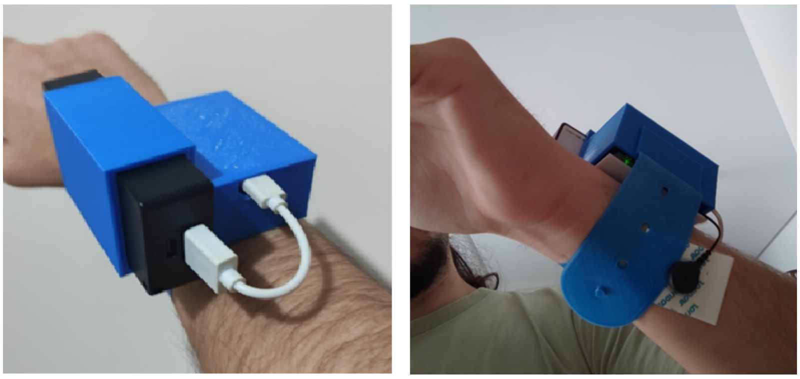

Figure 4. 3D printed bracer, on author's arm

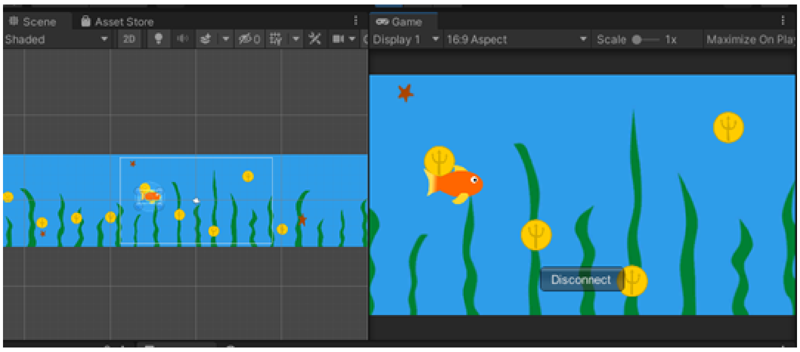

Figure 5. First version of the serious game, editing view on the left and gameplay on the right

30 and 60Hz). This discrepancy in speed can cause the messages to pile-up, resulting in increasing delays between user input and game response. To remedy this, a delay of 100 milliseconds was programmed between messages in the ESP32, keeping their frequency lower than the game's capacity to read them. Also, in order to filter out abnormal spikes in the readings, a moving average was implemented in the ESP32's code.

The first version of this project, EMG readings (from 0 to 4095) were directly mapped to the vertical coordinate of the fish (from -4 to 4). This related the EMG signal's value to the character's height on screen, so the fish would be higher the more the user contracted their muscle, and lower the more the user relaxed. This approach resulted in unnatural flicker, as the EMG signal could vary drastically between frames and result in the fish to "teleport" around the screen. This was remedied by using a method where the readings were mapped to a destination coordinate, and the fish then would move towards this destination with a set velocity.

Although this version resulted in a smooth and intuitive user experience, especially when tested in larger muscles like the biceps, fine contraction coordination seemed harder to achieve with the hand extensor muscles. Also, as [Cyrino et al. 2019] suggested in their work, parameter adjustment might be necessary as different patients suffer from different conditions.

Because of this, a new character control method was implemented. Much like the game "Flappy Bird" [Nguyen, Dong 2013], the new code rises the fish when the user contracts their muscle, and lets the fish lower by itself, according to in game "gravity", when the user relaxes. The threshold to activate this is set by default at 50% of the EMG's reading amplitude, but can be adjusted in the game's options menu, seen in Figure 6. To adjust the game session according to the patient's needs, there are also settings for the length of the game, the speed coins move on the screen and the interval between coin spawns.

Figure 6. Game options menu

To emulate mirror therapy, a virtual hand is displayed on a second monitor. Based on the same EMG signal that governs the fish's movement, it will open when the appropriate muscle is engaged and close when it is relaxed, even if the user's real hand cannot perform this motion perfectly (which is often the case, and can cause frustration). During the game session, the second monitor is positioned on top of the patient's heal hand, taking its place on the user's point of view. The game's two screens can be seen on Figure 7, side by side.

