BED FALL PREDICTION SYSTEM WITH INTEGRATED REMOTE HEALTH MONITORING

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Bachelor of Science in Electrical and Electronic Engineering

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Declaration

It is hereby declared that

1. The Final Year Design Project (FYDP) submitted is our own original work while completing a degree at Brac University.

2. The Final Year Design Project (FYDP) does not contain material previously published or written by a third party, except where this is appropriately cited through full and accurate referencing.

3. The Final Year Design Project (FYDP) does not contain material which has been accepted, or submitted, for any other degree or diploma at a university or other institution.

4. We have acknowledged all main sources of help.

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Ethics Statement

In conducting this research, the highest ethical standards have been upheld. Informed consent was obtained from all participants, and confidentiality and anonymity have been maintained throughout the project. Any data or information used in the thesis has been collected and reported in an ethical manner, in accordance with proper guidelines. The research has been conducted with integrity and objectivity, and any potential conflicts of interest have been disclosed. The sources used have been properly cited and acknowledged. Additionally, a Similarity check has been conducted through the Ayesha Abed Library at Brac University. The Plagiarism index result stands out to be 5% only. Overall, the ethics statement serves as a clear and transparent declaration of our commitment to conducting the study in a responsible manner and in compliance with the applicable practices and standards set forth by the IEEE.

Abstract/ Executive Summary

Patients with impaired mobility and neurological disorders such as Alzheimer’s, Parkinson’s disease, dementia etc. are vulnerable to bed falls which can be damaging to their physical and psychological well-being. Additionally, the growing old age population is also at risk of falling off the bed. The bed fall prediction system with remote health monitoring will enable caretakers/nurses to take care of them conveniently at homes, hospitals and assisted care facilities to ensure their health and safety. This integrated system is designed to identify patient’s different on-bed positions to determine the possibility of bed falls and monitor significant health vitals such as body temperature, heart rate and oxygen saturation. In case of any risky position or abnormal vital reading, the caretaker will be alerted via the Internet of Things (IoT). Therefore, this system will be beneficial to a wide range of patients and monitoring them will be more accessible and manageable.

Keywords: bed falls; force sensitive resistors; prediction system; remote health monitoring; Internet of Things.

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List of Acronyms

CNN	Convolution Neural Network
DGDA	Directorate General of Drug Administration
DR	Diabetic Retinopathy
FDA	Food and Drug Administration
FSR	Force Sensitive Resistor
GHTF	Global Harmonization Task Force
IDE	Integrated Development Environment
IoT	Internet of Things
IoMT	Internet of Medical Things
IR	Infrared
IRB	Institutional Review Board
JPGSPH	James P Grant School of Public Health
MLM	Machine Learning Method
QoS	Quality of Service
ReLu	Rectified Linear Unit
RFID	Radio Frequency Identification
RM	Rule-based Method
SDK	Software Development Kit
SVM	Support Vector Machine
THM	Threshold-based Method
WLAN	Wireless Local Area Network

Glossary

Bedsore	Pressure ulcers that happen on skin and underlying tissues are primarily due to prolonged pressure on the skin from lying in bed.
Convolutional Neural Network (CNN)	A particular network architecture used by deep learning algorithms. It is primarily utilized for processing pixel data and image recognition tasks.
Force Sensitive Resistor	Sensors made of a material which changes its resistance based on the force or pressure applied to them.
Gateway	A central hub that links Internet of Things (IoT) gadgets and sensors to the cloud, enabling communication among the devices through various wireless protocols.
Internet of Things (IoT)	A network consisting of connected devices that process and send data through the internet.
Internet of Medical Things (IoMT)	Network of medical devices and software applications connected to the healthcare information systems via the internet.
Piezoelectric Sensor	Sensor that utilizes the piezoelectric effect to assess the variation in pressure, acceleration, temperature, strain, or force by converting them into electric charge.
Support Vector Machines (SVM)	Supervised learning models that are used in data analysis for classification and regression problems.

Chapter 1

Introduction

1.1 Introduction

1.1.1 Problem Statement

Falling off a bed is a frequent and dangerous accident that can result in severe physical and emotional damage. Patients with both neurological and motor system disorders require special attention when they are lying down on the bed. Conditions such as Parkinson's disease, dementia, impaired mobility, and even old age can make them vulnerable to bed falls and it is a common concern of the caretakers of the patients for their well-being and safety, especially in the absence of nursing personnel. The consequences of a bed fall injury have an adverse impact on both the physical and psychological state of the patient. Also, there is a significant gap in the ratio of nursing personnel to patients in most hospitals and assisted living facilities. Thus, it is difficult to monitor and stay beside patients at all times. Additionally, it has been observed that bed falls occur mostly at night when only a few nurses are stationed to monitor each ward.

Bed rails are the most common existing solution to this problem. However, In [1], it can be seen that statistically, 60-70% of hospital accidents and 80% of home accidents are bed falls and even with bed rails, 50-90% of bed falls still occur. Besides, the aforementioned group of patients is susceptible to infrequent health vital levels and oftentimes they have difficulty addressing it and communicating clearly with the medical service provider. Moreover, according to research in [2], about 25% of the population is above the age of 65 and as mentioned in [1] it is expected to reach 1.4 billion by the year 2030 and 2.1 billion by 2050. Thus, approaching this growing problem with technological assistance makes the solution more reliable.

1.1.2 Background Study

Ibrahim et al [1] studied several systems related to bed falls and divided them into three categories depending on their sensor placement. They are as follows: wearable systems, non-wearable systems, and fusion systems. Firstly, the wearable system has its sensor placed directly on the patient's body, over or under clothing. They are used to detect the orientation and preliminary movements to predict the risk of a bed fall. Secondly, non-wearable systems have their sensors deployed in the surroundings rather than on the patient's body. They are mostly used to detect the motion of the patient. Lastly, fusion systems consist of the integration of both wearable and non-wearable systems, collecting data from multiple sources. Furthermore, the global categorization of analytical methods was discussed to process the data collected from the sensors. The methods are as follows: Rule-based (RM has a guideline of rules), Threshold-based (THM has threshold values fixed), and Machine Learning (MLM-based on decision trees and algorithms). Finally, several thorough studies and notable implementations have been done to solve the bed fall problem. A few of them have been reviewed below.

The U.S. Food and Drug Administration (FDA) [3] stated that despite the presence of bed rails, 22% of bed falls still occur. Also, it was stated that among 145 deaths, 143 deaths were caused due to rail entrapment, 11 were due to falls on the bed rail and 1 was due to head injury as the victim hit his head with the bed rail. Among these numbers, 129 people were above the age of 60 years. Half of them had conditions such as Alzheimer's disease, dementia, mobility limitations or paralysis, seizure, Parkinson's disease, Cerebral palsy, etc. Similarly, a bed fall prevention system designed in 2013 implemented a bodywear device. Choi et al [4] proposed a design where an accelerometer had been attached to the patient's chest and a threshold-based analytical method was used to determine the prediction. The system was very fast and low cost with the flexibility to modify the threshold. However, the wearable design can be uncomfortable to wear and might even cause injury to patients. Also, it did not include the case of a patient falling while turning to their sides. In 2018, another bed fall prediction design consisted of a fusion system. Umetani et al [5] designed a system to detect changes in sleeping conditions and the environment. To implement this, the temperature, acceleration, and humidity of the comforter were monitored and a camera was fixed on the wall to detect motion. The rule-based measurement of these environmental factors was put in place to minimize bed fall accidents. The independent systems had the advantage of increasing the reliability of the project. Also, it provided privacy to the patients. But on the other hand, the installation cost was too high and it also had high obstructiveness due to the complicated sensor systems.

In 2018, Sri-Ngernyuang et al [6] proposed a system that used an artificial neural network to recognize the on-bed movements of the patients and thus made predictions of bed falls. The non-wearable design had tactical sensors attached to the bed. They categorized the patient's position into two sections: stable and unstable. When the patient would be close to the edge of the bed, it would be considered unstable, and vice versa. This was accessed using a thermal imaging camera. The design had several advantages such as moderate cost and low obstructiveness. Also, their accuracy rate was 89.1% with 7 people in the experimental group. As they had no wearable device, it was user-friendly. Although, the patients could perceive the use of cameras as an intrusion of privacy. Furthermore, in 2018, a vision-based implementation was discussed. In this particular design by Inoue et al [7], a monocular camera, a non-wearable system, had been used to detect the patient's behavior to determine the possible risk of the patient falling or needing assistance from medical personnel. The analytical method of the Support Vector Machine (SVM) classifier was applied. A planar perspective transformation had been used to display the shape of the bed as a rectangular shape. This added the advantage of eliminating the need to manually input the bed coordinates every time the bed had been changed or moved. Also, they took two steps of consent for using the camera. Also, it has the feature to temporarily stop the camera for privacy in desired situations. However, there are many preconditions associated with it and the camera is variable only within a certain area.

Vangos Pterneas explains in [8] how using a depth-based processor and an IR sensing device such as Kinect is able to put into perspective three-dimensional space. The depth processor can measure the distance between the Kinect device and the physical points. For the representation of a certain physical point in a real three-dimensional realm, Microsoft Software Developer Toolkit (SDK) makes use of a structure known as CameraSpacePoint. A CameraSpacePoint is a collection of [X, Y, Z] three characteristics. The displacement (depth) between that real point and the sensor's surface is Z. In contrast, the displacement along the vertical plane is Y and the displacement along the horizontal plane is X.

Pterneas on [9] briefs that for configuring purposes, Microsoft SDK consists of an important feature known as CoordinateMapper. The responsibility of CoordinateMapper is to determine if a real point in space is corresponding to a pixel in two-dimensional space and vice versa. Each Kinect sensor has access to the CoordinateMapper.

Over the years, deep learning technologies such as Convolutional Neural Network (CNN) have been heavily utilized in the medical industry for creating prediction/detection models with good accuracy. For instance, a proposed framework by Sungheetha and Sharma [10], has been utilized to detect diabetic retinopathy (DR). For their analysis, they categorize the severity of DR into five classes. Also, a two-step CNN approach was suggested by Yang et al [11] for better accuracy in the same analysis.

In [12], Sharma et al emphasized the benefits of utilizing the powerful programming language, Python. One of the significant factors of python is that it supports the following multiple programming paradigms: procedural, functional, object-oriented, and imperative. It is highly popular due to its ease of use and currently, it is the 4th most used language on GitHub. It opens up opportunities in the machine learning field. Python can be used on a variety of operating systems. Moreover, it is open source which enables the user to make changes to improve as they use and distribute the software. It also supports a combination of other languages like C/C++ or Java with good scripting capability.

IoT is widely used in applications such as smart transport, smart home, smart health, etc. In [13], Cabral and Gomes designed an IoT-based healthcare system to assist their targeted group, the elderly population. Their system consisted of a We-Watch from where the collected vital data was displayed on their We-Care board by implementing IoT. Furthermore, the Internet of Medical Things (IoMT) has flourished in recent years. It is the integration of medical devices with IoT. In [14], Razdan and Sharma discussed the importance of IoMT and its architecture. They mentioned that IoMT has enabled healthcare systems to be more efficient in terms of both maintainability and service, and also made telemedicine and remote health monitoring more functional.

1.1.3 Literature Gap

Firstly, from the thorough analysis of the existing systems, it can be derived that body wear devices can be uncomfortable for patients to wear at all times for constant monitoring. In addition, non-wearable devices such as cameras that capture faces, involve privacy issues and discomfort as the patients are aware of them being recorded at all times. Secondly, there are more detection systems than prediction systems dedicated to this issue of bell falls but that is inefficient because it only alerts after the fall has occurred and the patient has already been subjected to injury. The established implementations of prediction systems have few positions that they can detect and they consist of too many preconditions that result in a complicated system. Therefore, integrating a simple system with a comfortable device that does not intrude on privacy is desired. Also, a system that can detect multiple positions could benefit vulnerable patients.

1.1.4 Relevance to current and future Industry

Fall prediction systems are more desirable than detection systems in the medical industry [15]. It is sought out for research and funding as it is considered more efficient than the available detection systems. Also, the remote health monitoring system will enhance job opportunities in the Telemedicine sector. Furthermore, the proposed solution will practice contactless monitoring that can be beneficial in cases where the patient is diagnosed with contagious diseases, for instance, the current covid situation. In outline, the targeted problem prevails so the solution to this is demanded and applicable throughout time.

1.2 Objectives, Requirements, Specifications and Constraints

1.2.1 Objectives

The objectives of the project are as follows:

- Detect multiple positions and orientations of impaired patients lying on the bed
- Warn caregivers and medical personnel when the patient is at risk of falling off the bed to help prevent bed falls
- Remotely monitor the patient's health even when asleep
- Analyze heartbeat, oxygen saturation (SpO2), and body temperature reading to offer better medical advice to patients and detect any anomalies

By integrating multiple pressure sensors within a medical bed, the system will be able to detect a patient's position and orientation in order to predict when the patient is at risk of falling. Warnings will be sent to the caregivers to attend to the patient before he/she falls off the bed. Also, patients will be granted much more privacy by allowing them to stay in their cabins/rooms without continuous supervision from family members or medical personnel. Moreover, patients with neurological disorders like Alzheimer's, and Parkinson's disease, impaired mobility, and even elderly patients, in general, can rest safely without bed rails and straps/restraints. This will allow these patients to receive better treatment and be monitored more efficiently. In addition, by wearing a small wearable device to monitor their heartbeat, oxygen saturation (SpO2), and body temperature, reliable information will be relayed to doctors who can give better medical advice and instructions. The device also sends out warnings to the medical team when an anomaly is detected and better health diagnoses will be provided.

This device will allow Assisted Living Facilities, hospitals, and care homes to monitor patients centrally and effectively by the nursing staff. Health Safety Environment data show that 22% of the reported falls from bed occurred with bed rails in place [16] which also limits the patient’s ability to exit or enter the bed and has also been linked to causing more damage to patients during a fall. Due to the rising number of elderly patients, the system will help to prevent these bed falls and bed rails related accidents even when there is a shortage of nursing personnel.

1.2.2 Functional and Non-functional Requirements

The functional and non-functional requirements are listed below to meet the objectives of this project.

