

ECE445 Team 28

Project Proposal

Intelligent Square Stepping Exercise System for Cognitive-Motor Rehabilitation in Older Adults with Multiple Sclerosis

By

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1. Introduction

- Problem

Persons with multiple sclerosis (MS) may experience declines in balance, mobility, strength, sensory, cognitive and mental health function. In 2019, almost a million people were diagnosed as MS (Nelson et al., 2019).

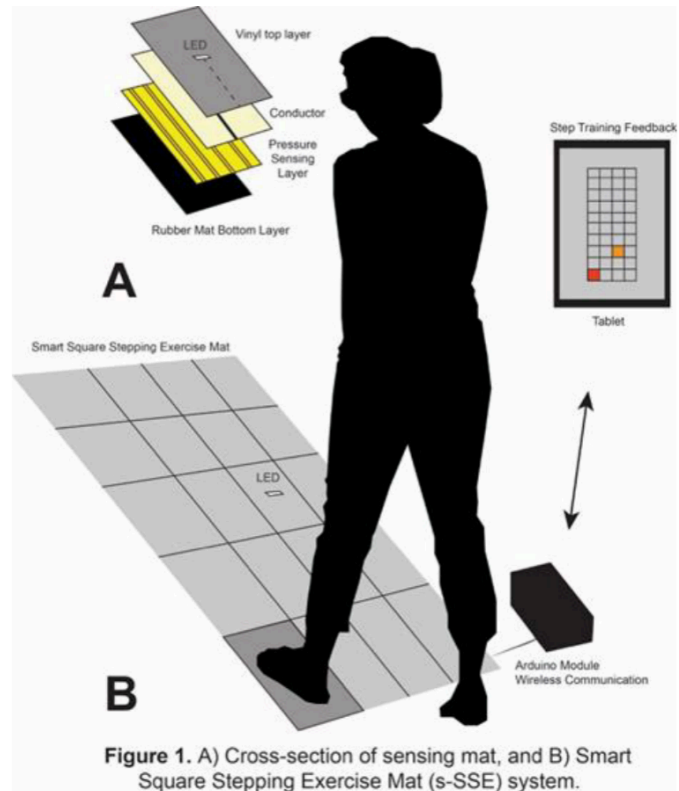
- Research shows that exercise training is associated with functional improvements in persons with MS (Sandroff et al., 2020). However, despite benefits, exercise participation remains low in persons with MS due to personal, environmental and societal barriers. Even though nowadays there are various devices for health people to monitor and aid their exercises, these devices may not be very suitable for people with MS. Therefore, there's a need to develop a system which specifically facilitates people with MS to do more physical exercise safely, thus helping them rehabilitate.

- Solution

The proposed solution is a smart exercise mat designed to facilitate physical exercise for individuals with multiple sclerosis (MS), aiding in rehabilitation. The mat integrates both hardware and software components, providing real-time feedback to users on their movement patterns. It addresses common barriers to exercise for MS patients by ensuring safe, guided exercise experiences that can be performed at home. This system will help users track their progress and provide tailored feedback based on their specific needs.

The system will consist of a multi-layered sensing mat, as depicted in the image, where each square on the mat can detect and analyze the user's steps or movements. The mat will be synchronized with a software application that interprets the data, offering insights into the user's balance, coordination, and overall mobility. We will use Arduino as the microprocessor in early stages, but will replace it by a custom PCB in the final product. The hardware, embedded with sensors, will communicate wirelessly with the software, which will be customizable to the individual's exercise regimen. The system is designed with at-home deployment in mind and could be refined through collaboration with an industry partner to ensure its robustness and user-friendliness.

