Musical Super Matrix: Hardware-Based Hand Rehabilitation Game

Abstract—Background: "The hand is the visible part of the brain" - Immanuel Kant

Just as Kant proposed, the hand is a crucial extension of the mind. It's not just about physical function – gripping, grasping, and manipulating objects – but also about how we interact with and understand the world. Our hands act as an extension of our senses, allowing us to explore and perceive details through touch. They can even communicate our emotions and intentions in ways that words sometimes can't. When hand function is compromised by war injuries, it significantly impacts not only daily activities but also our ability to connect with the world around us. [1]

Problem Definition: Millions of individuals worldwide struggle with the lasting effects of war-related injuries. These injuries often result in a combination of musculoskeletal and cognitive impairments. Musculoskeletal impairments can manifest as limitations in hand and upper body strength, dexterity, and coordination. Cognitive challenges can encompass memory deficits, slowed information processing, attention difficulties, and problems with abstract thinking. These combined impairments significantly hinder a person's ability to perform daily activities, impacting their independence, self-sufficiency, and overall well-being. Traditional rehabilitation programs for these impairments often lack engaging elements, leading to low patient motivation and adherence. This can significantly limit the effectiveness of therapy and hinder long-term patient outcomes.

Objectives: The rehabilitation aspect of the game will involve tasks designed to improve hand dexterity, range of motion, strength, and coordination.

The cognitive aspect of the game will integrate elements that target memory, attention, processing speed, and executive function.

Keywords—Rehabilitation, Upper extremity, 3D printing

I. Introduction

The upper extremity, particularly the hand, plays a pivotal role in human function. It enables us to grasp and manipulate objects, perform intricate tasks like writing, and interact with our environment. Unfortunately, a significant portion of the global population experiences hand dysfunction due to war-related injuries. Recovering from such limitations can be a significant challenge, often requiring lengthy and expensive traditional rehabilitation programs that may not be readily accessible to all patients.as multi-leveled equations, graphics, and tables are not prescribed, although the various table text styles are provided. The formatter will need to create these components, incorporating the applicable criteria that follow.

These challenges are further compounded by the high prevalence of co-occurring musculoskeletal and cognitive impairments among people with war injuries. Musculoskeletal impairments can manifest as limitations in hand and upper body strength, dexterity, and coordination [2]. Cognitive impairments can encompass memory deficits, slowed information processing, attention difficulties, and problems with abstract thinking [3]. The combined effect of these impairments significantly hinders a person's ability to perform activities of daily living (ADLs), impacting independence, self-sufficiency, and overall well-being.

Traditional rehabilitation programs for these combined impairments often struggle to maintain patient engagement, leading to decreased adherence and motivation, ultimately hindering therapeutic progress. Furthermore, these programs typically address hand function and cognitive function separately, neglecting the potential for integrated rehabilitation that can improve both areas simultaneously.

This project proposes a novel solution: a hardware-based game specifically designed to address both hand rehabilitation and cognitive rehabilitation for individuals with war-related injuries. This interactive game will utilize a 3x3 matrix interface to provide a fun and engaging experience that promotes recovery in both areas. By incorporating engaging elements, the project aims to improve patient motivation, adherence, and ultimately, achieve better overall rehabilitation outcomes.

II. Materials and Methods

A. Game Components:

The core component of the game will be a 3D printing 3x3 matrix interface designed to facilitate hand movements and interactions with the system. This interface will be connected to a microcontroller unit (MCU) that processes user input and controls the game logic. The MCU will be programmed using a language suitable for embedded systems development (C/C++).

To enhance user experience and reinforce successful actions, the game will incorporate a multi-modal feedback system. This system may include an LCD display for presenting visual information (e.g., time remaining, score), LEDs embedded within each cell to provide color-coded feedback, and a speaker for delivering auditory cues for successful or failed attempts.

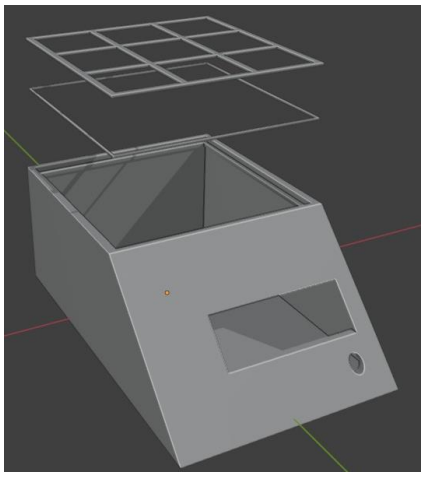

Figure 1: 3D printing game's layout

B. Methodology:

This section details the user experience within a chosen game mode and difficulty level, as determined by the supervising physician based on the patient's specific condition.