Functional Requirements:

- Detect three main postures of the patient - supine, left lateral, and right lateral
- Identify the position of the patient on the bed
- Predict the possibility of bed falls when a patient is near the edge of the bed, considering the left and right risky positions
- Alert the medical personnel and caregivers about the patient at risk every 5 seconds
- An additional alarm system if the patient is not attended after 6 alerts
- Record medical vitals - oxygen saturation, heart rate, body temperature and sleep quality.
- Inform the medical personnel about the patient’s vitals
- Notify if any vitals are out of the specified range

Non-functional Requirements:

- A Medical Bed of standard dimensions of 40” by 80” for a Bangladeshi patient of an average height of 5’2” (157.29cm) to a maximum height of 6’6” (198.12cm) [17].
- Ensure maximum comfort for the user by using a thick mattress and a light material for the wristband
- To maintain safety, sensors, and wires have to be well insulated, and electrical components should be enclosed in an insulated case
- Avoid physical restraints such as bed rails which could cause additional accidents

The requirements of the system focus on the movements of the targeted patients while they are lying on the bed. This is to identify the correct positions of the patient lying on the bed and further predict if the position detected has any possibility of the patient falling off the bed. If the patient is at a risky position, the system alerts the designated caregiver or the nurse to immediately attend to the patient and provide assistance.

Furthermore, a wearable on the patient’s hand will constantly take readings of the patient’s vitals such as heart rate and oxygen saturation while a digital probe is provided for taking measurements of the body temperature. Under any circumstance, if the vitals are out of the specified range, the medical personnel will be notified directly through a dedicated server dashboard containing the details of the patient.

Moreover, additional requirements of the system are to make sure that the system or the device provides comfort to the patients and also ensure safety by properly insulating the sensors and wiring inside the mattress. To ensure this, a very low voltage will be used to power the system. Also, the system overall provides privacy by encrypting patients’ data that are stored on the server. Additionally, an online survey was carried out to take the consumer’s feature amendments in consideration. Along with that, a stakeholder survey with the director of a hospital was done to have feedback on the design.

1.2.3 Specifications

To meet the aforementioned Functional and Non-functional Requirements, several subsystems have been incorporated for accurate and efficient prediction of a possible action due to bed falls. In addition, several components are mentioned in Table 1 below that fulfill the criteria of the sub-system level specifications.

Table 1. Subsystem Level Specifications.

Sub-system	Tentative Component(s)	Tentative Component Specification
Data Collection	**Force-sensitive resistors**	**Actuation Force:** ~ 0.1N **Sensitivity Range:** ~ 10N **Width:** ~ 1.75inch **Length:** ~ 1.75inch
	16:1 Multiplexer	**Configuration:** 16:1 **Operating temperature:** -55 to 125 °C **On resistance:** 60 ohms **Feature:** Break before make **Supply Voltage:** 5V
Processing Unit	**Arduino MEGA 2560**	**Clock Cycle**: 16MHz **Operational Voltage:** 5V **Input Voltage:** 6 ~ 12V **DC Current:** 800mA **Dimension:** 110 x 80 x 30 mm **Digital I/O Terminals:** 54 **Analog Inputs:** 16 **SRAM:** 8KB
Gateway	**ESP32-WROOM-32 (Wi-Fi + Bluetooth Board)**	**IEEE Standards:** 802.11b/g/n **Processor**: Tensilica LX6 dual-core **Clock speed**: 240 MHz **SRAM**: 512 kB **Memory**: 4 MB **Frequency**: 2.4 GHz **Bluetooth**: Classic / LE **Data interfaces**: UART / I2C / SPI / DAC / ADC **Operating voltage**: 3.3V/5V
Wristband	**Temperature Sensor**	**Accuracy:** ±0.5°C from -10°C to +85°C **Operational Temperature:** -55°C to +125°C **Pins:** 3 (DQ, GND, Data) **Programmable Resolution:** 9 Bits to 12 Bits
	Heart-Rate Monitor and Pulse Oximeter Biosensor	**Voltage:** 1.8 ~ 3.3V **Pins:** 14 **Power:** < 1mW **Current:** 600μA **Resolution (ADC):** 16 bits
Cloud Server	**Blynk**	Server used to store the data and send them to the mobile/pc for further viewing

Several subsystems have been categorized in Table 1 and the components required in each sub-system have been specified with some of their parameters and descriptions. The Data Collection subsystem integrated into the bed will be programmed to determine the particular positions of the patient on the bed. A microcontroller will control a series of sensors that detect a risk when a patient's body is near the edge. Processed data will be sent via IoT from the Gateway system to the mobile application or computer dashboard of the medical personnel/caregiver. A wristband will regularly record the patient's temperature, heart rate, and oxygen saturation level and send them to the processing unit and then to the gateway. A mobile/pc app regularly updates the medical personnel/caregiver about the patient's position and also shows a detailed report about the patient's vitals.

1.2.4 Technical and Non-technical Considerations and Constraints in the Design Process

While planning the Project, two possible constraints have been identified depending on several aspects such as the cost of the Smart Beds as well as the network traffic issues in a gateway server.

Consumer-end Constraint:

A typical hospital bed is already costly. Due to the integration of smart features, more costs would be added. There is also a remote health monitoring system which is done by a small wearable device on the wrist. All of these contribute to the cost of the bed. As a result, the Smart Bed can only be affordable by hospitals and medical care centers since it is not cost-friendly for individual use by a patient in their homes.

Technical Constraint:

A small delay is present in the transmission of data between the gateway and mobile/pc app. This is due to the network traffic in WLAN and also depends on the number of medical equipment or other devices connected to the network.

1.3 Applicable compliance, standards, and codes

A medical device has a huge responsibility of ensuring the patient's safety and protection while providing the respective service with high quality and reliability for proper diagnosis. Every country has its advisory authority to validate the design of the system and to ensure its operation falls under the policies of that country. Bangladesh's medical device compliance authority is known as the Directorate General of Drug Administration (DGDA) [18]. The medical device is required to be compliant with the rules and regulations of governmental bodies such as DGDA to prevent the violation of malpractices in the health sector.

The applicable standards, codes, practices, and their application to the project have been mentioned in Table 2.

Table 2. Applicable Standards and Codes.

Devices & technology	Standard Codes	Description	Application
Sensors	IEEE 2700-2017	Common framework concerning sensor performance specifications, units, conditions, and limits	In Bed Fall Prediction System for force sensitive resistors & Health monitoring system for temperature and SpO2 sensor
	ISO 20685-1:2018	Evaluation methodology for body dimensions generated from 3-D body scans in 3-D scanning technologies for internationally compatible anthropometric databases	Applicable to the use of Kinect sensor in the first design approach
Practices	IEEE 602-1996	Recommended Practice for Electrical systems in health care facilities such as buildings of hospitals and nursing homes, clinics, etc.	Hospital, care centers, nursing homes
Medical Equipment	IEC 60601-1-11:2015	Requirement instruction for medical electrical equipment and also their use in healthcare environment	Bed Fall Prediction System and Health monitoring system
	ISO 15223-1	Specifies the symbols that will express certain information with medical devices	
	ISO 13485:2016	Standard for quality management system of medical devices	
	ISO 14971	Developed a set of rules for risk management of the device and its appliance	
	ISO 1642-2:2017	Guideline for safety standards of medical devices	
IoT	IEEE P2413-2019	Developing an architectural framework for the Internet of Things	Bed Fall Prediction System and Health monitoring system
	IEEE P1451.99	Defines method for data sharing, interoperability of sensors, wireless network messages in communication technology	
Cloud	IEEE 2301-2020	Guideline for cloud portability, application, management interfaces, etc.	Remote health monitoring system for storing and sharing the data collected from the sensors
	IEEE 2302-2021	Standards for inter-cloud messaging operation	
Bluetooth	IEEE 802.15.1	Standards for telecommunications and	Transferring data from

		information exchange	devices to IoT
Hospital Bed	IEC 60601-2-52:2009	Applies to the basic safety and essential performance of medical beds intended for adults.	Medical bed
Neural Network	ISO/IEC TR 24029-1:2021	The robustness of neural networks is evaluated.	Applicable for the second design approach
	ISO 27001	The standard for the Assessment of Visual Experience Using Deep Learning and Human Factors.	
Electrical Safety	IEEE 1143-1994	Shielding for Low Voltage Cables: An IEEE Guide	Applicable for all designs
	IEC 60601	Safety standards	

1.4 Systematic Overview/summary of the proposed project

Alzheimer's Disease, Parkinson's Disease, and dementia are all diseases associated with old age. Patients who suffer from such diseases have a limited cognitive function and are usually in a state of confusion. Such patients are at risk of bed falls and absent-minded bed exits. A state of confusion seldom leads the patient to wander off without notice and lack of cognitive mobility and function may lead to bed falls which might injure the patient or worse, cause fatality.

The proposed project looks into a solution to prevent accidents from bed falls by identifying multiple positions and orientations of patients lying on the bed. The project will warn caregivers when the patient is at risk of falling off the bed to help prevent bed falls or bed exits. In addition, a remote health monitoring system will constantly analyze the patient's heartbeat, oxygen saturation, and body temperature and store them in a cloud for future diagnosis and send warnings when an anomaly is detected. The system has been designed per the applicable codes and standards. Both consumer-end and technical constraints have been identified and taken into consideration. Functional and non-functional requirements have been noted and the project seeks to meet the aforementioned objectives and safety standards.

1.5 Conclusion

From a thorough literature review it has come to light that old age patients and patients with neurological disorders and impaired mobility often suffer from Bed Falls. Bed fall accidents are very frequent and the subsequent treatments are very expensive. The patients are often at risk of falling off the bed so assistance is required from family members and nurses at all times. However, it is not feasible for nurses to monitor every patient at all times or even for a family member to be around without leaving the patient for a moment. To overcome this problem, the designed solution can detect the on-bed postures of the patient and then predict if the patient is at risk of falling off the bed and send alerts before any risk. Moreover, the design integrates a remote health monitoring system that continuously records the patient's vitals and notifies if there are any anomalies. Hence, the system will enable monitoring of the patient in a much easier and more effective way.

Chapter 2

Project Design Approaches

2.1 Introduction

In Chapter 1, specific objectives were defined for the project. To achieve those objectives independently, three unique designs have been explored. In the literature review conducted in Chapter 1, multiple methodologies were introduced to tackle bed falls. These include a non-wearable approach, a wearable approach, and a hybrid (combination of both wearable and non-wearable) approach. The project targets patients mainly with cognitive disabilities and dementia. As a result, wearable and hybrid approaches were excluded.

2.2 Multiple Design Approaches

2.2.1 Approach One

A Depth-based Fall Prediction System employs the Microsoft Kinect Sensor to collect multiple depth-based images using the built-in RGB camera, IR projector, and IR camera. The images are then analyzed to identify joints of the human body and detect their motion. To predict the risk of fall, the boundary of the bed is set manually and the 3D coordinates generated for each joint are converted to 2D screen coordinates which are then compared with the set boundary of the bed to check if the patient is lying inside the boundary of the bed or not. The level of risk is determined by the percentage of human joints lying outside the boundary.

2.2.2 Approach Two

An On-bed Pattern Recognition Classifier is implemented utilizing a feed-forward Neural Network. A pressure sensing mat made up of capacitive touch sensors collects the pressure data at different positions of the bed which would be used to generate images. The images are to be used to train the classifier implemented using Convolutional Neural Network (CNN). The dataset in [20] has been used to proceed testing out the model. It predicts the position of the patient on the bed and based on that position, the risk of a fall is predicted.

2.2.3 Approach Three

A Rule-based Fall Prediction System using multiple piezoelectric sensors are placed inside the mattress in a grid layout. The grid is then divided into 7 segments and the pressure reading from each sensor is recorded. Based on the number of sensors detecting pressure in each segment, the whole segment is considered to be High or Low. For a particular lying position, a combination of the segments should be High for the system to identify that exact position. The position is identified as risky if that is too off the bed center of the bed or closer to the edge.

2.3 Description of Multiple Design Approaches

2.3.1 Depth-based Fall Prediction system using Kinect Sensor

Design Approach One predicts the chance of a bed fall through continuous monitoring of the patient's position on the bed by collecting depth images using Microsoft's Kinect sensor. This sensor consists of an IR Projector and an IR camera to detect the depth of an object. Using its infrared depth sensors, the Kinect can take a real-time 3D image of a human skeleton at any time of the day or night. It is capable of locating up to twenty skeletal joints. This design is inspired by the work presented in [19].

At first, the four corners of the bed's RGB image are marked manually to create an artificial boundary and their corresponding (X, Y) coordinates are found. Then, for each human skeletal joint, its 3D coordinates are collected and converted to its corresponding 2D screen coordinate using the coordinate mapping technique. This can be done with the help of Microsoft Software Development Kit's (SDK) SkeletonPointToScreen function. Once the 2D screen coordinates of each human skeletal joint have been created, they are compared to the bed's predetermined boundary to see if they fall inside or outside of it. Each skeletal joint is assigned a percentage value which determines how much it contributes to the risk of fall. This value can be changed according to different patients and situations. Considering all the joints contribute equally to the risk of fall, then, if more than 25% of all the joints are outside the border, a warning signal would be given to the caregiver; if the risk is much higher, such as 50% or more, an alarm signal will be delivered via IoT. The processing is done by the microcontroller connected to the Kinect sensor and data is sent to the cloud with the help of Esp32 WiFi module.

