ECE445 Team 28
Project Proposal

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

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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

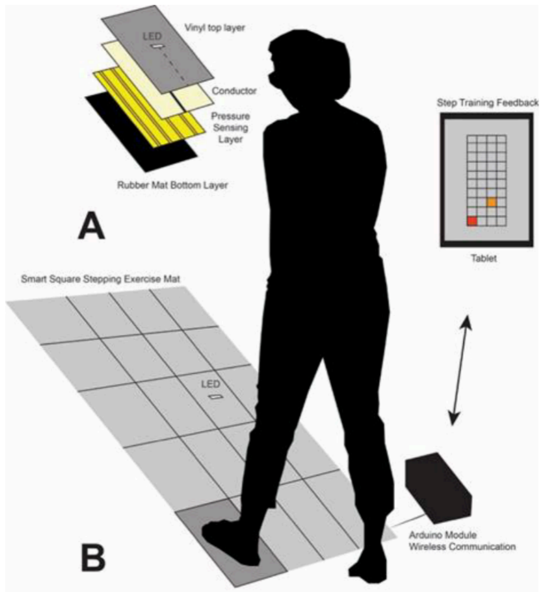


Figure 1. A) Cross-section of sensing mat, and B) Smart Square Stepping Exercise Mat (s-SSE) system.

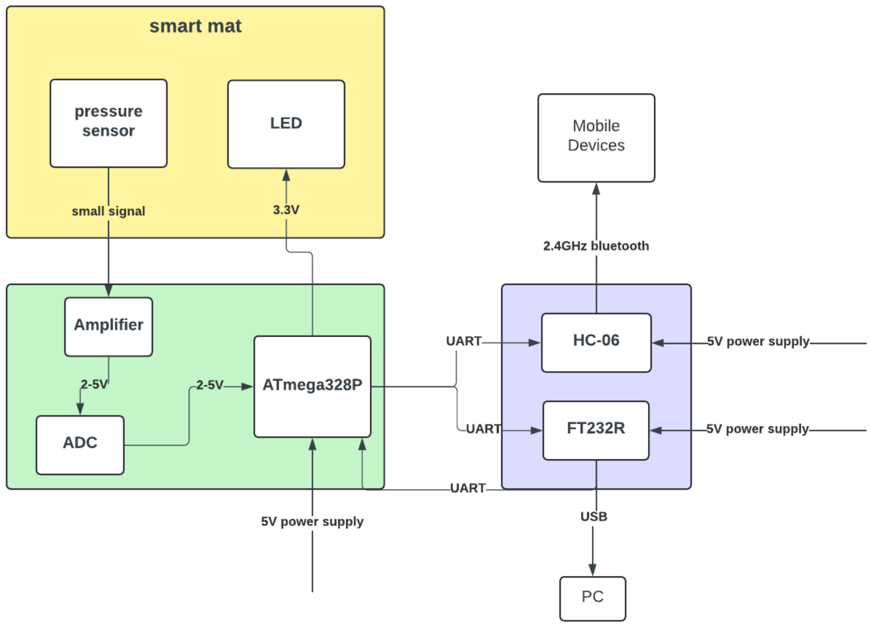
Source: Adapted from Dr. Hernandez's pitched project presentation

- 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 under the mat, which will provide raw data to the data processing unit,

- Data Processing Unit: This subsystem consists of a microprocessor and analog-to-digital converters (ADCs) that convert the analog signals from the smart mat's pressure sensors into digital data. 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.

- Data Transmission Module: The data transmission module is responsible for wirelessly sending the processed data from the data processing unit to smartphones or laptops. Utilizing protocols like Bluetooth or Wi-Fi, this module ensures that data synchronization occurs in real time, allowing users to view their exercise feedback right after they completed a set of tasks.

- **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:
  - Must correctly recognize the position of users' feet.
  - Must be easy to deploy and fold.
  - 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:
  - Must process data with a latency of less than 5s.
  - 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:
  - Must maintain a connection range of at least 10 meters.
  - Should transmit data with a latency of less than 5 s.

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).
- **Design Parameters**:
    1. Contact area (C): The area of the foot that is detected within the sensor's detection zone.
    2. Foot size (F): The area of the user's foot that makes contact with the mat.
- **Error Definition**:
    - A step is considered valid if less than 75% of the foot's contact area is detected within the sensor area of the block.
- **Mathematical Model**:
    1. Foot Size Initialization:
        - Set a default foot size (F)
    2. Valid Step Condition:
        - if $C \geq 0.75F$, the step is valid
        - If $C < 0.75F$, the step should not be detected as valid
    3. Block Edge Error Prevention:
        - To minimize false positives near the edge of the block, ensure that the detection zone is centered and does not extend beyond the block boundaries

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

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