บทความวิจัย

การออกแบบและพัฒนาระบบอัจฉริยะสำหรับตรวจจับท่านอนบนเตียงของผู้ป่วยสูงอายุ

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บทคัดย่อ

การพลัดตกหกล้มจากเตียงเป็นปัญหาสำคัญที่ส่งผลกระทบต่อผู้สูงอายุทั่วโลก ส่งผลกระทบให้เกิดการบาดเจ็บและต้องอยู่โรงพยาบาลเป็นเวลานาน ซึ่งอาจนำไปสู่ภาวะแทรกซ้อนอื่น เช่น แผลกดทับ ดังนั้นการเฝ้าระวังท่านอนของผู้สูงอายุจึงมีความสำคัญ เนื่องจากช่วยป้องกันและเตือนภัยการพลัดตกหกล้มจากเตียงได้ วัตถุประสงค์ของงานวิจัยนี้ คือ การออกแบบและพัฒนาระบบอัจฉริยะที่ตรวจจับรูปแบบการนอนหลับแบบตามเวลาจริง โดยใช้เซ็นเซอร์แรงกด 10 ตัว ที่ติดตั้งบนที่นอน โดยระบบสามารถตรวจจับท่านอนได้ 8 สถานะ ได้แก่ ตกเตียง นอนหงาย นอนตะแคงซ้าย นอนตะแคงขวา ยกตัวนั่งบนเตียง นั่งห้อยขาลงจากด้านซ้ายของเตียง และนั่งห้อยขาลงจากด้านขวาของเตียง นอกจากนี้ ยังใช้เซ็นเซอร์วัดอุณหภูมิและความชื้นในการตรวจสอบสภาพแวดล้อมที่เหมาะสม ข้อมูลจะถูกประมวลผลโดยไมโครคอนโทรลเลอร์ที่ส่งการแจ้งเตือนผ่านโมดูล Wi-Fi ไปยังเซิร์ฟเวอร์บนคอมพิวเตอร์และแจ้งเตือนผู้ดูแลผ่านแอปพลิเคชันบนมือถือ ประสิทธิภาพของระบบเตียงที่พัฒนาขึ้นได้ถูกทดสอบกับตัวอย่าง 4 คน แต่ละคนมีท่านอนทั้ง 8 สถานะ ผลการทดสอบแสดงให้เห็นว่าระบบสามารถตรวจจับสถานะตำแหน่งท่านอนดังนี้ ท่าไม่อยู่บนเตียง ท่านั่งบนเตียง และท่านั่งห้อยขาลงจากด้านซ้ายของเตียงด้วยความแม่นยำ 100% อีกทั้ง ผลทดสอบมีความแม่นยำ 91.67% สำหรับท่านอนหงายและท่านอนตะแคงซ้าย มีความแม่นยำ 75.00% สำหรับท่านอนตะแคงขวา มีความแม่นยำ 66.67% สำหรับท่านั่งห้อยขาลงจากด้านขวาของเตียงและท่านั่งยกตัวขึ้นจากเตียง และระบบสามารถแจ้งเตือนท่านอนเดิมทุก 2 ชั่วโมง ได้อย่างถูกต้อง

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Research Article

Design and Develop a Smart System for Monitoring Sleep Posture of Elderly Patients on a Bed

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Abstract

Falls from bed are a significant problem affecting the elderly population worldwide, leading to injuries and prolonged hospital stays, which can result in complications such as pressure ulcers. Therefore, monitoring the sleeping posture of elderly individuals is crucial, as it helps prevent falls and provides timely alerts. The objective of this research is to design and develop a smart system that detects real-time sleeping postures using 10 pressure sensors installed on a bed mattress. The system identifies 8 sleep positions: off bed, supine position, left lateral position, right lateral position, raised position, sitting on the bed, legs hanging down from the left side of the bed, and legs hanging down from the right side of the bed. Additionally, temperature and humidity sensors monitor the environmental conditions to ensure comfort. The data is processed by a microcontroller, which sends alerts through a Wi-Fi module to a server on a computer and notifies caregivers via a mobile application. The efficiency of the developed bed system was tested on 4 individuals, with 8 different sleeping positions per person. The results showed that the system accurately detected the following positions: off bed, sitting on the bed, and sitting with legs hanging off the left side of the bed, with 100% accuracy. It achieved 91.67% accuracy for the supine and left-side lying positions, 75.00% accuracy for the right-side lying position, and 66.67% accuracy for sitting with legs hanging off the right side of the bed and sitting up from the bed. Finally, during a 2-hour test in which the subjects maintained the same sleeping position, the system provided accurate alerts.

Keywords: Monitoring System, Getting Out of Bed, Force Sensor, Elderly People, Sleep Position

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1. Introduction

The global aging society is increasing rapidly. The World Health Organization predicts that by the year 2050, the global population aged 60 and above will reach a total of 2 billion people. This is an increase from 900 million in the year 2015, nearly doubling from 12% to 22% [1]. The transformation of the population structure into an aging society leads to subsequent public health issues. Elderly people are at a higher risk of health problems due to physical changes and age-related decline, which often hinder their ability to use their bodies normally. There is an increase in chronic diseases, such as cardiovascular diseases, obesity, endocrine disorders, and musculoskeletal diseases. When elderly individuals receive treatment for these diseases in hospitals, they may need to stay for an extended period, which increases the risk of pressure ulcers, particularly in patients who are bedridden or recovering from surgery. Preventing pressure ulcers can be achieved by regularly examining the patient's skin, frequent body position changes, good hygiene care, and using a mattress that allows air circulation. In addition to chronic illnesses that can cause pressure ulcers, injuries, especially falls in the elderly, are also a significant health problem that continues to rise globally [2].