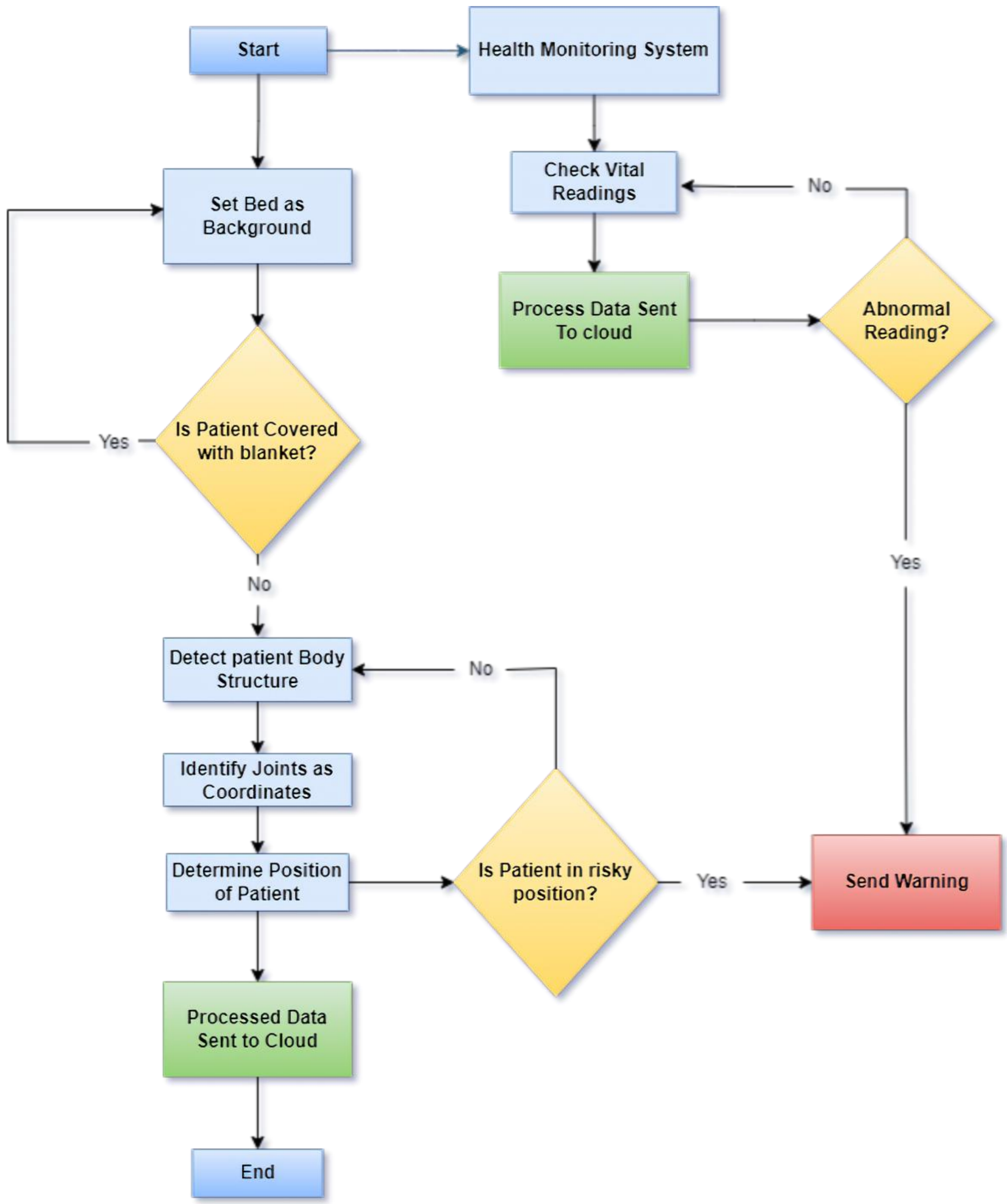

Fig. 1. Workflow of Approach One.

2.3.2 On-bed Pattern Recognition Classifier using Neural Network for Fall Prediction

Design approach two is a pattern recognition classifier that can accurately identify the posture of the patient lying on the bed and predict whether the patient is at risk of falling off the bed. The classifier is implemented using Convolutional Neural Network (CNN) as CNNs perform far better in image classification compared to Deep Neural Networks as it reduces the network complexity leading to fewer chances of overfitting. A pressure sensing mat collects the pressure data at different positions. It is further converted to image data and then fed to the classifier.

To train the model, a publicly available dataset in [20] has been used which contains on-bed pressure data for several participants. Since the implementation of a pattern recognition classifier that can predict the risk of a bed fall by continuously analyzing the patient’s posture, this dataset aligns and facilitates the project's objectives. Therefore, it was used to train the model.

The raw data is preprocessed to check if there is any missing value and remove any redundant data and then split into separate training and testing datasets. A CNN model is created with two 2D convolutional layers each followed by a Max Pooling layer which is fed to the input layer of Multi-Layer Perceptron. The CNN process is such that the preprocessed dataset is run through layers of convolutions which consists of many feature detectors/maps that filter an image for a particular feature. Then, it is passed through Rectified Linear Unit (ReLu) where the data is non-linearized, which helps to detect the feature in the filtered image. Next, max pooling is carried out where the data is condensed to reduce the size and preserve the main features. The data then goes through the process of flattening where it is sorted into a single column. Finally, Full Connection is done where through voting the processed data is trained via front and back propagation process. Here, the weights and feature maps are both trained which results in a strengthened model for accurate prediction. Output to the hidden layer is set to 5 (one for each position) as per the design objective. Then the model is instantiated and the Loss function and optimizer are set. If the probability of any risky position is high, a warning message is immediately sent to the caregiver.

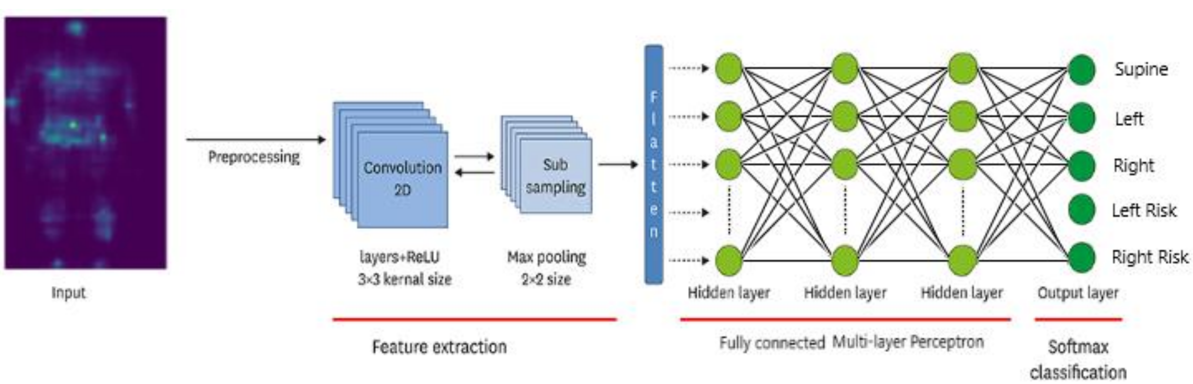

Fig. 2. Architecture of the CNN model [21]

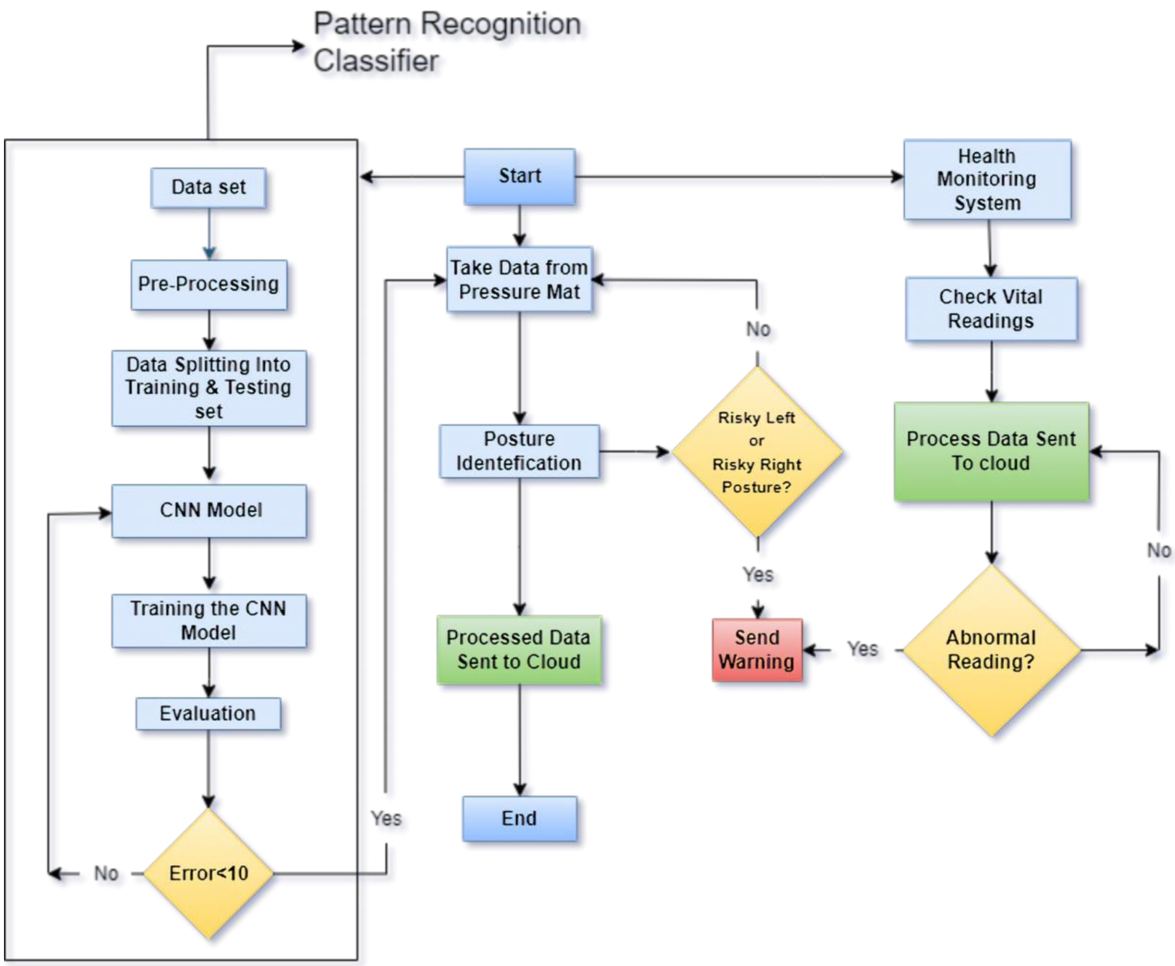

Fig. 3. Workflow of Approach Two

2.3.3 Rule-based Fall Prediction System using Embedded Piezoelectric Sensors

In this approach, a Rule-based Fall Prediction System is designed which continuously checks the position of the patient on the bed by analyzing the data collected from a pressure sensing mattress. This design is influenced by the work in [22]. The mattress has 50 Force Sensitive Resistors (FSR) as the piezoelectric sensors, placed in a grid layout of 5 rows by 10 columns with an adjacent sensor gap of 4.7 inches vertically and 6.8 inches horizontally. These FSR sensors work like variable resistors due to the piezoelectric material inside them so their resistance changes as pressure is applied and thus voltage drop across each resistor also changes. All the 50 FSRs are connected to a microcontroller through multiplexers which collects and converts the analog voltage readings to digital data for further processing.

The algorithm divides the grid layout of the sensors into 7 segments as shown in Fig. 4. below and then checks if a certain percentage of sensors are enabled in each segment. The sensors are considered to be enabled if the pressure reading is above a certain threshold value. The microcontroller then processes the number of active sensors and determines which segments are high according to a rule-based method. For instance, for a patient lying in the left risk position, a minimum of 4 sensors out of 6 (66.67%) in segments 1 and 3, and 6 out of 8 sensors (75%) in segment 2 should be active for the system to identify the position as left risky.

The percentage of the number of sensors that need to be activated was determined based on the amount of area that an average person might cover when he is at either of the risky positions of the bed. A similar program has been coded for other positions like left lateral, right lateral, and middle. The system predicts the risk of falling as a result based on the likely position of the patient. Whenever the patient is at risk, the caregiver or the medical staff gets an alarm/warning so that the patient can be attended to immediately before he or she falls off the bed. This algorithm runs continuously to check the position and postures of the patient in real-time. Additionally, these data are sent to a cloud to store data for future reference. This is done with the help of the IoT.