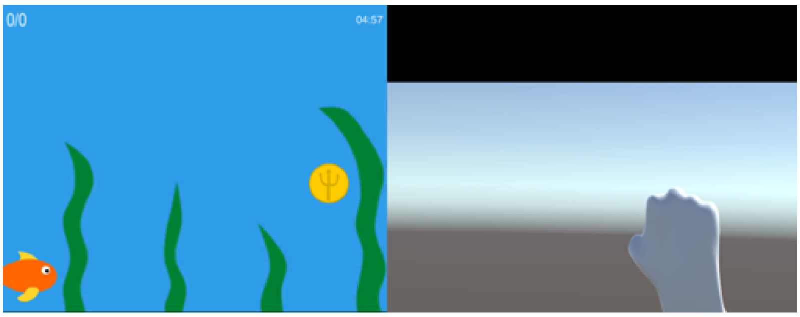

Figure 7. Game's screen capture, displaying the game itself on the left and the virtual hand on the right

The score is determined by the number of coins collected against the total number of coins that crossed the screen (the sum of collected coins and the ones that passed by, uncollected). As it can be seen on Figure 7, the score and a timer are displayed on top of the main screen, this last one counting down to the predetermined end of the game, when the game stops and displays the end screen seen in Figure 8, on the right. Pressing the "esc" key during game will pause it and display the pause screen, also seen Figure 8, to the left. Both screens display the score and its percentage to determine user accuracy during the game session. They also display buttons to quit to the main menu or restart the game with the same settings, the pause screen also displays the "resume" button, to resume the current game.

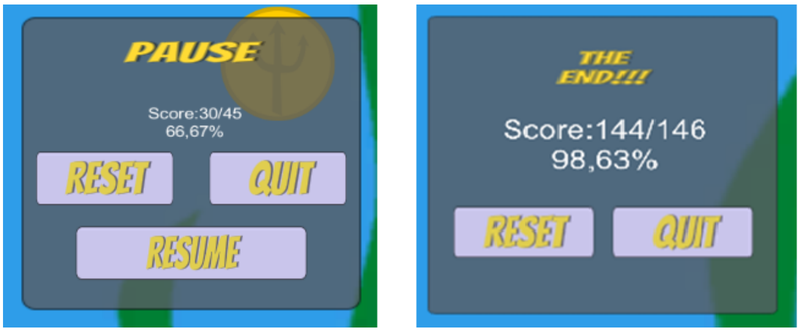

Figure 8. Pause screen and end screen

4. Testing and Results

At the conclusion of the game's development, it was presented to the physiotherapist Janaína Cardoso Costa, the same health professional consulted during the initial phases of development, who had previous experience with commercial serious games with similar goal, and works on rehabilitation of post-stroke patients. She was given the opportunity to test the game herself, as seen in Figure 9. This Figure also shows how the second monitor is meant to be placed, as described in Section 3.2, positioned on top of her real hand, taking its place in her point of view.

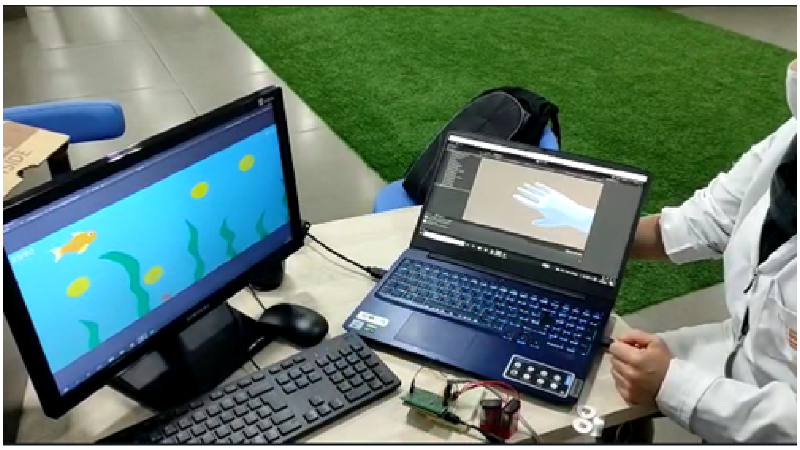

Figure 9. The game being tested by physiotherapist Janaína C. Costa

At the end of testing, the following interview was conducted, translation to English by the authors:

Interview with physiotherapist Janaína Cardoso Costa

Q: Did you have prior experience with this type of serious game?