Accidental falls result in individuals descending to a lower level unintentionally, causing injuries that can range from minor to life-threatening. The World Health Organization reports approximately 646,000 annual deaths from falls, making it the second leading cause of unintentional injury-related deaths globally [3]. Falls can be caused by various factors, including internal (such as bodily system deterioration), external (such as environmental conditions and obstacles), and contributing factors (such as age, history of falls, and medication use). Falls have physical, psychological, and financial impacts, with older adults being particularly vulnerable. Prompt notification and assistance from caregivers or nurses are crucial in reducing the risk and severity of fall-related injuries.

In the present, technology and communication advancements have led to the widespread use of IoT (Internet of Things). IoT enables the communication of various objects through the internet, benefiting healthcare professionals in elderly care. It facilitates monitoring patient responses through wearable devices and allows quick access to test results. IoT emphasizes connecting diverse devices to the internet network for extensive data collection, analysis, and decision-making. With the majority of the population having constant internet connectivity, incorporating features like health notifications via messaging apps has become convenient for everyday use.

Due to the aforementioned problems and their impact on the elderly, efforts have been made to find ways to prevent falls and reduce injuries from pressure ulcers. Various research studies [4]–[16] have explored the development of detection systems for bed exits in different forms. Some studies and developments have focused on detection systems for getting out of bed using video cameras to record events and analyse them [13]. While video camera usage is an effective method for monitoring patients, it may make them feel a lack of privacy and cause anxiety. Other types of sensors, such as accelerometer, are used to measure whether the patient is in a static or moving state, providing good indications of their status [14]. However, these sensors need to be attached to the patient's clothing or body, which can lead to discomfort or unintentional removal by the patient. Force sensors are also used in various research studies, placed in different positions, such as under the bed or under the mattress pad [15]. From the above researches, these systems can be used to detect getting out of bed alone, but Lee and team's [16] research has also successfully detected getting out of bed and measured pressure using force sensors. However, there are limitations in using these systems to measure the patient's environmental temperature and humidity.

Therefore, the objective of this research is to design and develop a system that integrates the Internet of Things (IoT) with patient beds, making it convenient, easy to install, and movable. Additionally, the system is easy to clean. The main components of the developed system are pressure sensors used to detect the position of the patient's sleep, detect getting out of bed, and monitor prolonged bed rest. Temperature and humidity sensors are also used to measure suitable environmental conditions. The data is processed, and the system sends it wirelessly via Wi-Fi to the server (Anto.io), which displays and notifies through a dashboard on the computer screen, LED lights, and the LINE application. This helps provide timely assistance to patients attempting to get out of bed. Furthermore, the system sends alerts to caregivers to encourage body movement for patients who have been in the same position for more than 2 hours, aiming to reduce pressure ulcer injuries. This system enables patient monitoring without the need for constant supervision, reducing the burden on nurses or caregivers. It also improves the patient's sleeping conditions and well-being.

2. Materials and Methods

In this research, an Arduino Mega 2560 microcontroller board is used to receive data from pressure sensors (FSR406), and a temperature and humidity sensor (DHT22) is connected to an ESP32 Wi-Fi module. The data is processed and wirelessly transmitted through the ESP32 module to the server (Anto.io). The system displays and notifies the data through a computer, LED lights, and the LINE application.

2.1 Operating Principle of the Bed System

The system operation begins with the pressure detected by pressure sensors, and the data is sent to the microcontroller (Arduino Mega 2560). Simultaneously, the temperature and humidity sensor (DHT22), connected to the Wi-Fi module (ESP32), checks the environmental conditions. The Arduino Mega 2560 then sends the pressure data to the Wi-Fi module (ESP32) for processing, along with data from the temperature and humidity sensor (DHT22). Subsequently, the Wi-Fi module (ESP32) forwards the processed information to the server (Anto.io) for online data presentation. The program specifies conditions for display and notifications in three formats: through a dashboard on the server (Anto.io) displayed on a computer screen, through an LED set by the Wi-Fi module (NodeMCU) that receives server data via Wi-Fi to indicate sleep status, and through a mobile application. The data is stored in an Excel file. An overview of the system

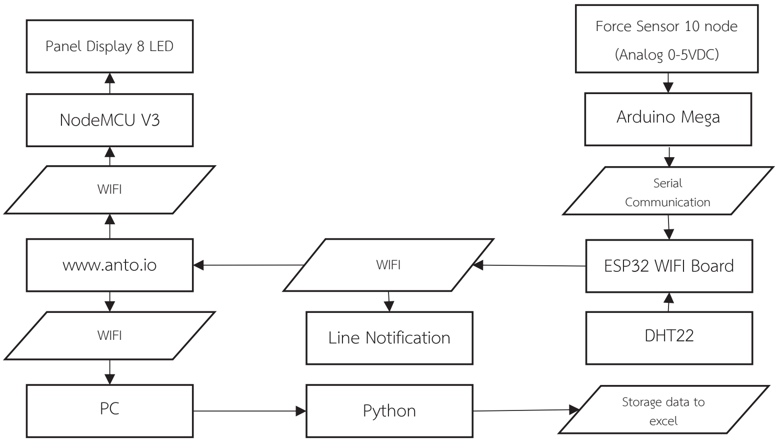

Figure 1 Overview of the system operation.

operation is presented in Figure 1. The details of each part in the developed system can be explained as following:

2.1.1 Bed Mattress

This research utilizes a bed mattress as shown in Figure 2 with dimensions of 78 centimeters wide, 185 centimeters long, and 3.2 centimeters thick. The outer material is made of polyesters and plastic (PEVA), while the inner filling consists of polyethylene foam. It can be folded and stored in five layers.