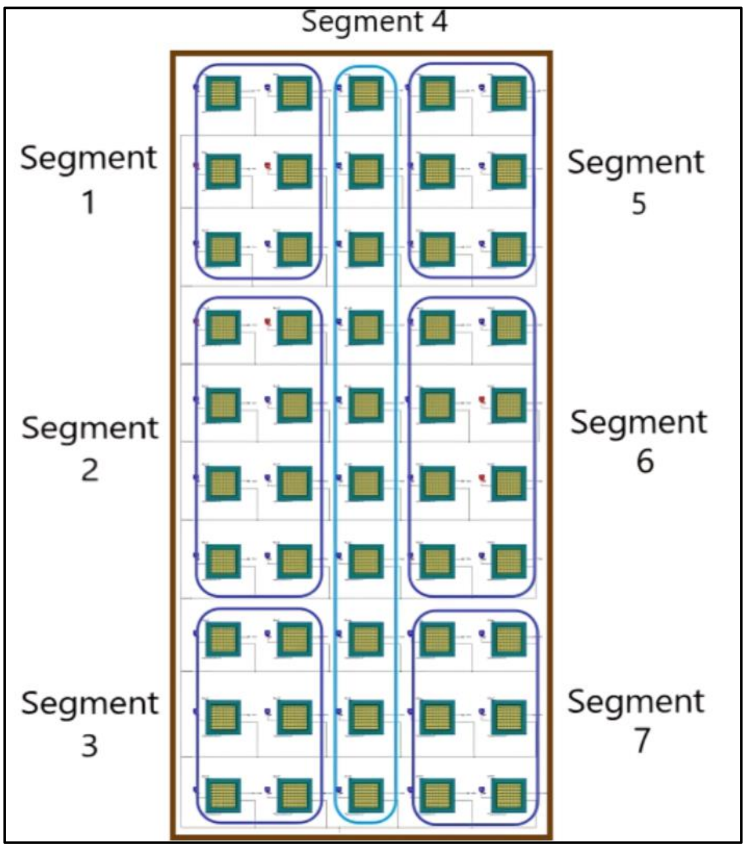

Fig. 4. Sensor Layout of Approach Three

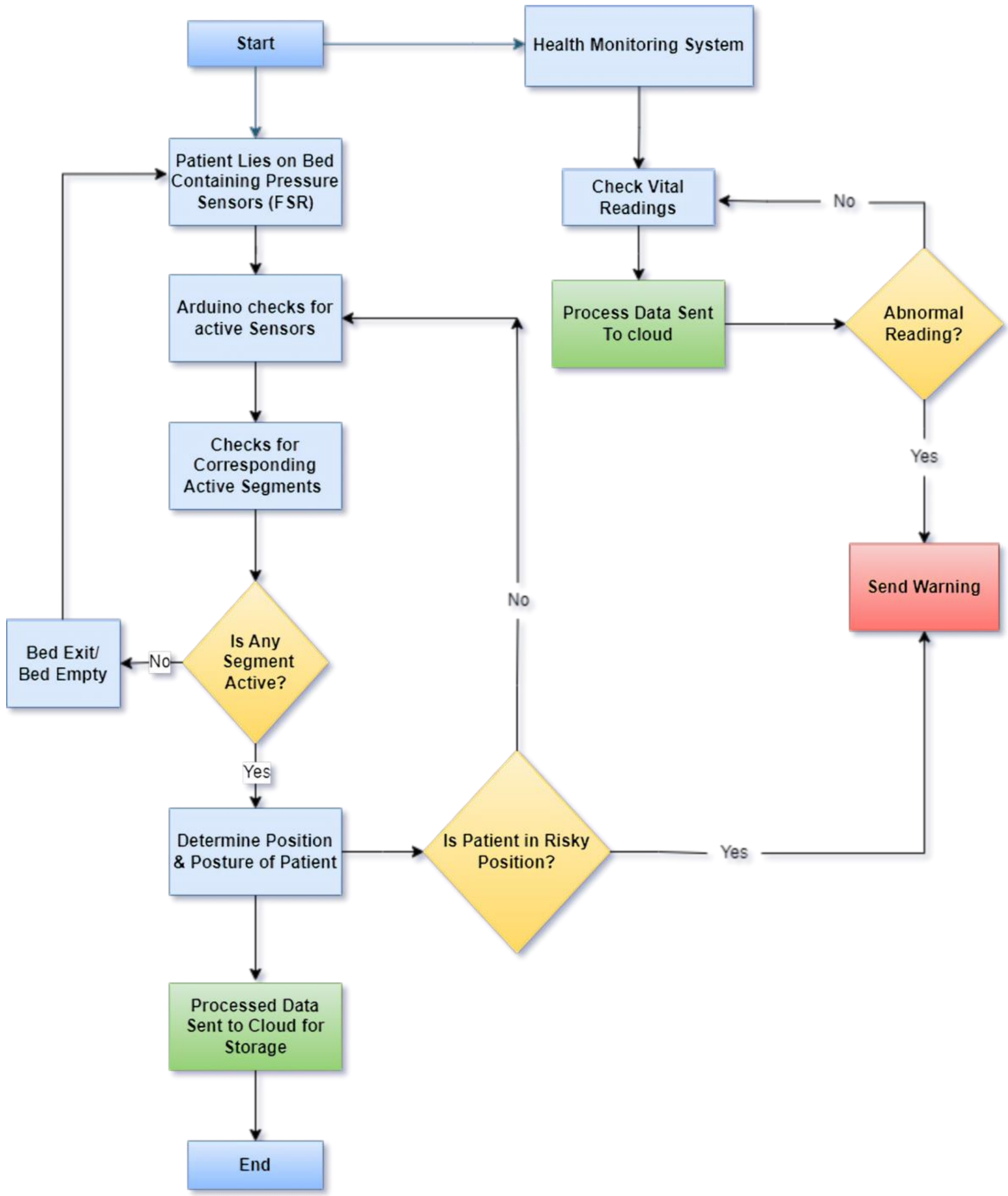

Fig. 5. Workflow of Approach Three

All three approaches include a gateway consisting of an Esp32 Wifi and Bluetooth module which sends the processed data from the microcontroller/processor to an IoT analytics platform to view the patient's position and health parameters. This data is also available for the users/caregivers to be accessed through a website or mobile application. The platform can also be used to send alerts via push notifications and emails.

2.3.4 Health Monitoring System

The Health Monitoring System has been designed to take readings of the patient's health parameters such as Heart Rate, Oxygen Saturation (SpO2), and Body Temperature. The data generated is then processed to check for any abnormalities in the reading and warn the medical personnel. The data is also stored in the cloud for future access by nurses and doctors. The system is designed in the form of a small wearable device worn by the patients on their wrists. The sensors used are MAX30100 for Heart Rate and Oxygen Saturation (SpO2) and DS18B20 for Temperature. The data collected is then processed by an ESP-32 development board which continuously checks whether the readings are within the standard range and sends alert messages to the caregiver if there is any irregular reading. Similar to the fall prediction system, the data can be viewed through a dashboard.

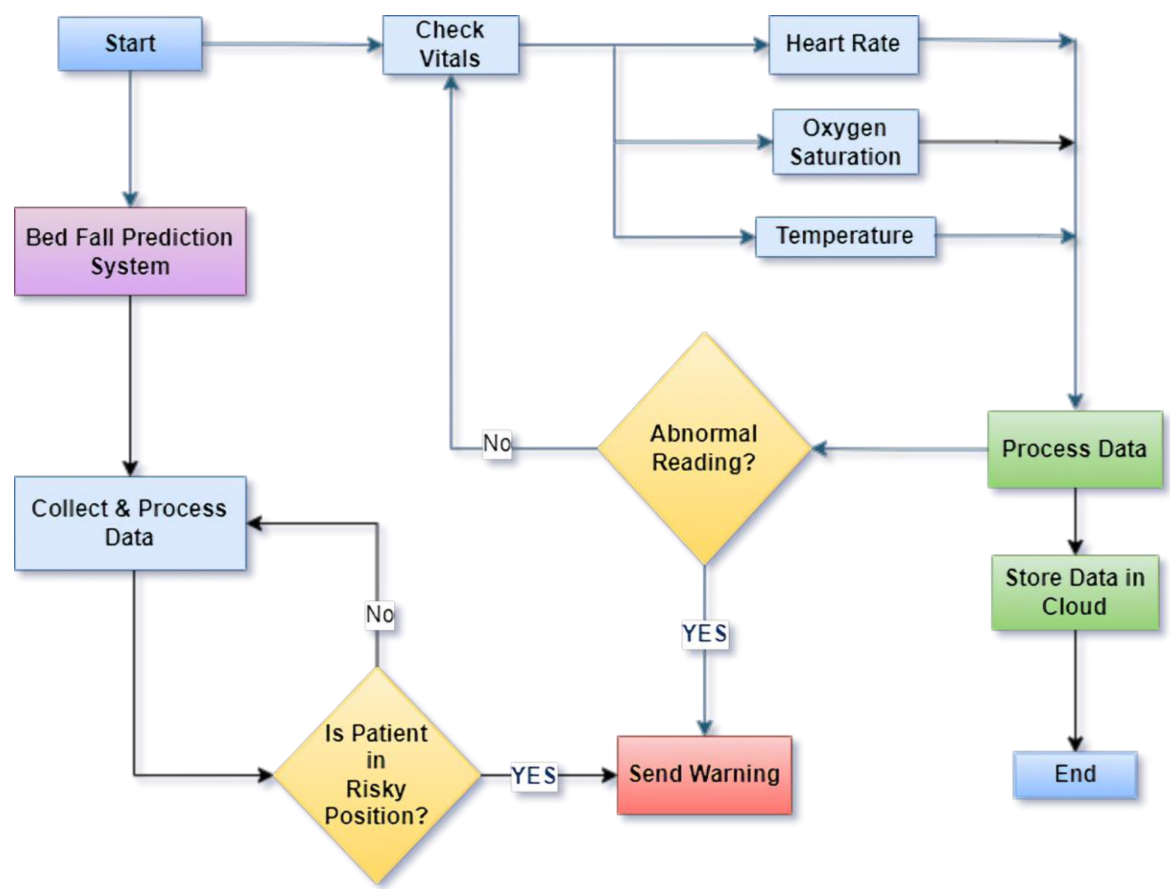

Fig. 6. Workflow of Health Monitoring System

2.3.5 Internet of Things (IoT)

All the design approaches use IoT to send the processed data to the cloud for future access and alert the caregiver or medical personnel about any risk of bed fall through the messaging system.

IoT stands for Internet of Things. This phenomenon enables the creation of a collective network where analog sensors can transfer their data to the cloud. Here, the data is not only stored but also sorted and further passed to the dashboard which can be viewed via mobile or personal computer.

The IoT has four main units for its generic function: connectivity, processing, visual, and storage. The IoT has essentially five layers that construct the flow of the application. They are the perception layer - consisting of sensors, and RFID chips, etc, the network layer - where the information is transferred from the perception layer to the processing system via Bluetooth, 4G, and WiFi, etc; the middleware layer - where the received data is processed and a decision is made via ubiquitous computing; application layer - this handles the global device management, and finally the business layer - provides the visualization to the final data so that is can be easily displayed for ease of interpretation.

IoT devices can be unidirectional or bidirectional to suit their desired communication means. For remote communication, a gateway is used to transfer the processed data. There are several network protocols available such as Wi-Fi (most suitable for LAN networks for several computer interconnections and low-power applications), Bluetooth (for short-range applications), Satellite, or a direct internet connection through the ethernet port. Additionally, an important factor for the assessment of IoT is Quality of Service (QoS). It is used to check the quality and performance of the device and its architecture.

2.4 Analysis of Multiple Design Approaches

2.4.1 Analysis of Approach One: Depth-based Fall Prediction System

Cost

This method only consists of the Kinect v1 sensor. The Kinect sensor was introduced in 2010 and was discontinued in 2015 after introducing the Kinect v2. Considering that a device that will incorporate an IR projector, an IR camera, and an RGB camera altogether, the Kinect functionality can be replicated. The cost would be meager considering that the device would have no gaming functions and would solely be used for this system. The cost for this approach is around BDT 9,600 to BDT 19,200 depending on the model and the alternative of the discontinued Kinect v1 device.

Efficiency

The device has a high latency of greater than 80 ms compared to the other two designs. In this case, the Kinect device also fails to properly distinguish the distance between two closely kept objects: the patient and the hospital bed. From the test cases performed, it was observed that the skeletal data appeared to be distorted when the subject lay down on the bed but appeared to be fine when standing or sitting due to this reason. The efficiency of this approach would be the least among the three designs

Usability

The Kinect sensor needs a clear field of view to detect objects. People, in general, tend to use blankets. This will obstruct the device's perception of distance and therefore detection of the patient's body and motion will not be possible. The design does not involve the usage of an RGB camera but the device already contains this. This can raise privacy concerns among users. Considering the Kinect device maps joints as coordinates, this may also raise privacy concerns as real-time movement can be observed. The Kinect v1 device needs to be within 2 meters of the bed and subject to detect movement. All these usability constraints do not exist in the other two designs.

Manufacturability

Considering the availability of the individual components in the Kinect device (IR projector, IR camera, and RGB camera), the manufacturability of the device will not be difficult. The system primarily depends on only one Kinect device so the replication and mass production of the design can be done with ease. This approach consists of the least amount of parts required among the three designs, hence making this approach the one with the highest manufacturability.

Impact

The design aims to enforce the safety of the patients by monitoring their movement and sending warnings accordingly. Bed rails contribute to injuries and even death. Patients who suffer from Parkinson's Disease, Alzheimer's Disease, or any other neurological diseases that affect their cognitive abilities, are at severe risk of injury by bed rails. Strapping them to the bed will only cause them to feel much more uncomfortable and may also pose mental and physical health risks. Having them remotely monitored and not being bound by straps and bed rails will contribute greatly to their safety both physically and psychologically. Moreover, the individual components (IR projector, IR camera, RGB camera) do not pose any health risk to the patient. It is completely safe.

Sustainability

This approach has moderate to low environmental sustainability factors. The system does not contribute to carbon emissions. The only place where this can be an issue is in the manufacturing process that makes the components and the bed. The device itself is fully electrically operated and does not require any natural fuel resources. This project aims to reduce bed falls. This approach acts as a movement monitoring system and will help monitor patients. Alerts and warnings will be sent accordingly to on-duty nurses. This will ultimately reduce the burden on caregivers and nurses as they do not have to frequently check up on patients. Family members of the affected will also be less tense.

Maintainability

This approach only consists of a single Kinect/Depth camera device which is to be installed within 2 meters of the bed. The bed itself will not have any other function. The bed will be set as the background by a simple line of code. The IR camera and IR projector itself do not need to be physically interfaced at any point in time besides the installation. If properly cleaned periodically, the system should run properly. The maintainability of this approach is the best among the three designs.

2.4.2 Analysis of Approach Two: On-bed Pattern Recognition Classifier using Neural Network for Fall Prediction

Cost

In this design approach, a pressure mat acts as the input device for the trained CNN model. However, this method requires a significantly more number of pressure sensors to generate enough data to create images or heat maps accurately. Also, a Raspberry Pi processing unit or tiny machine is required to run the model which costs much higher than simple Arduino microprocessors. These two factors contribute to the cost of the model which is likely to be at least ten times higher than other approaches.

Efficiency

This method showed higher accuracy in identifying different postures of the patient. Currently, it can classify 5 different postures but if trained with more data, additional postures can also be classified. This also creates a future scope for integrating a bed ulcer prediction system as this model performs well on stationary pressure data. However, one significant constraint of this approach is that it takes a little longer to predict the risk of bed fall so it might fail to predict a fall if the patient moves too fast. Additionally, due to the higher number of pressure sensors needed, the power consumption could be high.

Usability

The pressure mat is safe for anyone to use as the sensors are well insulated and the patients are likely to feel more comfortable using this device as it has no privacy concerns. For this device, if the model is trained with diverse data, it can accurately predict a bed fall for a larger number of users. Moreover, it is very easy for patients to use and can be set up in any standard medical bed. This device, if installed in hospitals, will enable nurses to monitor more patients at the same time.

Manufacturability

The pressure mat has a fairly simple circuit and does not require a variety of components. Although the budget of the prototype is significantly higher than other approaches, mass production can reduce the per-unit cost, as well as customized processing units can be made by collaborating with manufacturing companies.