A: I had experience because I have been working with this kind of technology for over five years.

Q: What was your first impression of the presented serious game?

A: I had a great impression; I found it to be a more interactive game than any that I have encountered so far.

Q: Are the sensors with their respective electrodes comfortable to use?

A: The sensors are very comfortable and do not cause any discomfort to the patient.

Q: Was the response time between muscle contraction and character movement adequate?

A: The response was adequate.

Q: Is the game interface intuitive? Are the objectives and scoring system stimulating?

A: I found the interaction with the patient very interesting; it provides active stimulation.

Q: Are the sensitivity and difficulty settings of the game sufficient to accommodate different stroke patients? Are there suggestions for adjustments to be included in future versions?

A: The settings are excellent and cater to stroke patients. In future versions, I suggest incorporating a robotic hand that can offer more interactive mirror therapy.

Q: What is your opinion on the virtual hand represented over the real hand of the patient? How does it compare to traditional mirror therapy?

A: This virtual hand can be compared to mirror therapy since the patient has the impression that their hand, which has difficulty moving, is opening and closing.

5. Final Considerations

The resulting prototype achieved the goals set at the start of the present work, being a proof of concept of a serious game based on EMG, aimed at rehabilitation of post-stroke patients suffering from upper limb hemiparesis. The feedback from a physiotherapist validates further development and suggests what elements would be valuable if implemented.

The concept of a robotic hand orthosis that could be integrated with the serious game, in place of the second screen, is promising, and research was started in this direction. Assistive gloves, both passive and active, are of common usage in this type of treatment, but the basis of the technology used to develop a EMG based robotic glove, such as the mechanical project and advanced signal interpretation, might also be used for applications such as prosthetic hands.

A second approach to further develop this project is the implementation of immersive virtual reality, keeping the fish screen on a virtual monitor, but implementing the mirror therapy element of the virtual screen on the VR avatar. This implementation was started and a screen capture is shown in Figure 10.

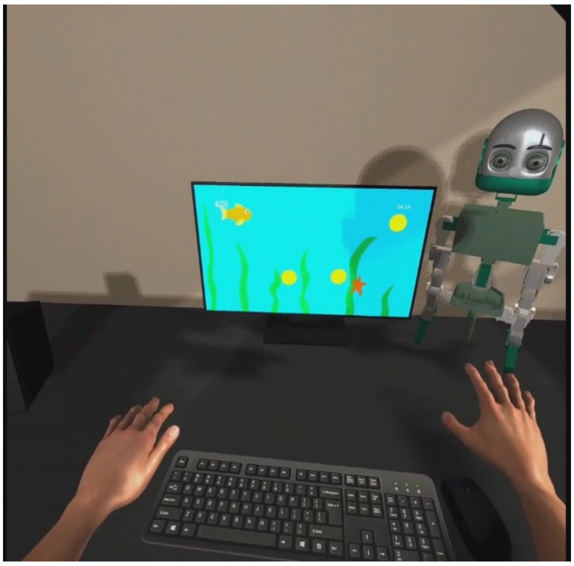

Figure 10. Initial prototyping of a VR version of the serious game

Minor adjustments such as sound, better graphics, and better interface are to be made, as well as improvements in hardware. Testing shows that both sensor reliability and Bluetooth connectivity may be lacking with the present devices, suggesting that alternatives should be analyzed.

However, any future development of this project also calls for rigorous clinical testing with groups of post-stroke patients, to correctly access their response to the addition of such a serious game in their treatment.

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