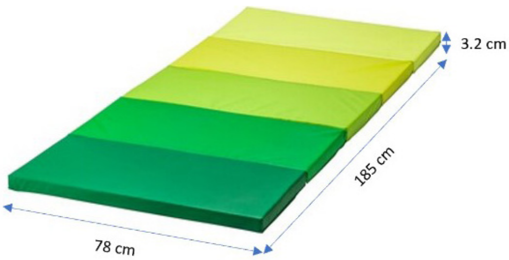

Figure 2 Bed Mattress.

2.1.2 Force Sensors for Motion Detection

In this work, the sensor used for detecting the motion of patients is a Force-sensing Resistor (FSR406), which has an electrical resistance value of less than 10 megaohms when there is no significant force applied because it is reliable and can support a weight range of 100 grams to 10 kilograms and has a weight-receiving area of 43.69 × 43.69 millimeters with a thickness of 0.45 millimeters. It operates by changing its resistance value based on the weight or pressure that is applied to the sensing area. The greater the applied weight, the lower the resistance. Each sensor is connected through a 10-kilohm resistor before being connected to a microcontroller (Arduino Mega2560) via analog pins (A0–A9). A total of 10 force-sensing resistors are used for detecting the pressure caused by lying down or changing sleeping positions in various orientations. The Force-sensing Resistor (FSR406) is illustrated in Figure 3.

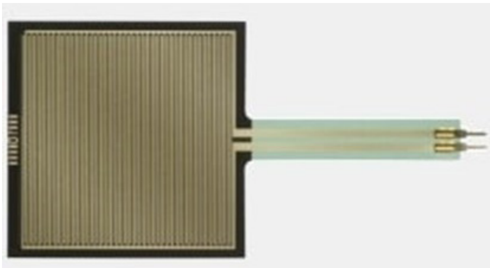

Figure 3 Force Sensors for Motion Detection.

2.1.3 Microcontroller

The Arduino Mega2560 is used as a microcontroller during this work. It has 256 kilobytes of flash memory and 8 kilobytes of RAM. It can operate by connecting to a computer via USB or by using an external power source through an AC/DC adapter with a voltage range of 6 to 20 volts, although the recommended operating range is 7 to 12 volts. The system voltage is at 5 volts. In addition, it has 54 digital input/output pins and 16 analog input pins. Its primary function is to receive pressure values from the 10 force-sensing resistors and transmit these values to an ESP32 Wi-Fi module via the TX pin of the Arduino Mega2560 and the RX pin of the ESP32 module.

2.1.4 Temperature and Humidity Sensor

The DHT22 temperature and humidity sensor is used to measure temperature and humidity of the patient. It operates within a voltage range of 3.3 to 6 volts and can measure temperatures in the range of -40 to 80 degrees Celsius with an accuracy of ±0.5 degrees Celsius. It can also measure relative humidity in the range of 0 to 100% with an accuracy of ±2 to ±5% relative humidity. The sensor has a 2-second processing time, is durable, and can be used for extended periods.

The temperature and humidity sensor are connected to pin 23 of the ESP32 Wi-Fi module. Temperature and humidity in the air are essential factors that directly affect human health. Suitable temperature and humidity conditions contribute to human comfort, especially in the patient's bedroom. The air quality in the patient's bedroom should allow for easy breathing, without feeling stuffy or uncomfortable. The relative humidity in the patient's bedroom should not exceed 60% to prevent the growth of mold or disease-causing microorganisms, which can lead to various health issues. These microorganisms thrive in high humidity conditions. Additionally, excessive humidity can make patients uncomfortable, causing them to feel sticky and congested. On the other hand, humidity should not drop below 30% because it can lead to dry or cracked skin, eye or nasal irritation. Therefore, the ideal conditions for human comfort involve a temperature of around 23 to 25 degrees Celsius and relative humidity ranging from 30% to 60%RH. These conditions align with the standards set by the Department of Disease Control of the Ministry of Public Health and the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE).

2.1.5 Wi-Fi module

The Wi-Fi module (ESP32) is a 32-bit microcontroller developed from the ESP8266. It is cost-effective and operates on standard 802.11 b/g/n Wi-Fi at a frequency of 2.4 gigahertz. It comes with built-in Bluetooth supporting both 2.0 and 4.2 BLE modes. The module operates within a voltage range of 3.0 to 3.6 volts. The role of the ESP32 is to process data received from the microcontroller (Arduino Mega2560) and the temperature and humidity sensor (DHT22). After processing the data, it forwards it to the server (Anto.io), serving as an intermediary for hardware communication over the Internet, enabling online data on the server.