Impact

Studies have shown that patients choose to reduce their participation in daily activities, mainly those related to mobility, due to the fear of falling which is caused by the mental trauma experienced earlier during a fall. This device not only helps those patients to regain their confidence but also eases the job of caregivers.

Sustainability

The pressure mat is made from force-sensing resistors so the design sustainably of this approach is similar to that of the third approach. Although the unit cost is comparatively higher, commercializing the device will significantly lower the price and more hospitals and care homes can afford it.

Maintainability

This device only predicts bed falls but cannot prevent them, a caregiver must be present to reposition the patient if the device sends any warning signal. Since this is a medical device, it needs to be thoroughly checked if there is any insulation fault or loose connections before the patient uses it.

2.4.3 Analysis of Approach Three: Rule-based Fall Prediction System using Embedded Piezoelectric Sensors

Cost

The cost of each force sensitive resistor is relatively lower than that of Approach Two. The price would decrease further when these will be custom ordered in large quantities directly from the manufacturer or even collaborate with distributors for large-scale production of the device. The cost of the whole device will be around BDT 50,000 which is moderate comparatively.

Efficiency

This method performs a faster real-time prediction which has been observed from the Proteus simulation results. This enables the system to have enough room for latency in wifi, Bluetooth, or multiplexing and still predict the risk in a very short time. In addition, the system requires no other training models to run to predict whether a patient might fall off the bed or not. The FSRs have a very low response time of less than 1 ms and low power consumption comparatively as well [22]. It can also be observed that the prediction has been made with only 50 sensors with only a small amount of these sensors being activated for the system to make a decision and send a warning.

Usability

The model incorporates the FSRs inside the mattress with proper insulation and the sensors can immediately measure or detect whether a person is on the bed or not. The device does not require any special alignment or calibration to be used like the Kinect device in Approach One. It can be accessible to all kinds of patients who have the risk of falling off the bed.

Manufacturability

The FSRs are made up of polymer thick films which change pressure when pressure is applied to their surface. The FSRs are very small and can replace the bulky load cells [22]. It also has a very simple design so the sensors can be manufactured at convenience and it would not require much raw material to produce each unit.

Impact

The use of FSRs has several impacts in reaching the desired objectives. The patient does not need constant surveillance by a caregiver and can be attended to only when the patient wants or when the patient is at risk. The traditional bed rails are not needed anymore. Additionally, the device performs real-time monitoring of the patient's position on the bed so the chances of an accident are very low as a faster prediction algorithm has been developed.

Sustainability

The force sensitive resistors have a long life and can be used in the long term [23]. The system also requires a simple inexpensive Arduino microcontroller for processing the data and monitoring the movements effectively. The design also uses components that do not harm the environment or give off any harmful vapors or gasses. In addition, the sensors have a very low power consumption so offer a very sustainable use in the long run.

Maintainability

The medical device needs to be constantly checked for any fault in the insulation as well as perform test runs to see if the sensors are working properly at regular intervals and before a patient uses it. However, due to its durability, maintenance is easy and requires a small amount of work to be done. However, the gateway protocols need to be constantly observed to make sure that the system sends data continuously to the cloud for the warning to be sent at any given time required.

2.5 Conclusion

Specific project objectives were laid forth in Chapter 1 of the book. It has been investigated how three different designs can each independently accomplish the specified goals. The three approaches explored have been explained in detail. A comparison of the three approaches has been provided in terms of Cost, Efficiency, Usability, Manufacturability, Impact, Sustainability, and Maintainability. All three approaches have been integrated with a remote health monitoring system that stores data and sends warnings through IoT accordingly.

Chapter 3

Use of Modern Engineering and IT Tools

3.1 Introduction

For the successful implementation of the project, various IT tools have been used. These helped to evaluate the performance and design of each of the design approaches and identify areas of improvement before actual hardware implementation. Hence, the optimal design could be verified.

3.2 Selection of Engineering and IT tools

3.2.1 Arduino IDE

The Arduino IDE is an open-source software that was used to program the microprocessors used. The optimal solution consisted of Arduino Mega 2560 as its main processing unit while the ESP-32 development board was used for the transmission of data via Wi-Fi. Both the Arduino Mga2560 and ESP-32 development boards were programmed using the Arduino IDE software. The software allows convenient programming and is based on the C++ language. The program can be easily uploaded to the microprocessors by choosing the specific board, processor, and serial communication port that the microcontroller is connected to the designated computer. Moreover, for design 3, the program could also be converted to a hex file for simulation in software such as Proteus.

3.2.2 Blynk

A vital factor of the project is the implementation of IoT to store and display the patients' data. This has been achieved with the help of the Blynk web dashboard and mobile dashboard. Blynk can be used to display the patients' data in words and numbers and can be viewed from both computers and smartphones, whichever seems preferable to the respective users. For cases where a nurse/caregiver is attending to a single patient, the mobile dashboard seems convenient and for cases of multiple patients, the web dashboard of the Blynk can be used for alerts and notifications.

3.2.3 Proteus

For the software implementation, particularly for the schematic design, Proteus has been chosen due to its variety of components available. For design 3, the circuit schematic diagram has been designed using a square force-sensitive resistor (FSR) for pressure sensor simulation and Arduino

Mega 2560 for processing the data. The Bluetooth module HC05 has been used for communication between the processing units to pass the data wirelessly.

3.2.4 Kinect for Windows SDK v1.8 & Kinect for Windows Developer Toolkit v1.8

The Kinect for Windows Software Development Kit (SDK) allows developers to build apps that are capable of supporting gesture movements and voice. The Kinect v1 has depth sensors that enable the device to track movement. The first approach utilizes the Kinect sensor's ability to perceive depth and track human joints as coordinates. To track the patient's movement on the bed, a rectangle border is set which is defined as the bed's boundary. The developer Toolkit contains source code samples and other resources to assist in developing Kinect for applications. To use the Kinect, both Windows SDK and Windows Developer Toolkit are necessary. With the help of the Kinect for Windows Software Development Kit, programmers may use the Kinect sensor technology in PCs running Windows 7 and later for the creation of programs that support movement and even voice recognition.

3.2.5 Microsoft Visual Studio

Visual Studio is an integrated development environment otherwise known as IDE developed by Microsoft. It plays a vital role in the development and creation of websites, web services, web applications, computer programs, and mobile applications.

Visual Studio allows the debugger and code editor to support almost every programming language if a language-specific service is available. Microsoft Visual Studio has been extensively used to develop the application for the first approach. C# programming language has been used to develop the app in this case.

3.2.6 C# programming language

According to [24], A contemporary, type-safe, and object-oriented programming language is C# (pronounced "See Sharp"). C# enables programmers to build a wide range of .NET-compatible applications which are reliable and secure. Some C# features are useful in building powerful and robust computer and mobile applications. C# has been used to configure the Coordinate Mapper code provided in [8].

3.2.7 Google Colaboratory

The Google collab platform has been used for programming the CNN model. The programming has been done in python. The convenience of multiple users coding simultaneously with quick updates has facilitated working on the code collectively. This has made the debugging process easier as well.

3.3 Conclusion

The above-mentioned Engineering and IT tools have been used throughout the development and implementation phase of the project. These have helped to assess the viability of each of the design approaches and ultimately choose the optimal design for implementation. Various strengths and constraints of the design approaches could be identified before hardware execution which has made the design process faster. The rest of the tools are used for the final prototype development.

Chapter 4

Finding the Optimal Solution and Optimization of the Design

4.1 Introduction

After analyzing the multiple design approaches, design approach 3 has been selected as the optimal design solution. This design is then implemented and its performance has been evaluated. The system fulfilled all the objectives and requirements however, its accuracy could be further improved. Hence, a few optimizations have been done which significantly improved its performance and usability.

4.2 Identification of Optimal Design Approach

From the tabular analysis of all three approaches in Table 3, the most optimal solution of the three is Approach Three which uses the Rule-based algorithm by incorporating 62 units of square force-sensitive resistors in a grid layout inside a mattress.

Table 3. Analysis Summary of the three Multiple Design Approaches.

Aspect	**Approach One**	**Approach Two**	**Approach Three**
Cost	BDT 9,600 ~ BDT 19,200	5,00,000	BDT 50,000 approx
Efficiency	Latency >80ms	Depends on the processing unit + not best for real-time monitoring	Response time <1ms
Usability	Obstruction + Privacy Issues	Obstruction not an issue + wide sensing area + no privacy issues	No special alignment required + Obstruction not an issue + Properly insulated
Manufacturability	Single device, therefore easy to manufacture and standardize	Requires more numbers of sensors for the pressure mat, and faster processing unit	Simple design, therefore easy to manufacture and assemble

Impact	Bed rails not required + Fewer accidents + mental and physical health ensured	Bed rails not required + Fewer accidents + mental and physical health ensured	Bed rails not required + Fewer accidents + mental and physical health ensured
Sustainability	Moderate life cycle + Low Power consumption	Long life cycle + High power consumption + Data hungry + High processing power	Long life cycle + Low power consumption
Maintainability	Regular cleaning + Server connection needs to be observed	+Server connection needs to be observed	Insulation checks + Server connection needs to be observed

The cost of the Design Approach Three is relatively moderate in comparison to the inexpensive Kinect (Approach 1) and costly pressure mats (Approach 2). This approach uses a much lower number of piezoelectric sensors than the number of sensors that a pressure mat contains making it cheaper. Moreover, the system of the third design approach has the lowest response time compared to approach 1 which uses the primal version of the Kinect, and approach 2 which depends significantly on the processing power of the microprocessor used. As a result, Approach Three is ideal for real-time monitoring. Furthermore, the third approach has a moderate manufacturability factor, as it uses more components than the first approach 1 but uses significantly less number of sensors than the second approach. This approach is estimated to have a long life cycle and less power demand due to the simplicity of its design.

4.3 Optimization of the Optimal Design Approach

Hardware implementation of Approach Three had been performed based on the sensor layout as shown in Fig. 4. It had 50 FSR sensors divided into 7 segments and based on the combination of the segments activated, the position of the patient was determined.

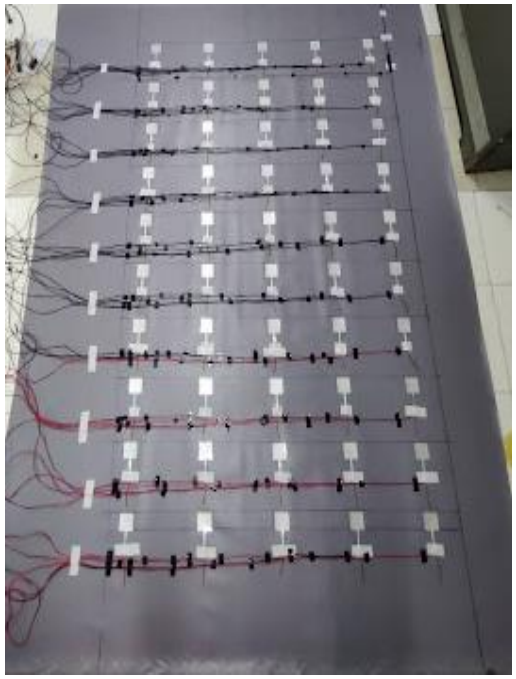

Fig. 7. Hardware Implementation of the optimal solution before optimization

The system had been tested out by volunteers and the results were inconsistent due to the variation of the body structure of each subject. It was observed that the recognition rate was low especially for lean subjects who would fall in between the columns of sensors, resulting in segment activation. Also, it was difficult to differentiate between a normal lateral position and its corresponding risky position, for instance, the right lateral and right risky position.

To make the system more universal and standard for the inclusion of all types of body structures, 12 more FSR sensors have been added at positions, which were not previously covered by the sensors, to correctly differentiate between different positions. This has been done to increase the recognition rate which was previously low.

The optimized design with additional 12 FSRs can be seen in Fig. 8. The upgraded system consists of 62 FSRs in total that are divided into 11 segments. The extra segmentations solved the issue of proper segment activation and elevated the performance of detection as well as distinguishing the lateral and risky positions more accurately.

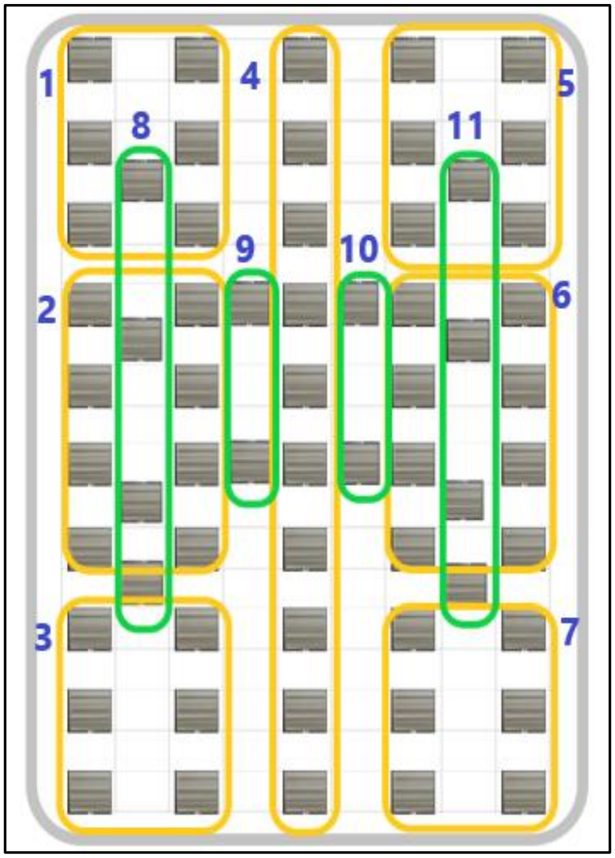

Fig. 8. Sensor Layout after optimization

To get better results, the fall prediction system has been tested for two different threshold values. That is, the minimum analog input from each sensor has to reach a certain value for it to be considered active when pressure is applied on the sensor. It was observed that higher threshold values give a better posture recognition rate. This is because sensors detect a small amount of pressure due to the weight of the pillows and bed sheets as well as the cushioned layer of the mattress which are used to ensure the comfort of the patient. Therefore, setting a higher threshold value helps to detect the pressure only due to the human body when a patient lies down on the mattress.

