Smart Mattress Pad for Tracking Pressure Injuries in the Geriatric Population

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***Abstract*—Medical technologies are transforming healthcare, yielding significant advantages. However, detecting pressure injuries in the elderly remains a challenge without efficient monitoring devices. In response, we introduced a novel pressure-sensitive mattress pad, discreet and user-friendly, catering to the geriatric demographic. Enabling continuous monitoring, this device facilitates timely interventions and improves patient outcomes, holding promise to elevate the quality of life for at-risk elderly individuals. This device also empowers caregivers and medical practitioners with these critical insights, as it lays the foundation for timely interventions, tailored treatment plans, and ultimately, improved patient outcomes.**

***Keywords*—medical technology, pressure injuries, pressure-sensitive mattress pad**

I. INTRODUCTION

The increasing global trend of population aging is leading to a growing concern, with various chronic diseases becoming the primary cause of death among the elderly. Many of these chronic diseases that afflict the elderly often render them bedridden, which in turn, gives rise to additional complications. However, in clinical settings, medical and nursing personnel face challenges in monitoring the elderly due to the difficulty of continuous surveillance. One of the issues commonly faced by elderly patients in hospitals due to their bedridden condition is the development of pressure injuries. Geriatric patients, in particular, are highly vulnerable to pressure injuries due to their decreased mobility, poor circulation, and frail skin. The consequences of pressure injuries in this population can be severe, leading to prolonged hospitalization, increased healthcare costs, and decreased quality of life [1]. Therefore, developing innovative solutions to address this health issue is imperative.

Pressure injuries are localized areas of damage to the skin and underlying tissues that occur due to prolonged pressure on a specific area of the body. This poses a significant clinical problem, leading to complications, increased healthcare costs, and prolonged hospital stays [2]. In the United States alone, there are over 2.5 million reported cases of pressure injuries annually, costing hospitals about $10,708 per patient to treat [1, 3].

Current technologies used in healthcare settings, such as ultrasound, thermography, subepidermal moisture (SEM) measurement, reflectance spectrometry, and laser Doppler, are effective in identifying pressure injuries [4]. Ultrasound plays a vital role by providing clinicians with detailed images of underlying tissues, aiding in the precise assessment of pressure-induced damage [5]. Thermography utilizes infrared imaging to detect variations in skin temperature, allowing healthcare professionals to identify potential pressure injury sites and monitor their progression [6]. SEM is a non-invasive technique that measures moisture levels beneath the skin's surface, providing early detection of tissue damage [7]. Reflectance spectrometry and Laser Doppler help evaluate tissue oxygenation and blood flow, respectively, offering valuable insights into the severity of pressure injuries [4]. However, the limitation inherent in all these devices lies in their capacity to only detect pressure injuries after they have developed, while their ability to prevent the occurrence of such injuries remains constrained.

The objective of this study was to create a Pressure Sensitive Mattress Pad, a functional pressure sensor-based device, that tracks pressure and actively prevents pressure injuries. This device was designed to detect pressure changes in a geriatric patient's body and provide real-time data to the healthcare team. By continuously monitoring pressure points, the device can alert healthcare professionals promptly, allowing them to take timely and appropriate action to prevent pressure injuries before they escalate into severe health concerns. The Pressure Sensitive Mattress Pad serves as a testament to the potential of interdisciplinary collaboration in healthcare to address critical challenges faced by aging populations. The original contributions to this project include:

- Hardware Design: The study presents a novel hardware design for the Pressure Sensitive Mattress Pad, incorporating advanced pressure sensors and materials to accurately detect and monitor pressure changes on the patient's body.
- Software Design: The research introduces an innovative software design that processes and analyzes data from the pressure sensors in real-time using MATLAB, allowing the device to promptly alert healthcare professionals of potential pressure injury risks.
- Design Engineering: This work showcases unique design to create an effective and practical pressure injury prevention solution for geriatric patients.