In addition, the Wi-Fi module (NodeMCU) is a board that utilizes the ESP8266 for processing. It can connect to Wi-Fi and operates at a frequency of 2.4 gigahertz. In this work, it is connected to a set of 8 LED bulbs. The role of NodeMCU is to receive data from the server (Anto.io) via Wi-Fi, and based on the received values, it controls the LED bulbs to display the patient's status on the bed.

2.2 Installation and Role of Sensors

The sensors are installed with specific distances between each position on the mattress under the bedsheet, as illustrated in Figure 4. This configuration covers the areas where the patient's body comes into contact with the bed, as well as the edges on both the left and right sides of the bed. The placement of sensors in these positions was tested with an initial sample group of four participants to evaluate the accuracy and suitability of using 10 sensors. The goal is to balance cost-effectiveness with the precision of detecting the patient's sleeping posture. This information helps identify the patient's posture status, as depicted in Figures 5 through 12, and corresponds to the sleeping status related to the sensor's operation at each point, as detailed in Table 1.

Status 0 is a state where the patient is not on the bed. Sensors at every position detect low pressure levels. If it meets the alert conditions, the system will notify, "Emergency: Patient has left the bed."

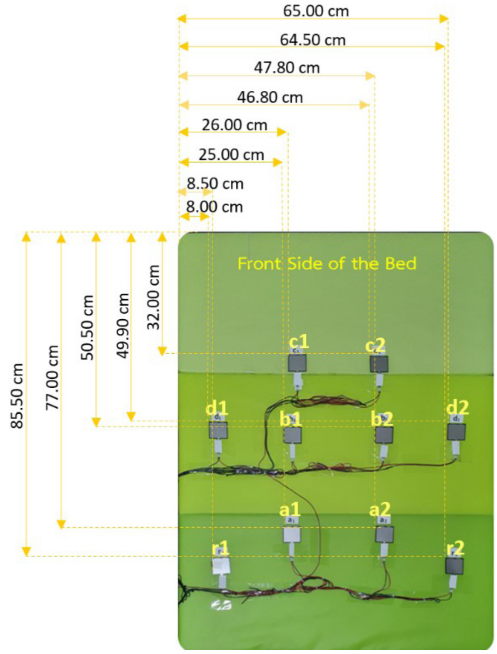

Figure 4 Positioning of Sensors on the Bed.

Status 1 is a state where the patient is lying on the back. Sensors at positions a1, a2, b1, b2, c1, and c2 can detect high pressure levels, while sensors at positions d1, d2, r1, and r2 detect low pressure and do not meet the alert conditions.

Table 1 Relationship between sleeping status and sensor operation at each point.

Sleeping Status	Sensor Positions									
	a1	a2	b1	b2	c1	c2	d1	d2	r1	r2
Status 0	0	0	0	0	0	0	0	0	0	0
Status 1	1	1	1	1	1	1	0	0	0	0
Status 2	0	0	0	0	0	1	0	1	0	0
Status 3	0	0	0	0	1	0	1	0	0	0
Status 4	1	1	1	1	0	0	0	0	0	0
Status 5	1	1	0	0	0	0	0	0	0	0
Status 6	0	0	0	0	0	0	0	0	0	1
Status 7	0	0	0	0	0	0	0	0	1	0

Figure 5 Posture of the patient on the bed in status 0: The patient is not on the bed (off bed position).

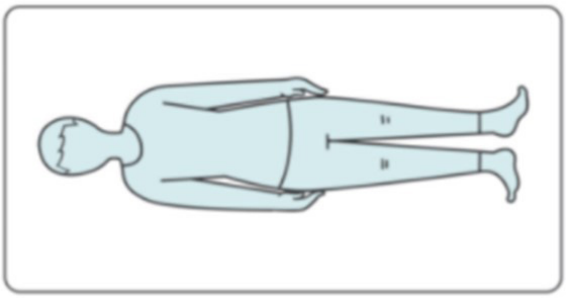

Figure 6 Posture of the patient on the bed in status 1: Lying on the back (supine position).

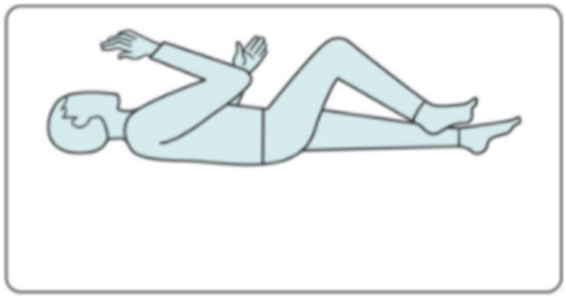

Figure 7 Posture of the patient on the bed in status 2: Lying on the left side (left lateral position).

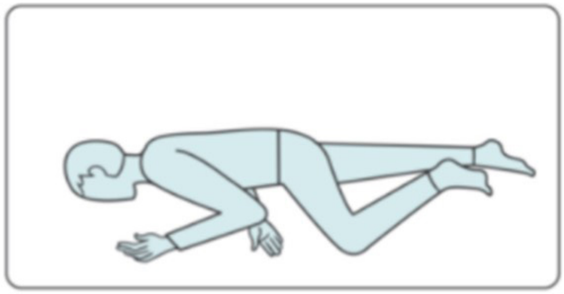

Figure 8 Posture of the patient on the bed in status 3: Lying on the right side (right lateral position).