- Visual Aid



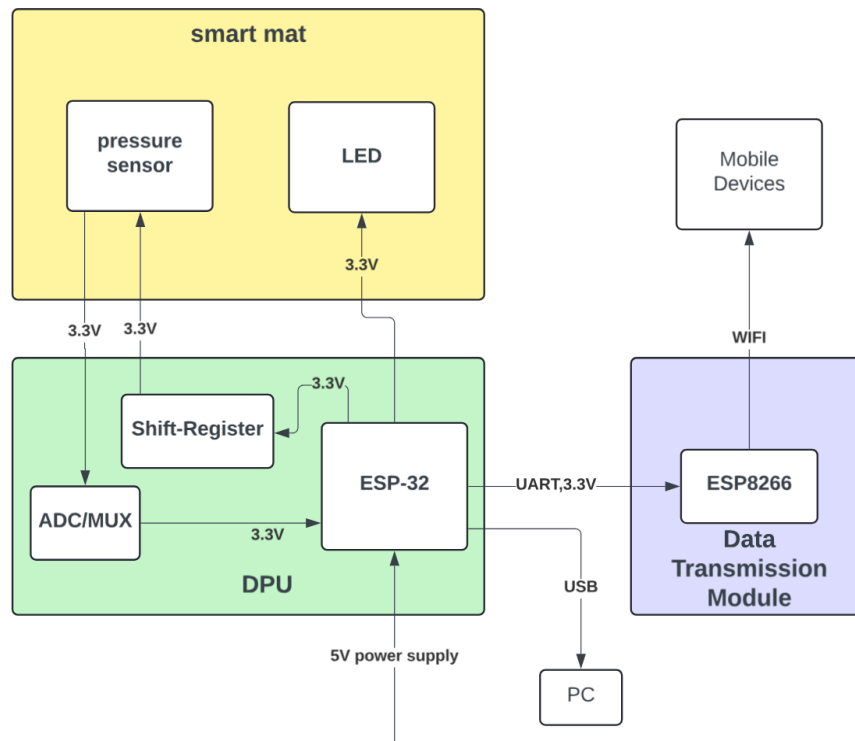
Source: Adapted from Dr. Hernandez's pitched project presentation

- High-level requirements

1. The mat must correctly detect stepping positions and time of users, with a minimum accuracy of 90%.
2. The system should provide feedback of the user's exercise within 10 seconds after each walk .
3. The mat should weigh less than 10kg and must be able to fold or roll.

2. Design

- Block Diagram



- Subsystem Overview

- **Smart Mat:** The smart mat serves as the primary interface for users. It consists of multiple 25cm x 25cm squares, with LEDs attached to each of them. The user will step on these squares following the instructions given by the LEDs (and mobile apps) to step these squares in a given order. In this way, the user can get exercised to rehabilitate. There are customized low-cost pressure sensors beneath the mat, which will provide raw data to the data processing unit.
- **Data Processing Unit:** This subsystem consists of a microprocessor, its peripherals, several multiplexores and shift-registers. Since we have to monitor 40 sensor cells using the limited pins of the microprocessor, we introduced a scanning method. We use the shift register to circle through all cells row by row, setting a copper stripe to high voltage each time. At the same time, we use a multiplexor to scan the cells column by column to monitor the output voltage. In this way, we can detect the time and location of a cell and when it was stepped on. The scan frequency is set to

8 HZ to reduce the number of samples to an appropriate amount, but this frequency is still high enough compared to humans' walking frequency. This unit also manages the communication with the data transmission module to send the analyzed data to connected devices. The accuracy and responsiveness of the data processing unit are essential for providing timely feedback to users.

- The DPU should run on at most 5V, which means it can be easily powered by a conventional USB wire with a power adapter.
- Data Transmission Module: The Data Transmission Unit is responsible for sending the processed data from the Data Processing Unit to external devices, such as a mobile app or computer, for user feedback and analysis. This subsystem will use wireless communication technology to transmit real-time information about the user's movements on the mat, allowing them to receive instant feedback on their performance and progress. For our design, we will use Wi-Fi or Bluetooth communication protocols, depending on the target platform and distance requirements. The ESP8266 SoC, which has built-in Wi-Fi and Bluetooth capabilities, will handle the data transmission.
- Software subsystem: The software is used as a user interface on mobile devices. Which can let users select exercise plans and give feedback to users. Since this is a pitched project, other group members outside of this class will work on the software for remote devices, including the user interface. We will not put too much effort into this part, while making sure it matches well with the hardware and firmware. Here's a flow chart of the current software design from the software group.

- Subsystem Requirements

Smart Mat

- Description: The smart mat must accurately detect foot pressure and movements using pressure sensors. It communicates with the data processing unit to transmit raw data and provides visual instructions via LEDs. We will custom pressure sensors to achieve low cost , light weight and deformation ability. The early prototype consisted of two layers of tinfoil grid, separated by a layer of insulator.
- Requirements:
 - o Must correctly recognize the position of users' feet.
 - o Must be easy to deploy and fold.
 - o Must withstand repeated use without performance degradation.

Data Processing Unit

- Description: This unit processes signals from the smart mat, converting them to digital format, and performs initial analysis of users' movement. It interfaces with the data transmission module for data communication.
- Requirements:
 - o Must process data with a latency of less than 5s.
 - o Should operate on a power supply from 7-12V.