II. MATERIALS AND METHODS

A. Sensor Array Design

To address the problem of early detection and prevention of pressure injuries, we designed a pressure-sensitive mattress pad (36 x 50 in) using an innovative approach. The design consists of 10 rows and 6 columns of sensors, totaling 60 sensors arranged in a checkerboard pattern (Figure 2). This layout ensures comprehensive coverage of the mattress surface, allowing for accurate pressure monitoring across the entire area. Each sensor was integrated into a multiplexer circuit pattern, enabling sequential scanning of the sensors for precise readings. To make each sensor independent and reduce interference between neighboring sensors, we integrated diodes into the design. The diode allows current flow from the sensor's output to the multiplexer circuit, preventing current from the other sensors from affecting its output (Figure 2). We created a matrix of sensors. By selectively applying the voltage across specific rows and columns of the matrix, we effectively minimized interference between neighboring sensors while reading a specific sensor's data. This approach ensured the accurate collection of pressure data while maintaining the independence of each sensor. By selectively activating and deactivating the voltage for individual rows and columns, the system could precisely measure pressure levels from each sensor without cross-talk or interference from adjacent elements.

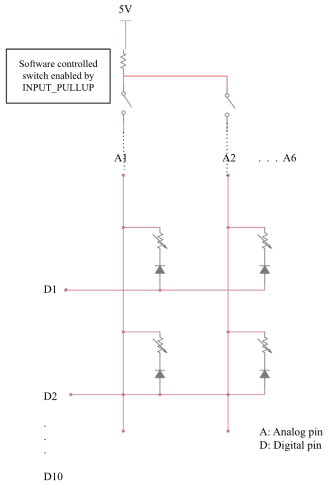

Figure 1: Schematic layout of the pressure-sensitive mattress pad, showcasing a multiplexer design with 10 rows and 6 columns of sensors arranged in a checkerboard pattern

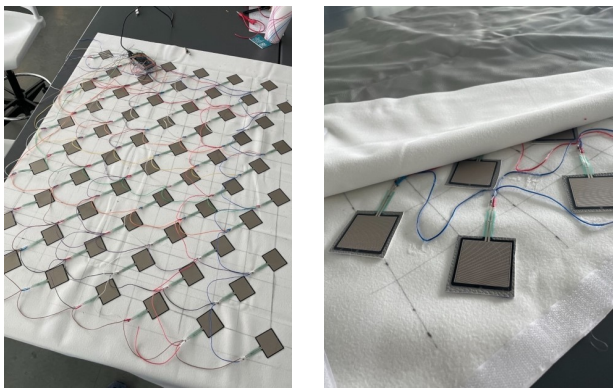

Figure 2: Sensor array designed in a checkerboard pattern

B. Data Acquisition Unit

To ensure rapid processing and precise control of the pressure-sensitive mattress pad, we selected and integrated the Arduino Due microcontroller as the central control unit. This high-performance microcontroller serves as the brain of the system, managing and coordinating the operations of the entire setup. The sensors used in the mattress pad are varying resistors based on pressure, and the Arduino Due is specifically designed to interface with such sensors efficiently with large number of input-output pins and higher operating frequency.

Each row of sensors is connected to a digital pin, and each column is connected to an analog pin on the Arduino Due. The program running on the microcontroller employs a technique where it activates one row at a time and deactivates one column at a time. By doing so, it reads the voltage values from each sensor through the analog pins. These voltage values correspond to the pressure levels detected by each sensor on the mattress pad. The acquired pressure data from the sensors are directly transmitted to the MATLAB software, which acts as the interface for data analysis and visualization. This seamless data transfer pathway established between the Arduino Due and MATLAB facilitates efficient data synchronization and storage.

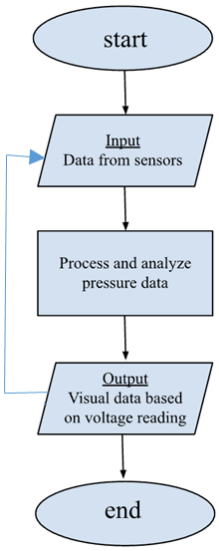

Figure 3. Illustrating the sequential scanning technique used in the pressure-sensitive mattress pad system. The acquired pressure data is transmitted to MATLAB software for efficient data synchronization, analysis, and visualization. This process is repeated until the user stops the system.