Status 2 is a state where the patient is lying on the left side. Sensors at positions c2 and d2 can detect high pressure levels, while sensors at positions a1, a2, b1, b2, c1, d1, r1, and r2 detect low pressure and do not meet the alert conditions.

Status 3 is a state where the patient is lying on the right side. Sensors at positions c1 and d1 can detect high pressure levels, while sensors at positions a1, a2, b1, b2, c2, d2, r1, and r2 detect low pressure and do not meet the alert conditions.

Status 4 is a state where the patient is raising the upper body from the bed. Sensors at positions a1, a2, b1, and b2 can detect high pressure levels, while sensors at positions c1, c2, d1, d2, r1, and r2 detect low pressure. If it meets the alert conditions, the system will notify, "Patient is starting to get up from bed."

Status 5 is a state where the patient is sitting on the bed. Sensors at positions a1 and a2 can detect high pressure levels, while sensors at positions b1, b2, c1, c2, d1, d2, r1, and r2 detect low pressure. If it meets the alert conditions, the system will notify, "Patient is sitting on the bed."

Status 6 is a state where the patient is sitting with legs hanging down from the left side of the bed. Sensor at position r2 can detect high pressure, while sensors at positions a1, a2, b1, b2, c1, c2, d1, d2, and r1 detect low pressure. If it meets the alert conditions, the system will notify, "Patient is starting to get off the bed from the left side."

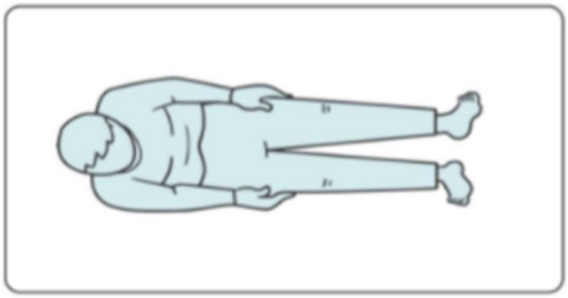

Figure 9 Posture of the patient on the bed in status 4: Raising the upper body from the bed (raising position).

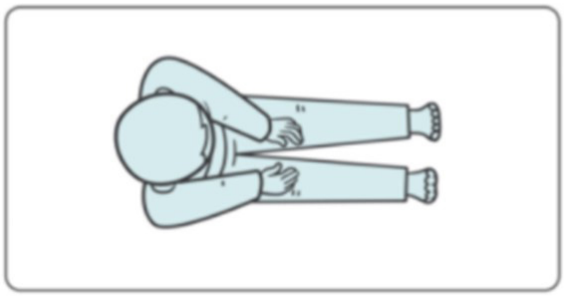

Figure 10 Posture of the patient on the bed in status 5: Sitting on the bed.

Status 7 is a state where the patient is sitting with legs hanging down from the right side of the bed. Sensor at position r1 can detect high pressure, while sensors at positions a1, a2, b1, b2, c1, c2, d1, d2, and r2 detect low pressure. If it meets the alert conditions, the system will notify, "Patient is starting to get off the bed from the right side."

In addition to detecting pressure levels, the pressure sensors can be used to check the sleeping position to detect if the patient remains in the same position for more than 2 hours. This is especially important for patients prone to immobility, such as those at risk of pressure ulcers due to reduced skin elasticity, decreased subcutaneous fat, and diminished blood circulation. The system will alert the caregiver to encourage patient repositioning every 2 hours. This is based on the recommendation from the National Pressure Injury Advisory Panel (NPIAP), which advises caregivers to reposition bedridden patients every 2 hours to stimulate blood circulation and prevent prolonged pressure on the body that can lead to pressure ulcers.

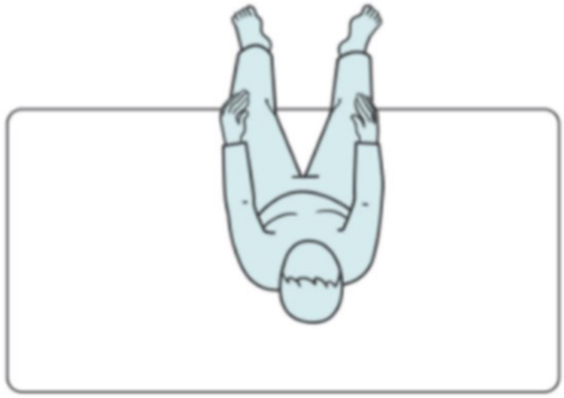

Figure 11 Posture of the patient on the bed in status 6: Sitting with legs hanging down from the left side of the bed.

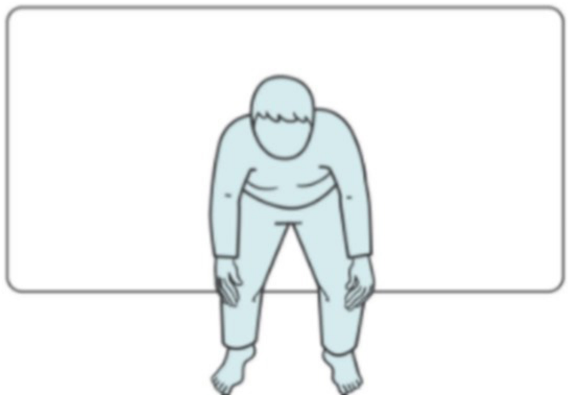

Figure 12 Posture of the patient on the bed in status 7: Sitting with legs hanging down from the right side of the bed.