Data Transmission Module

- Description: This module is responsible for sending data from the data processing unit to the user interface application using wireless communication protocols.
- Requirements:
 - o Must maintain a connection range of at least 10 meters.
 - o Should transmit data with a latency of less than 5 s.

Software subsystem

- Description: Provides a user interface on mobile devices, enabling users to select exercise plans and receive feedback. Although it is developed by another group, it must be well-integrated with the hardware and firmware.
- Requirements:
 - o The interface must effectively match hardware and firmware capabilities.

Tolerance Analysis

- **Risk Aspect:** In the smart mat design, a critical aspect is ensuring accurate detection of foot placement on the mat's individual blocks. A potential error arises when the user steps near the edge of a block, leading to a false positive (misinterpreting the step as on the block when it should be detected as not on the block).
- **Sensor Configuration:** Each block has three vertical copper strips with a layer of piezoelectric material underneath. Below the piezoelectric layer, there are three horizontally arranged copper strips, forming nine intersection points. When a foot presses down on any of these intersections, the resistance of the piezoelectric layer at the intersections decreases, copper strips above and below the piezoelectric material connect and conduct electricity.
- **Geometrical Definitions:**
 - Block area (B): Let the area of each block be a square, with side length s , so $B=s^2$.
 - Detection area (D): The area enclosed by the nine intersections formed by the copper strips.
 - The intersection points form a grid within the block.
 - Let the side length of the detection area be d , so $D=d^2$.
 - d must be smaller than s to prevent false positives near the edges of the block.
- **Valid Step Condition:**
 - A step is considered valid if the foot's pressure falls entirely within the detection area D .
 - The foot should activate one or more of the intersections inside D .
- **Error Definition:**
 - False positive: When a step near the block's edge is detected as being inside the detection area.
 - This happens when the foot overlaps the boundary of D but does not fully land inside D .
- **Mathematical Model for Tolerance:** To minimize edge errors, we can define a tolerance factor, t , representing the margin between the detection area and the block's edges.
 - Step Validity Condition: The detection area must be centered within the block with a margin to the edges.
 - The foot should land in an effective detection zone that excludes a buffer region of width t along the edges of the block.
 - This gives: $t = (s-d) / 2$
- **Design Constraints:**

- The detection area should be sufficiently smaller than the block area to avoid errors: $D < B$
- You can adjust t based on the desired sensitivity and precision of detection to minimize false positives. A larger t reduces the chance of errors near the edge but decreases the detection zone.
- **Risk Analysis:**
 - A large margin t reduces the false positives but may lead to missed steps if the foot falls near the boundary.
 - Too small t increases the chance of false positives, as pressure on the block's edge might trigger the intersections.

3. Ethics and Safety

- Ethical Issues

1. User Privacy and Data Security: Collecting user data for feedback and monitoring raises concerns about privacy and security. According to the IEEE Code of Ethics, engineers must ensure the privacy of individuals and protect sensitive data (IEEE, 2020). To mitigate this, we will implement robust data encryption, anonymization techniques, and ensure compliance with data protection regulations like GDPR or HIPAA. User consent will be obtained for data collection, clearly outlining how the data will be used.
2. Accessibility: Ensuring that the smart mat is accessible to individuals with varying degrees of mobility and cognitive function is crucial. The ACM Code emphasizes the importance of considering diverse user needs in technology design (ACM, 2018). We will involve users with MS in the design process to ensure usability and effectiveness across different levels of capability.
3. Misuse of Technology: There is a risk of the mat being misused, intentionally or unintentionally, leading to injuries or ineffective rehabilitation. The IEEE Code advises that engineers should avoid harm to others (IEEE, 2020). To address this, we will provide comprehensive instructions and guidelines for safe use, along with safety warnings in the user manual.

- Safety Concerns

1. Physical Safety: Users may be at risk of falling while exercising on the mat. To minimize this risk, we will ensure the mat has a non-slip surface and is lightweight enough to be easily repositioned for safe use.

Additionally, we will conduct user testing to identify potential hazards during exercise.

2. **Electrical Safety:** The integration of electronic components poses risks related to electrical safety. We will ensure that all components are properly insulated and that the mat is water-resistant to prevent short-circuits.
3. **Data Security:** With sensitive health data being transmitted, it is essential to follow cybersecurity standards such as the NIST Cybersecurity Framework (NIST, 2024). We will incorporate security protocols to protect against unauthorized access and data breaches.

Reference

[1] Association for Computing Machinery, “ACM Code of Ethics and Professional Conduct,” *Association for Computing Machinery*, Jun. 22, 2018.

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