To reduce circuit complexity and simplify the connection setup for the pressure-sensitive mattress pad, we utilized internal pull-up resistors available in the Arduino Due microcontroller. Typically, the sensors used in the mattress pad are varying resistors based on pressure, and they require a stable voltage reference to function correctly. In a traditional setup, external pull-up resistors would be needed to maintain a stable high voltage (logic 1) and create a voltage divider circuit on the digital pins connected to the rows of sensors when they are not actively driven. This ensures that when the sensor is not being pressed (open circuit), the voltage on the pin is consistently at a logic high level, and when the sensor is

pressed (closed circuit), it tries to pull the voltage down to a logic low level.

The Arduino Due microcontroller has built-in internal pull-up resistors that can be enabled on each digital pin. By configuring these internal pull-ups, we eliminate the need for external pull-up resistors, reducing the number of components in the circuit and simplifying the wiring. To enable the internal pull-up resistors, we set the corresponding digital pins to INPUT_PULLUP mode in the Arduino program. This configuration ensures that when the digital pin is not actively driven, it is pulled up to a logic high level internally. When the row is activated, the sensor's varying resistance will then pull the voltage down, and Arduino can detect this change as a logic low, indicating that the sensor has been pressed.

Using internal pull-up resistors also helps in reducing potential noise and interference that could affect sensor readings, as the internal pull-ups have relatively low resistance values. This contributes to more stable and accurate readings from the pressure sensors. By leveraging the internal pull-up resistors in the Arduino Due, we achieve a more streamlined and efficient circuit design for the pressure-sensitive mattress pad, resulting in rapid processing and precise control of the data collected by the sensors.

C. MATLAB Software

MATLAB serves as the primary platform for data visualization and analysis. The dynamic nature of our pressure-sensitive mattress pad relies on the relationship between pressure and resistance. Each sensor exhibits varying resistance in response to the pressure applied, resulting in fluctuating voltage readings. MATLAB's customized software program accurately visualizes the pressure distribution on the mattress pad, precisely matching the checkerboard pattern of the sensors. The pressure values recorded by the sensors are visualized using a color-coded representation based on the corresponding voltage values. This representation allows for intuitive identification of high-pressure areas, aiding in detecting potential risk areas and implementing proactive prevention strategies (Figure 4). Additionally, MATLAB stores the acquired pressure data, providing a valuable resource for further analysis and signal processing. This data is saved and recorded through MATLAB's GUI app design which allows making functions and customizing app for analyzing the pressure data.

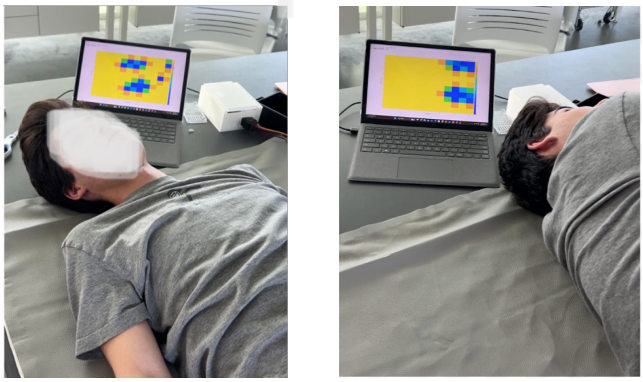

Figure 4. Image of device capturing and measuring the pressure at each position, a) participant sleeping on their back b) participant sleeping to their side. The results are visualized and displayed on a screen in real-time

D. 3D Print and Final Design

For optimal design, we implemented a 3D printed solution using Fusion360. The 3D printing technology allowed us to create a precise and customizable box for storing all components including the Arduino Due, circuit boards, and connectors. This approach contributed to the ease of manufacturing and assembly of the pressure-sensitive mattress pad. Additionally, to enhance the device's practicality for clinical settings, we designed printed circuit boards as featherboards, equipped with connectors that facilitate easy connection and disconnection of the device. The sensor circuit is placed between two layers of waterproof and cleanable PVC faux leather pads, ensuring convenient cleaning and disinfection between patient uses, thus maintaining hygiene standards.