2.3 Testing the Weight Used to Activate the Sensors

Finding the weight that triggers the sensor and causes it to start detecting pressure is crucial. This weight is compared against a digital value set in the program, typically 100, which is obtained through testing. Since individuals vary in weight distribution, especially in certain body parts like the arms where pressure might not be as high, it's necessary to use a lower digital value to ensure the sensor can detect the pressure accurately. The sensor won't detect pressure if the digital value is below 100.

To find the weight used to activate the sensor, a digital weighing scale with a maximum capacity of 3000 grams, accuracy of 0.01 grams, and a margin of error of ±0.05 grams is employed. This scale has been calibrated using calibration weights. The results of the weight tests used to activate each sensor are presented in Table 2.

Table 2 Testing the weight used to activate the sensors.

Sensor Positions	Digital Value	Weight Used to Press (grams)
a1	100	65.14
a2	100	76.05
b1	100	62.17
b2	100	51.33
c1	100	86.03
c2	100	85.30
d1	100	76.99
d2	100	53.34
r1	100	55.72
r2	100	64.22
Average	100	67.63

2.4 Display and Notification

2.4.1 Display through the dashboard on the server (Anto.io)

This display shows the patient's sleep status, environmental temperature, and humidity, as illustrated in Figure 13, with details as follows:

1) Light bulb color display to indicate that the patient is currently in a normal state, i.e., statuses 1-7, will be displayed in green light.

2) Light bulb color display to indicate that the patient is currently in an abnormal state, i.e., status 0, will be displayed in orange light.

3) Operation mode button used to toggle data recording:

- When set to off, data will be recorded continuously during operation.

- When set to on, data will be recorded according to the set time intervals.

4) Button for setting the start recording time (hours/minutes).

5) Button for setting the stop recording time (hours/minutes).

6) Display of sleep status (0–7).

7) Display of environmental temperature.

8) Display of air humidity value.

2.4.2 Display the status of sleep through an LED set.

When the patient exhibits a posture corresponding to a particular sleep status, the LED tube associated with that status will light up. An example of the display characteristics is shown in Figure 14, where LED S1 is lit, indicating that the patient is in a normal condition, specifically in Status 1, which signifies that the patient is lying on their back.

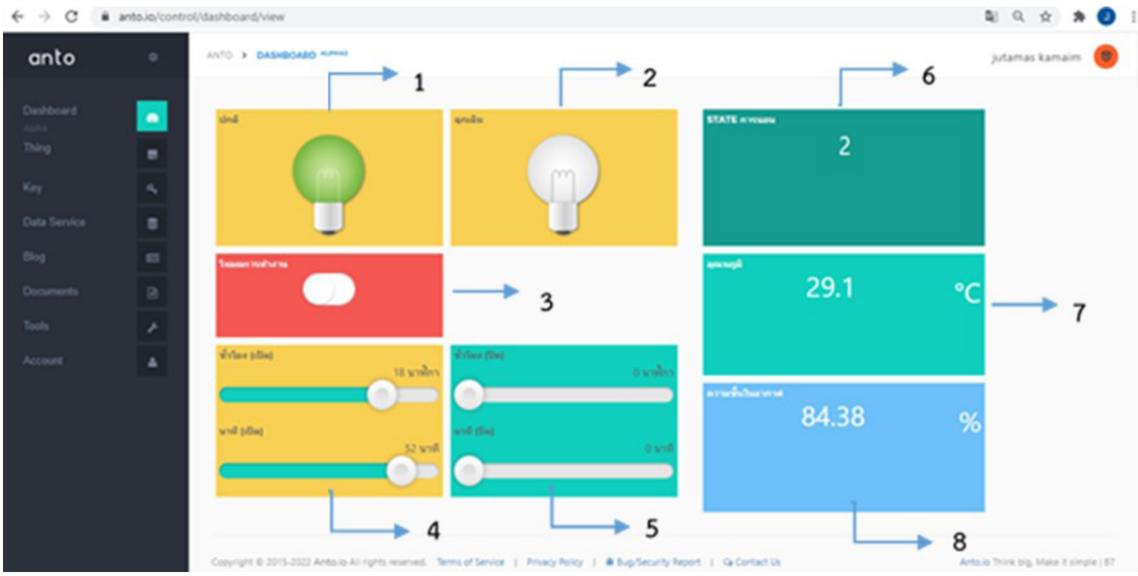

Figure 13 Display through the dashboard on the server (Anto.io).

Figure 14 Example of the display represented the status of sleep through an LED set. For example, this Figure shows the position where the patient is lying on their back, the LED corresponding to (S1) will illuminate.

2.4.3 Notification via the LINE application

This LINE notification can be for three purposes: notifying about the temperature and humidity of the environment, alerting when the patient gets up from the bed, and notifying when the patient remains in the same position for more than 2 hours.

- Notification regarding inappropriate temperature and humidity will be sent when the temperature is not within the range of 23 to 25 degrees Celsius and when the relative humidity is not within the range of 30 to 60% RH.

- Notification of the patient getting up from the bed will be sent starting from when the patient is in state 4, which is the state where the patient is raising themselves from the bed, state 5, where the patient is sitting on the bed, state 6, where the patient is sitting with their legs hanging down from the left side of the bed, or state 7, where the patient is sitting with their legs hanging down from the right side of the bed, until state 0, where the patient is not on the bed.