The prediction system works on a rule-based method that if a certain combination of the segments is active, then it would identify a position based on that. The number of sensors activated varies from person to person. Thus many trial tests had to be done to find out the common sensors which are active for all or the majority of the patients. Based on that, the average number of active sensors was calculated and set as the requirements for the activation of each segment.

4.4 Performance Evaluation of the Developed Solution

Table 4. Recognition rate based on the Threshold value of the sensor

Threshold value	**No of tests**	**Successful recognition**	**Recognition rate (%)**
200	35	30	85.71
300	37	34	91.89

From Table 4 above, it can be seen how the recognition rate is affected by the different threshold values. The threshold value was first set to 200, that is, the analog reading of the FSR sensor has to reach a minimum of 200 when pressure is applied on it. With this threshold value, the prediction system was tested 35 times and gave an average recognition rate of 85.71%, yielding successful recognition for 30 tests.

For further improvement of the system, a higher threshold value of 300 was used. This scenario could better identify with a recognition rate of 91.89%. 37 tests were performed, out of which the system could properly detect positions 34 times. Both scenarios involved all 5 positions as control.

Table 5. Recognition rate percentage

Lying posture	**Recognition rate (%) before optimization**	**Recognition rate (%) after optimization**
Supine	86.67	93.33
Right Lateral	72.73	81.82
Right Risk	73.33	86.67
Left Lateral	61.54	84.62
Left Risk	69.23	84.62

Table 5 shows recognition rate data for the different postures before and after the system had been optimized using the additional 12 FSRs. To evaluate the improvement in the device's performance, the results of the system before and after optimization were compared. In Table 5 above, we can see that after optimization, the recognition rate has increased significantly for each of the positions.

The main purpose of the system is to identify risky positions of the patient and here, the recognition rates for Right and Left Risky positions are both above 80%.

4.5 Conclusion

The third design method has been chosen as the most feasible design based on the analysis in Table 3. In terms of Cost, Efficiency, Usability, Manufacturability, Impact, Sustainability, and Maintainability, the third system proved to be viable and optimal. The hardware implementation has been performed based on this optimal system and its performance is also evaluated. Upon further modifications of the optimal system, the system yielded much better and more consistent results. The modifications included adding 12 more sensors in the design for better risk predictability. The recognition rate for the different postures and positions as well as the risky scenarios has been improved after the optimization.

Chapter 5

Completion of Final Design and Validation

5.1 Introduction

The optimized solution was tested and verified on 13 test subjects (7 male and 6 female) and a total of 67 tests were done. It was tested for two different threshold values which is the minimum pressure exerted on a force-sensitive resistor (FSR) sensor for it to be counted as active. After analyzing the data, it was found that for higher threshold values, the posture recognition rate increased significantly.

5.2 Completion of final design

5.2.1 Fall Prediction System

The final optimized design consists of 62 force-sensitive resistors in grid layout as shown in Fig. 9. The design has been optimized based on the results that were obtained from the design that used 50 FSRs. This was done to improve the response of the system to different body structures and increase the accuracy of the system. Each of the force-sensitive resistors has two terminals, one for supply and another for obtaining data which is also further grounded by a pull-down resistor. All of the 62 sensors have been supplied with a 5V supply with a 5V 5A AC adapter. The data pin from each of the sensors is connected to a 16:1 multiplexer and also pulled down parallelly to the ground of the Arduino. For the processing unit, the Arduino Mega 2560 microprocessor has been used which has a clock speed of 16 MHz and 16 analog pins. Since there is a shortage of analog pins to accommodate all of the 62 FSRs in the Arduino microcontroller, a total of four 16:1 multiplexers have been used. Each of the multiplexers then transmits corresponding analog readings from each of the sensors connected. These analog readings measure the amount of pressure applied when a patient lies on the mattress. The program analyzes these analog readings obtained and makes a decision which is then sent to the cloud via IoT.

For the implementation of IoT, ESP-32 has been used to transfer data over 2.4 GHz WI-FI to Blynk. The ESP-32 obtains the processed data of the patients' position from the Arduino microprocessor and then transmits the data to the Blynk dashboard. The Blynk dashboard can be viewed from the web interface as well as from the mobile application depending on the feasibility of the caregiver or the nursing staff.

Furthermore, the layer of sensors in Fig. 9 will be integrated into a mattress with a proper insulating layer and a piece of waterproof fabric will be used as a cover for the maintainability of the system and for the safety of the patients. It is to be noted that the system has been tested out upon the integration of an insulating cushioned layer on top of the sensor layout with proper calibration.

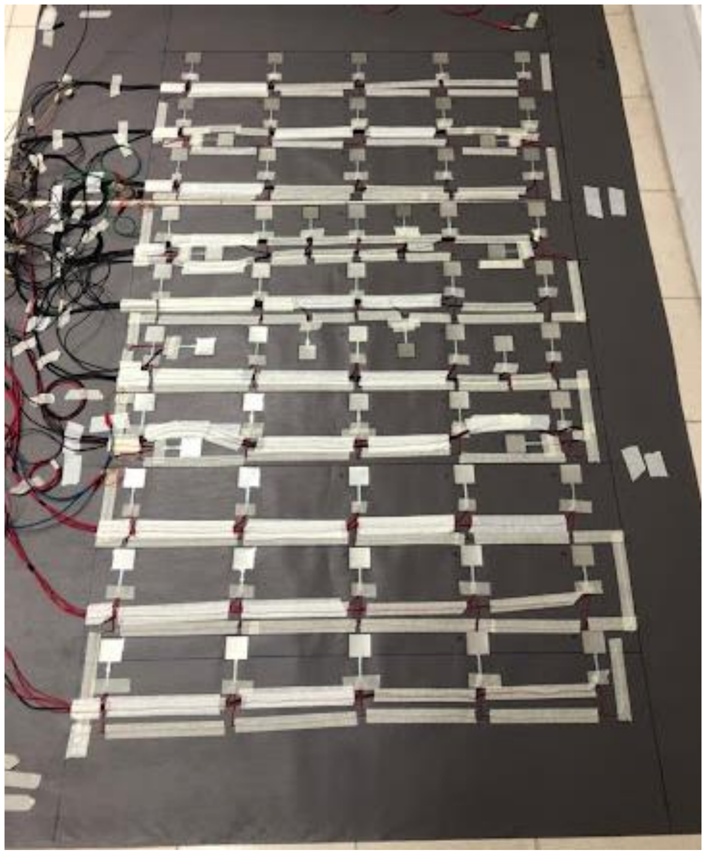

Fig. 9. Hardware Setup of the Final Optimized System

5.2.2 Remote Health Monitoring System

The Health Monitoring System consists of a temperature sensor DS18B20 and MAX30100 sensor consisting Pulse Oximeter and Heart rate sensors, connected to an ESP-32 module and the whole system is similar to the size of a standard smartwatch. The temperature sensor is placed at the side of the bed connected to the mattress and the MAX30100 sensor is placed at the bottom of the band. This is done to ensure that the sensor is in contact with human skin and can accurately take readings. For the temperature sensor, the probe is to be held for reading.

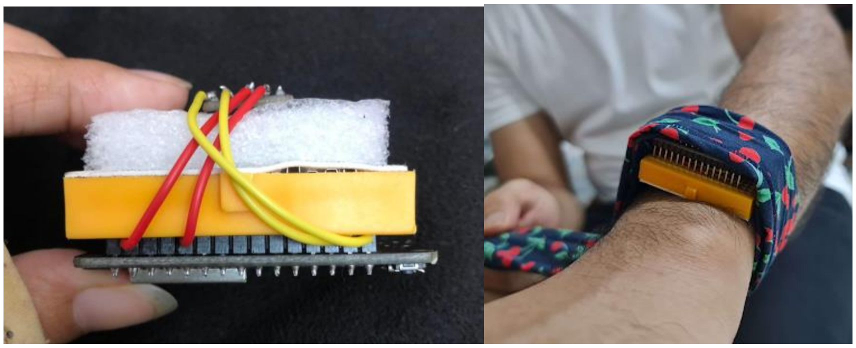

Fig. 10. Health monitoring system component setup

For the prototype level implementation, the MAX30100 sensor along with the ESP-32 is powered by a power bank. The analog readings of the sensor are checked against the standards set for each health parameter. The data is then sent to the Blynk Dashboard for the user to view and if any of the readings is out of the set range, an alert message is sent to the caregiver or user.

5.2.3 Algorithm of the Bed Fall Prediction System

The algorithm divides the data from the 62 FSRs in grid layout into a total of 11 segments as shown in Fig. 8. The segments then follow a rule-based threshold depending on the analog readings from the corresponding sensors in the particular segment. However, each of the sensors are considered to be active if the analog reading is above 300. When a particular number of sensors in a particular segment gives a reading above 300, the segment is then activated. The predetermined combination of the activated segments then detects the position of the patient lying on the bed. For instance, when a minimum of 3 sensors out of 8 in Segment 2 gives a value above 300 then the segment is considered to be active.

Hence, when a particular number of segments dedicated to a specific position detects the active sensors, the system confirms that specific position of the patient lying on the bed. Based on the position, the algorithm decides whether a risky position is detected and finally predicts the possibility of a bed fall. Accordingly, an alert is sent to the caregiver or nurse via the Blynk dashboard. The Fig. 11 shows the flowchart for the algorithm of the system.

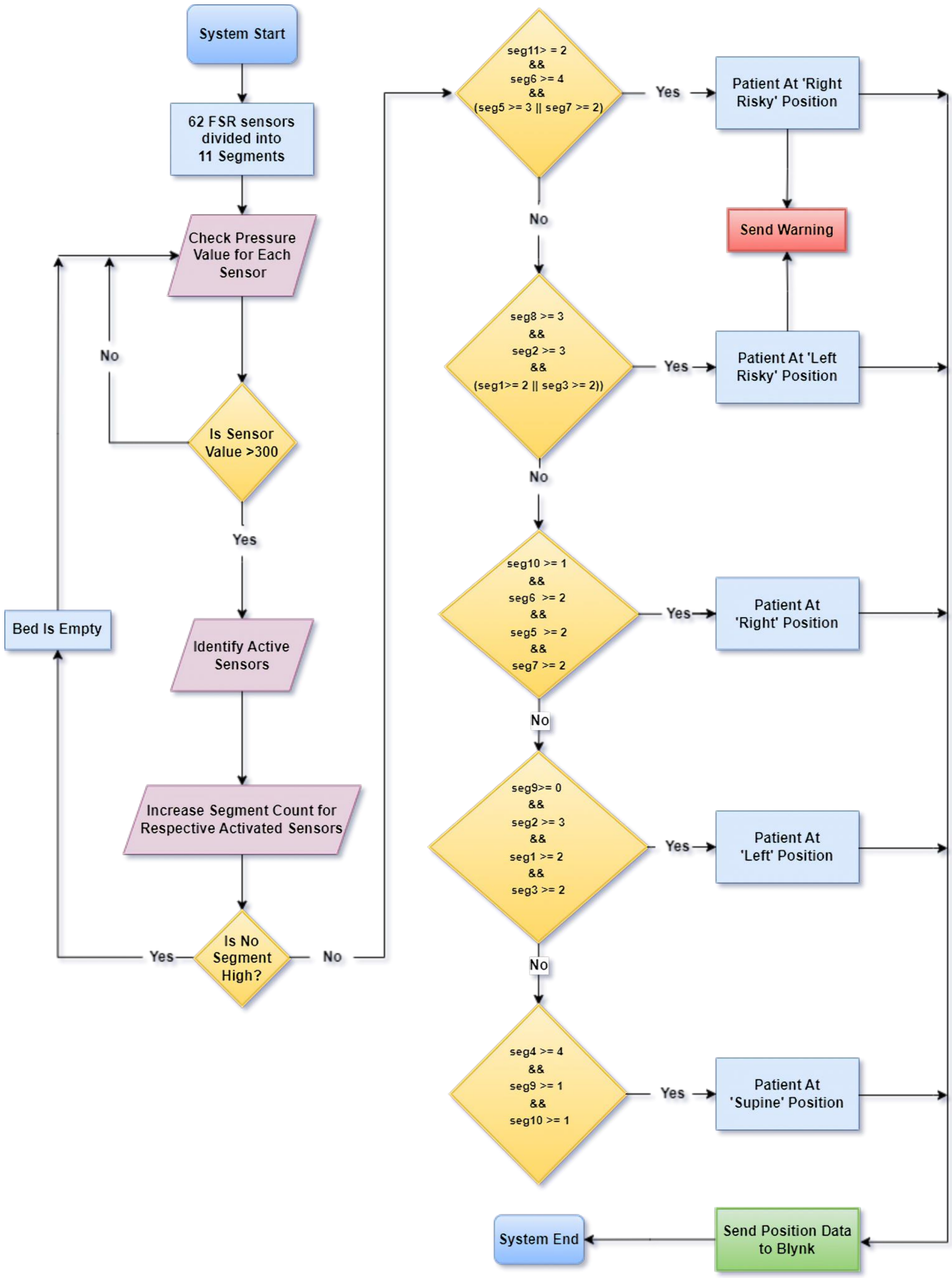

Fig. 11. Algorithm of Bed Fall Prediction System

5.2.4 Algorithm of the Health Monitoring System

The MAX30100 sensor is capable of measuring both oxygen saturation and heart rate simultaneously. The data received from the sensor is processed by the ESP-32 development board. The temperature reading is taken using DS18B20 and it is processed by the arduino mega. The program first declares a variable to call the PulseOximeter library of the MAX30100 sensor. The sensor measures the data every time a Beat is detected.

Data of the three parameters is then compared with the standard set. The set conditions for warning are as follows: heart rate above 100 bpm, SPO2 level below 95, and body temperature above 100F. The system checks with the conditions and in case of those conditions, immediately a warning message is sent through Blynk.