Figure 5. 3D printed circuit board serving as a featherboard connection between the sensor array and Arduino Due

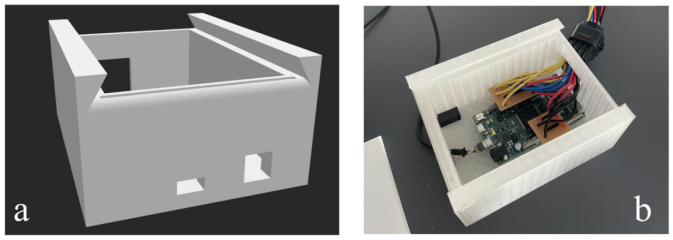

Figure 6. a) 3D box designed using Fusion360 b) 3D box printed to store microcontroller and components

III. RESULTS AND DISCUSSIONS

During internal testing, the prototype successfully detected pressure points and portrayed them on a screen according to the point of activation, confirming the functionality of the sensor array and data acquisition unit. A variety of sleeping positions were tried, ranging from the supine to lateral orientations and the device captured their positions, as depicted in Figure 6. This interplay between the pressure-sensitive mattress pad and the participants' postures demonstrated the device's adeptness in accurately monitoring pressure distribution throughout the testing sessions. By providing real-time data to healthcare professionals, this device allows them to take timely and appropriate action to prevent pressure injuries before they escalate into severe health concerns.

The use of the Arduino Due microcontroller as the central control unit ensures efficient data management and communication. Its high-performance capabilities are well-suited for handling the continuous flow of pressure data, allowing for real-time monitoring. Furthermore, the direct transmission of data to the MATLAB software streamlines the data synchronization and storage process, enabling easy access to pressure information for further analysis and decision-making.

MATLAB proved to be a robust platform for data visualization and analysis. The customized software precisely matched the checkerboard pattern of the sensors, providing an accurate overlay on the corresponding meshgrid. Pressure values from each sensor were visualized using a color-coded representation, aiding in the identification of high-pressure areas. The data obtained served as a valuable resource for detecting pressure patterns and implementing proactive prevention strategies.

IV. CONCLUSIONS

The pressure-sensitive mattress pad offers a promising solution for early detection and prevention of pressure injuries in geriatric patients. Its innovative design, coupled with robust data processing and visualization capabilities, empowers healthcare professionals with a practical tool to proactively manage pressure distribution and enhance the overall quality of care for vulnerable patients.

The successful preliminary internal testing not only demonstrates the device's feasibility but also validates its effectiveness and reliability in real-world applications. Additionally, the device's cost-effectiveness, owing to its cleanable and reusable attributes, holds the potential to mitigate healthcare expenses by preventing pressure injuries and reducing the financial burden of treating such cases.

We will continue developing this device to improve its capabilities and performance. The integration of an interactive monitor using a Raspberry Pi will be implemented for the convenience of nurses. This will enable the healthcare team to access comprehensive patient history logs derived from the Smart Mattress Pad's data. We plan to conduct clinical trials, which will expose potential weaknesses in our device and allow us to assess and improve the Smart Mattress Pad. Through this process we will gain valuable insight to create a cutting-edge product that significantly enhances patient care and wellbeing.

In conclusion, the pressure-sensitive mattress pad shows great potential to revolutionize pressure injury prevention and positively impact the well-being of geriatric patients. Continued research and refinement of the device holds the promise of reducing the incidence of pressure injuries, improving patient outcomes, and ultimately enhancing the quality of life for the elderly population.

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