- Notification of prolonged sleeping in the same position for more than 2 hours will be sent when the patient sleeps in any of the three positions for an extended period. LINE will send a notification when the patient is in one of the three sleeping positions: position 1 when the patient sleeps on their back (supine), position 2 when the patient sleeps laterally on the left side, and position 3 when the patient sleeps laterally on the right side.

2.4.4 Testing the developed bed system

The positioning of individuals during sleep was tested to indicate the posture of the sleeper through experiments with a sample of 4 individuals, consisting of 2 males and 2 females, aged between 20 and 28 years old, with weights ranging from 60 to 90 kilograms. The posture of the sleepers in all 8 states was tested three times each, and the system was tested for sleeping in the same position for more than 2 hours, focusing on three sleeping positions: supine, left lateral, and right lateral. During each test, the system measured temperature and humidity levels within the body. Data collected from the server was compiled and analyzed, then inputted into an Excel file for further assessment.

3. Results and Discussions

This study aims to design and develop a smart bed system capable of monitoring the position of the sleeper to detect getting out of bed, detecting pressure, measuring temperature and humidity in the surrounding environment, and testing the functionality of the developed bed system. The analysis of the data is divided into two parts:

3.1 Smart System for Monitoring Elderly Patients

This study involves designing and developing a bed system capable of monitoring the position of the sleeper to detect getting out of bed, detecting pressure, and measuring temperature and humidity in the surrounding environment. It utilizes an Arduino Mega2560 board to receive data from a pressure sensor (FSR406) and sensors for temperature and humidity (DHT22) connected to an ESP32. Data processing and wireless connection are facilitated through the ESP32 module to a server (Anto.io). The system displays and notifies user activities through a computer interface, LED set, and Line application. The developed smart system for monitoring sleep positions of elderly patients shown in Figures 15 and 16 is divided into two parts: the smart system part and the display and notification system part, detailed as follows:

3.1.1 Smart system

- Bed mattress: Sized at 78 cm wide, 185 cm long, and 3.2 cm thick, made of Polyethylene Vinyl Acetate (PEVA) on the outside and Polyethylene foam on the inside, foldable for storage.

- Patient movement sensor: Utilizes force-sensitive resistor (FSR406) to detect pressure changes caused by the patient's movements.

- Microcontroller (Arduino Mega2560): Installed to receive pressure readings from 10 FSR406 sensors.

- Temperature and humidity sensor (DHT22): Measures environmental temperature and humidity every 2 seconds to ensure patient comfort.

- Wi-Fi module (ESP32): Processes and transmits data from Arduino Mega2560 and DHT22 sensors to the server (Anto.io) for online data display.

Figure 15 Developed smart bed system for monitoring sleep position.

Figure 16 Bed mattress with force sensors installed.

3.1.2 Display and Notification System

- Dashboard display (on www.anto.io): Shows patient's sleep status, temperature, and humidity.

- LED display: Consists of 8 LEDs representing sleep statuses from S0 to S7. Each LED lights up red according to the patient's sleep position.

- Line application notifications: Notifies inappropriate temperature and humidity, patient leaving the bed, and prolonged immobility in one of the three sleeping positions: supine, left lateral, and right lateral.

3.2 Results of the Usability Testing of the Developed Bed System

The testing involved examining sleeping positions ranging from status 0 to 7 with a sample of 4 individuals, each tested 3 times, totaling 12 tests. The testing and data analysis results are presented in Table 3.

Table 3, testing results of sleeping positions in Status 0 to 7 with 4 individuals, each tested 3 times, totaling 12 tests, reveal the following:

Status 0 (Off bed): The system accurately detects and displays the absence of the patient on the bed in all instances, with an average accuracy of 100.00%.

Status 1 (Supine position): The system accurately detects and displays the supine position in 11 out of 12 tests, with a slight detection error in the third repetition of the second tester, resulting in an average accuracy of 91.67%.

Status 2 (Left lateral position): The system accurately detects and displays the left lateral position in 11 out of 12 tests, with a slight detection error in the third repetition of the fourth tester, resulting in an average accuracy of 91.67%.

Status 3 (Right lateral position): The system accurately detects and displays the right lateral position in 9 out of 12 tests, resulting in an average accuracy of 75.00%

Table 3 Results of testing sleeping positions in status 0 to 7.

Sleep Status	Tester 1			Accuracy (%)	Tester 2			Accuracy (%)	Tester 3			Accuracy (%)	Tester 4			Accuracy (%)	Average Accuracy (%)
	1	2	3		1	2	3		1	2	3		1	2	3		
Status 0	✓	✓	✓	100.00	✓	✓	✓	100.00	✓	✓	✓	100.00	✓	✓	✓	100.00	100.00
Status 1	✓	✓	✓	100.00	✓	✓	×	66.67	✓	✓	✓	100.00	✓	✓	✓	100.00	91.67
Status 2	✓	✓	✓	100.00	✓	✓	✓	100.00	✓	✓	✓	100.00	✓	✓	×	66.67	91.67
Status 3	✓	✓	✓	100.00	✓	×	✓	66.67	✓	×	✓	66.67	×	✓	✓	66.67	75.00
Status 4	✓	×	✓	66.67	✓	✓	×	66.67	✓	×	✓	66.67	×	✓	✓	66.67	66.67
Status 5	✓	✓	✓	100.00	✓	✓	✓	100.00	✓	✓	✓	100.00	✓	✓	✓	100.00	100.00
Status 6	✓	✓	✓	100.00	✓	✓	✓	100.00	✓	✓	✓	100.00	✓	✓	✓	100.00	100.00
Status 7	×	×	✓	33.33	✓	✓	✓	100.00	✓	×	×	33.33	✓	✓	✓	100.00	66.67

Status 4 (Raising position): The system accurately detects and displays the raising position in 8 out of 12 tests, resulting in an average accuracy of 66.67%.