5.3 Functional Verification

Position: Supine

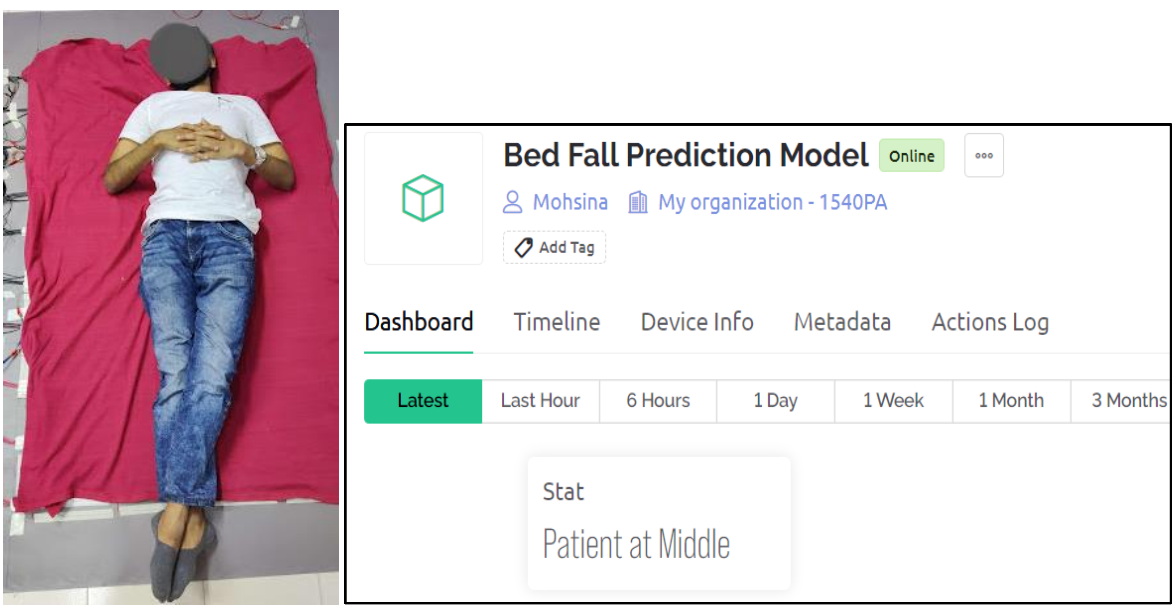

Fig. 12. Position ‘Middle’ Detected alongside Blynk Dashboard

The patient is lying in the middle of the bed and this position is known as supine. Fig. 12 shows the system can accurately identify the posture based on the combination of the segments activated. The Blynk dashboard displays the position detected.

Position: Left Lateral

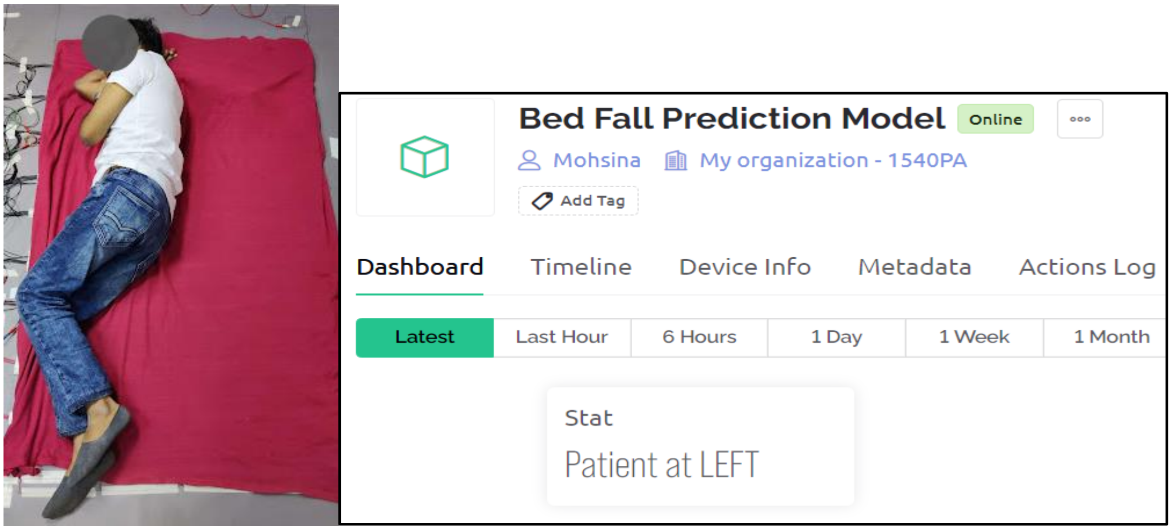

Fig. 13. Position 'Left' Detected alongside Blynk Dashboard

In Fig. 13 the patient is lying in the left lateral position. The posture is correctly identified by the system and shown in the Blynk dashboard.

Position: Left Risk

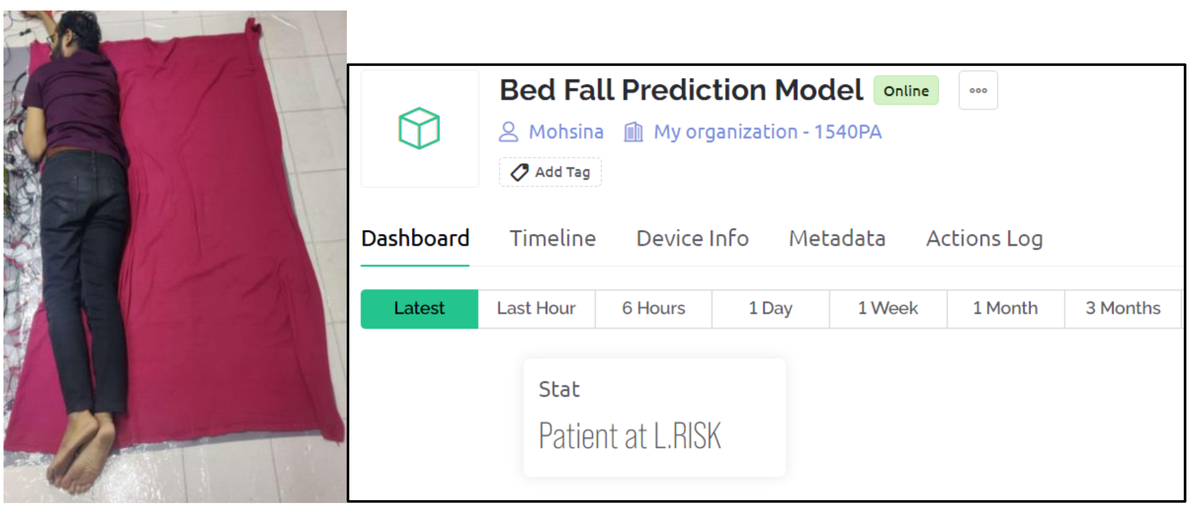

Fig. 14. Position 'Left Risk' Detected alongside Blynk Dashboard

In Fig. 14, the patient is very close to the edge of the bed and is at risk of falling. The system identifies this as a risky position and sends an alert via Blynk.

Position: Right Lateral

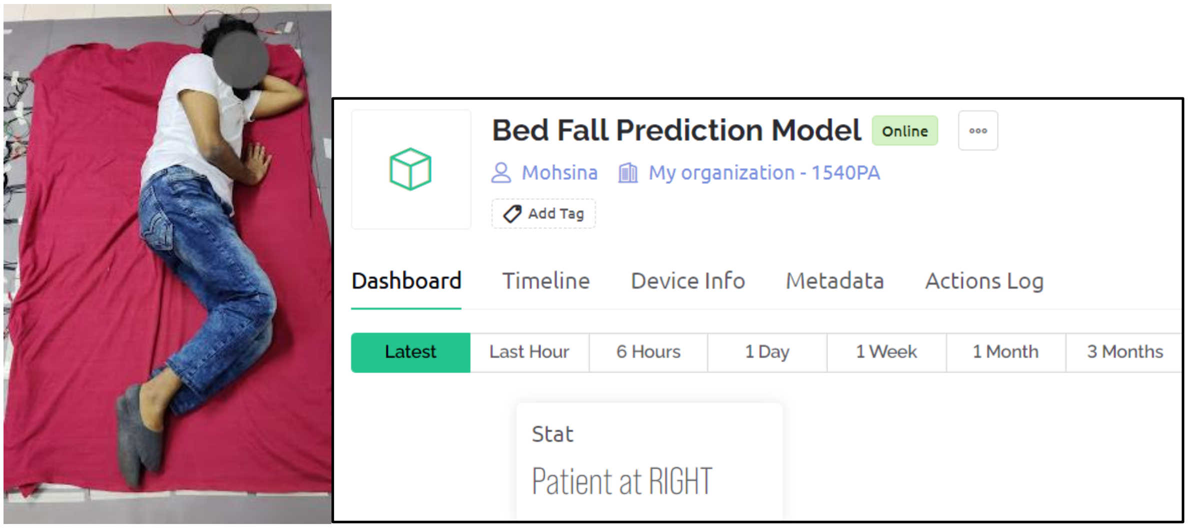

Fig. 15. Position ‘Right’ Detected alongside Blynk Dashboard

In Fig. 15, the patient is on the right side of the bed, in a right lateral position and the Blynk dashboard shows the correctly identified position by the system.

Position: Right Risk

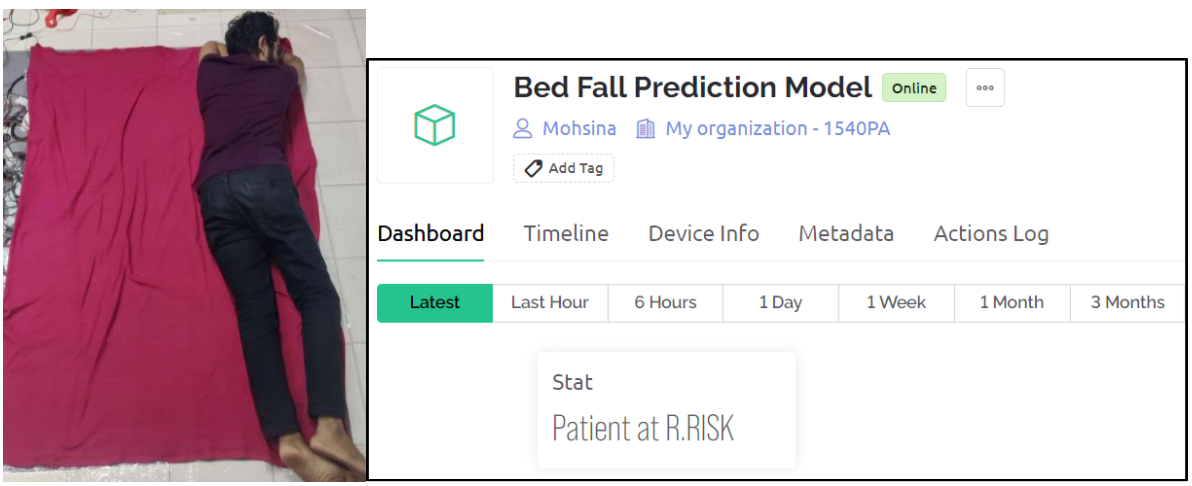

Fig. 16. Position ‘Right Risk’ Detected alongside Blynk Dashboard

In Fig. 16, another risky position where the patient is at the right edge of the bed. Based on the combination of the active segments, Blynk displays that this position is also accurately identified by the system. An alert is also sent to the caregiver or nurse.

Table 6. Total test subjects

Total test subjects	Male	Female	Total Test cases
13	7	6	67

For the verification of the final design, the fall prediction system has tested a total of 67 times on 13 different test subjects, 7 of them are male and 6 are female. Students of Brac University volunteered and their permission was received upon signing the Consent Form. Each of the subjects were asked to lie down on the mattress and their on-bed movements and positions were detected and stored for Data Analysis and System Validation.

Table 7. Recognition success in relation to total number of tests performed of a specific position

Lying posture	No of Tests	Successful recognition	Recognition rate (%)
Supine	15	14	93.33
Right Lateral	11	9	81.82
Right Risk	15	13	86.67
Left Lateral	13	11	84.62
Left Risk	13	11	84.62

In Table 7 the test results are summarized. It shows the number of tests carried out for each position and the corresponding number of successful recognition. The supine position has the highest recognition rate of 93.33%. And all the positions have a recognition rate higher than 80%. Most importantly, the Right Risk position has an 86.67% recognition rate and the Left Risk has 84.62% which is considerably high. Thus, it can be said that the main objective of the fall prediction system has been successfully met as the recognition rates of the Risky positions are high, and it can predict bed falls with high accuracy.

Table 8. Latency of the System

Latency	Minimum	Maximum	Average
Processing + Communication + SMS transmission	1.57s	2.70s	2.14s < 3s

The overall latency includes the processing delay, communication delay over wireless, and the sms transmission delay. The latency was measured several times where the minimum latency was 1.57s and the maximum latency was 2.70s as depicted in Table 8. The communication delay depends on the network traffic of the WiFi. However, the sms transmission delay contributes most to the overall latency of the system. This is due to the network traffic at the time of transmission and reception. Even after considering all the delays, the average delay is less than 3s. Therefore, bed falls can be easily prevented after the system has predicted a fall and a warning message is sent to the caregiver.