Stimulus Presentation: The 3D game matrix dynamically activates individual squares in a randomized sequence. These illuminated squares serve as the visual stimuli for the patient.

Patient Interaction: The patient, equipped with a handheld magnetic object, is tasked with aligning the magnet with each illuminated square on the matrix as it lights up.

Response Detection: The 3D game matrix utilizes the Hall effect principle to detect the patient's response. When the magnet is positioned correctly over a lit square, the Hall effect sensor registers the change in magnetic field. This detection indicates a successful patient response.

Performance Feedback: A successful response (magnet aligned with lit square) triggers a score increment. This score reflects the patient's performance within the chosen game mode and level.

Visual Feedback: The game likely provides visual feedback on the LCD screen, potentially displaying the updated score or other performance metrics relevant to the chosen mode.

C. Game Modes:

Time Mode: This mode introduces a time-based challenge. The supervising physician sets a specific time limit, and the user (patient) interacts with the game within that timeframe. The system then evaluates the number of "chips" (presumably stimuli) the user successfully processed during the allotted time.

Trials Mode: This mode enables the physician to define a pre-determined number of trials for the user to complete. This allows for a structured assessment and potentially facilitates data collection across multiple attempts.

Reaction Time Mode: This mode focuses on measuring the user's reaction speed. The physician sets a time threshold. If the user's response time to a stimulus exceeds this threshold, the game automatically terminates. This provides valuable data regarding the user's reaction capabilities.

D. Service Mode:

The game includes a dedicated service mode designed for maintenance and calibration purposes. This mode allows for:

1. Sensor Calibration:

Data Acquisition: The service mode triggers the acquisition of sensor data from the four integrated circuit (IC) Hall effect sensors. Each sensor reading is sampled 500 times.

Outlier Reduction: To mitigate the influence of potential noise or transient fluctuations, a statistical approach is employed. The average value is calculated for each sensor based on the 500 readings. This averaging technique reduces the impact of large variations in individual readings, leading to a more robust and representative sensor value.

2. Stored Value Mode:

Calibration Storage: Following successful sensor calibration, the calculated average values for each sensor are stored within the IC's memory. These stored values serve as reference points for future comparisons.

Data Integrity Verification: The service mode incorporates a data integrity verification function. This function retrieves the stored average values from the IC's memory and compares them against newly acquired sensor readings. Deviations beyond a predefined threshold flag potential corruption of the IC chip or its memory, enabling timely identification and repair or replacement.

III. Expected Outcomes

This project anticipates achieving the following outcomes: (1) Improved hand function: Through targeted exercises and challenges within the game, the project aims to enhance patients' hand dexterity, range of motion, strength, and coordination. (2) Enhanced cognitive function: By integrating cognitive elements, the game seeks to improve memory, attention, processing speed, and executive function in patients with war-related injuries. (3) Increased patient motivation and adherence: The engaging and interactive nature of the game is expected to improve patient motivation and adherence to the rehabilitation program, leading to better long-term outcomes. (4) Development of a cost-effective and accessible rehabilitation tool: The hardware-based game has the potential to be a more cost-effective and accessible rehabilitation tool compared to traditional methods, particularly in resource-limited settings.

IV. Conclusion

This project proposes a novel hardware-based game designed to address the combined challenges of hand and cognitive impairments in individuals with war-related injuries. By promoting recovery in both physical and cognitive domains, the game has the potential to significantly improve patient well-being and independence. The project's emphasis on gamification principles and user engagement aims to overcome limitations associated with traditional therapy, potentially leading to improved adherence and overall rehabilitation success.

References

[1] Rabinovich, R.V., Zbeda, R.M., Beldner, S., Polatsch, D.B. (2023). Rehabilitation of Hand Disorders. In: George, T.K., Mostoufi, S.A., Tria Jr., A.J. (eds) Orthopedic Rehabilitation. Springer, Cham.

[2] Banerjee A, Jadhav S, Bhawalkar J. Limitations of activities in patients with musculoskeletal disorders. Ann Med Health Sci Res. 2012 Jan;2(1):5-9. doi: 10.4103/2141-9248.96928. PMID: 23209982; PMCID: PMC3507122.

[3] Castaneda AE, Tuulio-Henriksson A, Marttunen M, Suvisaari J, Lönnqvist J. A review on cognitive impairments in depressive and anxiety disorders with a focus on young adults. J Affect Disord. 2008 Feb;106(1-2):1-27. doi: 10.1016/j.jad.2007.06.006. Epub 2007 Aug 20. PMID: 17707915.