Status 5 (Sitting on bed): The system accurately detects and displays the sitting position on the bed in all instances, with an average accuracy of 100.00%.

Status 6 (Legs hanging down from left side of bed): The system accurately detects and displays the legs hanging down position in all instances, with an average accuracy of 100.00%.

Status 7 (Legs hanging down from right side of bed): The system accurately detects and displays the legs hanging down position in 8 out of 12 tests, resulting in an average accuracy of 66.67%.

In Table 4, the results of testing the notification for maintaining the same sleeping position for 2 hours in Status 1 (Supine Position), Status 2 (Left Lateral Position), and Status 3 (Right Lateral Position) reveal that the system can accurately notify according to the set time in all statuses. The overall average accuracy is 100.00% for all statuses when tested with a sample of 4 individuals.

Table 4 Notification testing results for maintaining the same Sleeping position for 2 hours.

Sleep Status	Notification for 2 Hours				Overall Average Accuracy (%)
	Tester 1	Tester 2	Tester 3	Tester 4	
Status 1	✓	✓	✓	✓	100.00
Status 2	✓	✓	✓	✓	100.00
Status 3	✓	✓	✓	✓	100.00
Total	100.00	100.00	100.00	100.00	100.00

4. Conclusions

This research involved designing and developing a monitoring system to monitor sleep posture and detect when elderly patients rise from their beds. Ten pressure sensors were utilized to detect pressure changes caused by sleeping movements or changes in sleeping positions in various contexts. These sensors were installed on a bed sheet measuring 78 centimeters wide, 185 centimeters long, and 3.2 centimeters thick. The system processes signals from the pressure sensors installed to cover the torso and side areas of the bed, totaling 10 points. This setup allows for monitoring the sleeping postures of patients in different conditions in real-time. The processed data is then transmitted via Wi-Fi connection to a server (Anto.io) to provide online information. The system is capable of notifying caregivers when patients begin to rise from their beds, enabling timely assistance. Additionally, it includes a function to notify if a patient remains in the same position for more than 2 hours. Notifications are displayed through a dashboard on the server (Anto.io), computer screens, and LED light sets. In this research, a unique functionality has been introduced, setting it apart from previous works. An alert system has been integrated via the LINE application, along with continuous monitoring of temperature and humidity to ensure patients remain in optimal environmental conditions. This is essential for preventing complications and enhancing patient comfort.

The testing results of the smart bed system for monitoring elderly patients revealed varying detection efficiencies across different sleep statuses. The accuracy rankings from highest to lowest were as follows: Status 0 (Patient not on bed), Status 5 (Sitting on bed), and Status 6 (Sitting with legs hanging down from left side of bed) demonstrated 100.00% accuracy. This was followed by Status 1 (Supine position) and Status 2 (Left lateral position) with 91.67% accuracy. Subsequently, Status 3 (Right lateral position) showed 75.00% accuracy, while Status 4 (Rising from bed) and Status 7 (Sitting with legs hanging down from right side of bed) had the lowest accuracy at 66.67%. It was observed that in Status 6, where patients sat with legs hanging down from the left side of the bed, the system could only detect accurately when sensors at position r2 were activated. Similarly, in Status 7, where patients sat with legs hanging down from the right side of the bed, the system could only detect accurately when sensors at position r1 were activated. These two statuses shared similar postures but had different sensor contact points, leading to significant differences in detection accuracy.

Moreover, when testing the system’s notification capability for prolonged maintenance of the same position for more than 2 hours, the system demonstrated 100.00% accuracy in notifying correctly.

Overall, this study has contributed to the development of a more suitable smart system for monitoring elderly patients on a bed, providing a valuable tool for caregivers and enhancing elderly care through IoT technology. The system’s detection accuracy across various sleep statuses reached 86.46% overall.

However, this research still has room for improvement in several areas. For instance, increasing the number of sensors in specific positions on the bed mattress or using plastic coverings over the sensors to distribute pressure and cover a larger area could improve the system. Additionally, in this research, the sensors operate in an on/off mode, which limits the precision of the analysis. Using pressure values as percentages for processing could potentially enhance the system's accuracy. Also, adding algorithms could improve the system’s ability to accurately detect patients’ sleeping positions in each posture. Furthermore, testing sensors on surfaces with different softness or hardness characteristics to determine if they affect weight distribution from above is advisable. Moreover, allowing users to adjust temperature and humidity notification settings directly through the display screen would be beneficial. These temperature and humidity settings should be adjustable to suit the specific environment where the system is deployed. In addition, assessing the comfort or discomfort of the subject after sleeping, particularly any discomfort felt when lying on the pressure sensors, is an area that can be further explored and developed.

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Author Contributions

S.U.: conceptualization, research design, data curation, writing-reviewing and editing, project administration, funding acquisition; J.K.: investigation, methodology, data analysis, writing an original draft. All authors have read and agreed to the published version of the manuscript.

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