Health Monitoring System

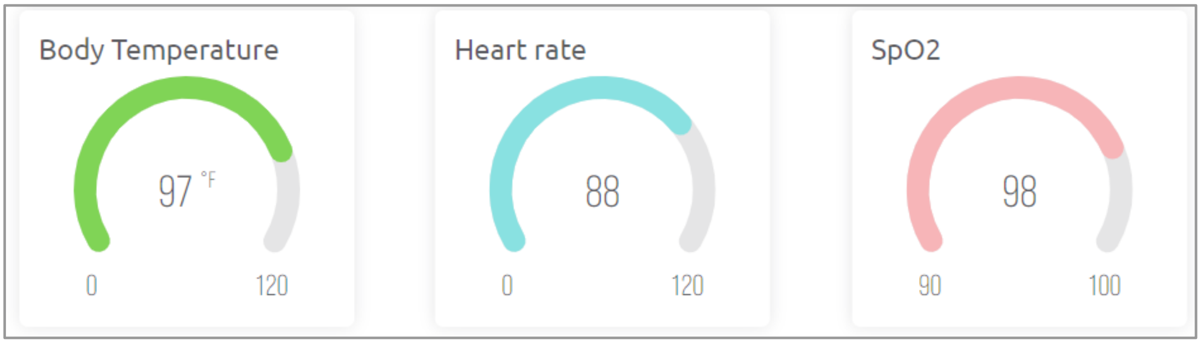

Fig. 17. Health Parameters observed from Blynk Dashboard

Table 9. Normal Specified Range of the Vitals [25]

Temperature	Normal Heart Rate Range	Normal Oxygen Saturation Range
96°F - 98°F	60 bpm - 100 bpm	95% - 100%

Fig. 18. Remote Health Monitoring System as wristband and probe

In Fig. 17, it can be observed that the Blynk dashboard displays the vital readings for Body Temperature, Heart rate and Oxygen Saturation (Spo2) of a patient when he/she wears the wristband on the hand and grips the digital temperature probe in the palm as seen in Fig. 18.

Furthermore, a reference of the normal specified range of the vital is listed in Table 9.

Alert Messages

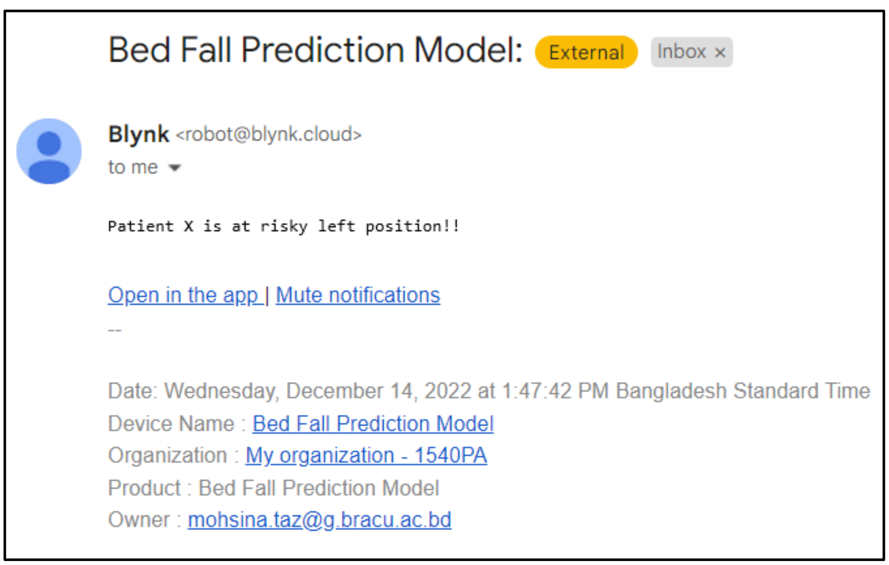

Fig. 19. Alert message of the Fall Prediction System at a risky position

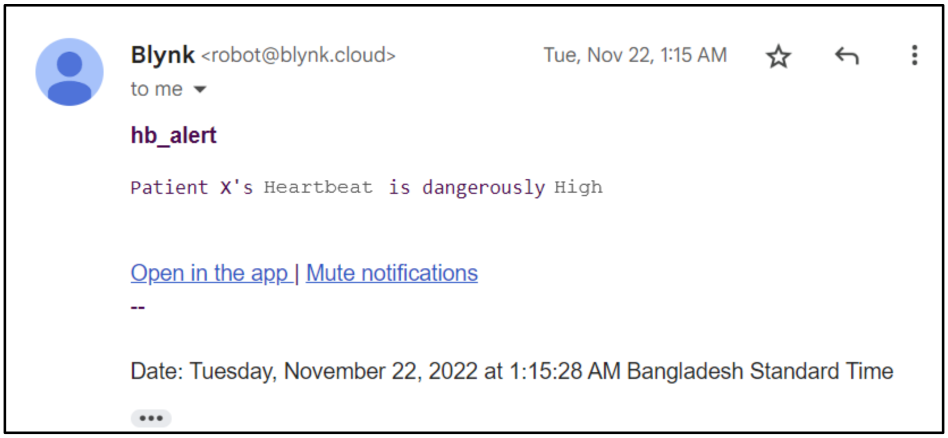

Fig. 20. Health Monitoring System alert message for high Heartbeat

Fig. 21. Health Monitoring System alert message for low SpO2

5.4 Conclusion

Therefore from the data analysis, we can say that all the objectives of the project have been successfully achieved. The system can accurately identify the position of the body with high accuracy and the caregiver can be informed in a very short amount of time. Moreover, the health monitoring system can continuously monitor the patient's health parameters and warn the caregiver if any of the parameters go beyond the normal range. Hence, all the objectives of the project have been met and the requirements have also been fulfilled.

Chapter 6

Impact Analysis and Project Sustainability

6.1 Introduction

Impact analysis is the probable future impact of the project. It is applied to determine the expected and unexpected effects a project might have on the surrounding environment including people. It can be said it is a process of analyzing consequences and future events. Here, project impact analysis has been broken down into the following sections- Society, Health, Safety, Legal, and Cultural.

6.2 Impact Assessment of the Solution

6.2.1 Societal Impact

With the implementation of this design, more patients can be monitored simultaneously with the same number of nursing personnel. By not having to constantly check up on patients with cognitive disabilities, nurses can monitor all the patient's movements and postures from the nurse station.

It is a generalized belief that bed rails prevent injuries or restraints prevent patients from harming themselves. However, studies have shown bed rails are linked to causing injuries which include broken or dislocated limbs. Strangulation has also been reported which caused death due to bed rails and restraints have been linked with mental health problems. Bed rails and restraints/straps would no longer be necessary upon the implementation of this design. A paradigm shift will be imminent and thus reduce injuries or even death due to injuries caused by bed rails. Patients can also be mentally free if they are not tied down by restraints.

6.2.2 Health Impact

The mental burden of being unable to move at will weighs down a human being. Patients with Parkinson's disease, Alzheimer's disease, Dementia, and cognitive disabilities are usually strapped to the bed which prevents them from moving. This will no longer be necessary since the device monitors the patient's position and also their posture on the bed at all times. This means any sort of risky movements like involuntarily rolling off the bed, or intentional or unintentional bed exits will be monitored and warnings will be sent to caregivers or nurses before the patients harm themselves. Even though the design aims to prevent accidents, the patients themselves will have a newfound sense of confidence due to not being restrained or not being constantly under watch.

The materials used in the system will not contribute to the patient's health decline. Accidental consumption of any compounds or materials will not contribute to health decline.

Since the system constantly monitors the patient's movement on the bed, caregivers and nurses will be less burdened by not having to periodically check up on patients. If emergencies do arise, the system will send warnings to the on-duty nurses about any abnormalities. It is also possible to monitor more patients with fewer staff. It can therefore be said that stress and burden on caregivers could be lessened by the implementation of this design

6.2.3 Safety Impact

Physical restraints can impose risk to the patient on the bed. Over the years, a lot of accidents and deaths took place due to patients getting injured while trying to climb over the rails or patients dislocating their limbs, or even getting strangled upon the rails. The project functions to protect the patient from falling off which diminishes the need for such physical restraints as bed rails.

Since electrical wiring and sensors will be installed inside the mattress, proper insulation has been applied and circuit breakers have been used to prevent high current from flowing at any given instance. The insulation is very important since the patient might come in direct contact with the wires if not insulated properly.The patient is under constant surveillance through their pressure data and medical vitals collected through the remote health monitoring system continuously over time. So they are being checked upon consistently and if any of the vitals or position is abnormal, the medical staff are notified immediately for further check-ups.

6.2.4 Legal Impact

Unlike many existing fall prediction or detection systems, this design does not include any cameras. The system entirely relies on Force Sensitive Resistors which, when patients lie on, detect the pressure applied and map out their location on the bed and the posture they are lying in. No images of the patient are produced, only pressure data. The generated data is exclusive to the patient's file only and not accessible by anyone else.

The optimal design that has been developed meets the proper standard and codes. It is vital to maintain those standards while manufacturing such a biomedical device. Medical devices are sophisticated instruments that play a critical role in a person's treatment so the need to maintain the applicable codes during its development is a legal necessity that has to be followed.

6.2.5 Cultural Impact

It is difficult for family members to constantly keep an eye on someone who suffers from cognitive impairment. Their movement patterns are unpredictable. Patients who suffer from such diseases are at high risk from their random movements. This approach will constantly monitor their movement and their posture on the bed. If they are at risk of falling over or if they try to leave the bed, warnings will be sent to the caregiver to prevent accidents. Family members and loved ones will be more at ease knowing that they do not have to constantly physically monitor them and warnings will be given accordingly.

Bed rails contribute to injuries or even death year round. Injuries include fractured or dislocated limbs. Straps are sometimes used to tie down patients with cognitive impairment to the bed. Though for safety reasons, this causes mental distraught among patients. As explained above, the design aims to constantly monitor the patient’s movement and posture so the use of bed rails and straps will not be necessary anymore which will ultimately reduce injuries or even deaths among elderly or impaired patients. This will inspire new-found confidence among patients. The budget that goes into bed rails and restraints/straps can be directed to the funding of this design.

6.3 Evaluate the sustainability

The force sensitive resistors are long-lasting and suitable for long-term use [23]. In order to process the data and effectively monitor the movements, the system also needs a basic, low-cost Arduino microcontroller. Additionally, the components used in the design do not harm the environment or emit any hazardous vapors or gasses. Also, the sensors have a very low power consumption, making them a very sustainable option over time. Before a patient uses the medical device, test runs should be conducted to ensure that the sensors are functioning properly and that there are no insulation faults. These checks should be done frequently. The maintenance is simple and only necessitates a small amount of work because of its durability. In order for the system to send data continuously to the cloud and send the warning message, the gateway protocols must be carefully followed at all times.

6.4 Conclusion

Therefore successful execution of this project has a number of positive impacts for the patients, family members and caregivers. Employing this device in hospitals and care homes will enable effective monitoring of patients as less number of staff would be required. Moreover, this device will not only prevent bed fall-related accidents but patients will also feel more confident as they won't be restrained or continually watched.

It can be stated that the application of this system could minimize caregiver stress and load. By preventing the patient from sliding off, this bed fall prediction system reduces the need for physical constraints like bed rails. The entire system is based on Force Sensitive Resistors, which, when patients lie down, activate and map out their position on the bed and their posture. Only data is generated, not any pictures of the patient. The best design that has been chosen complies with the relevant standards and codes. Family members and close friends will feel more at peace knowing that warnings will be given when necessary and that they do not need to physically monitor them all the time.

Chapter 7

Engineering Project Management

7.1 Introduction

In order to accomplish all the objectives of a project in the given time frame, a proper management outline is essential to have a neat process for effective results. Engineering project management is concerned with both technical and non-technical aspects. According to a study in [26], the whole flow of the project can be divided into five main categories. They are initiation, planning, execution, monitoring and control, and closure.

Fig. 22. Five Key Factors of Engineering Project Management

7.2 Define, plan and manage engineering project

7.2.1 Initiation

To begin any project, targeting a cause to solve is important. Brainstorming is an essential task to identify the problems that need to be solved. Upon selection of a problem, it is important to do a literature study and review the existing solutions to the problem. Next, identifying the research gap is a crucial part to introduce innovative solutions or elevate existing ones.

7.2.2 Planning

To understand the function and non-functional requirements of the project, an online survey was done before the project proposal. The received feedback from peers and stakeholders has been incorporated into designing the system. Based on the requirements and objectives of the system, multiple designs of the prediction system were proposed. Each of the design approaches was then simulated using modern IT tools and their performances were evaluated. Finally, the optimal design among the three design approaches was selected based on cost, efficiency, usability, maintainability, impact, and sustainability.

7.2.3 Execution

The execution of the solution started with the purchase of the hardware components and learning about their specifications. The hardware setup was then tested out. Design optimization of the system was also carried out to fill in the gaps between theoretical and experimental differences. Troubleshooting was done thoroughly to ensure quality and make the system more efficient. Finally, data was collected from peers as test subjects with their consent. Upon collection, the results were analyzed to check for functional verification in order to confirm if the system fulfills the objectives set.

7.2.4 Monitoring and Control

The system validation was performed based on functional verification to find out whether the objectives were met and the requirements were fulfilled. After the system was validated, the data were analyzed to determine the accuracy of the system and also decide if any further optimization is required in the design. A contingency plan was also made for risk management.

7.2.5 Closure

The system went through a thorough evaluation by analyzing the data before and after the optimization. The data were compared and the success rates of recognition were calculated to further assess the accuracy of the solution. In addition, the progress and results have been continuously documented and recorded.

7.3 Gantt Chart/Project Timeline

The project management plan was executed throughout the year following a structured division of three phases: project planning, project development, and project completion. To track the progress of the project, identified tasks were assigned a deadline, and responsibilities were distributed to ensure the work was completed in the given time frame with accountability. The Gantt Charts are depicted in Fig. 23, Fig. 24 and Fig. 25.

Phase		Tasks	Assigned to	Duration (Days)	EEE400P (JAN: 1 7 14 21 31; FEB: 1 7 14 21 28; Mar: 1 7 14 21 31; Apr: 1 7 14 21 30)
EEE400P	Project Planning	Research & Literature Review	Fahad, Mohsina, Abrar, Fariha	38	Feb 9 - Mar 18
		Problem Identification & Planning	Mohsina, Fahad, Abrar	23	Feb 24 - Mar 18
		Concept Note	Fahad, Mohsina, Abrar, Fariha	19	Feb 28 - Mar 18
		Stakeholder Survey	Fariha, Fahad, Abrar	12	Apr 3 - Apr 14
		Justification	Mohsina, Fariha	52	Feb 28 - April 21
		Project Proposal	Fahad, Mohsina, Abrar, Fariha	37	Mar 23 - Apr 28

Fig. 23. Gantt Chart/Project Timeline for EEE400P

Phase		Tasks	Assigned to	Duration (Days)	EEE400D (May: 1 7 14 21 31; June: 1 7 14 21 30; July: 1 7 14 21 31; Aug: 1 7 14 21 31)
EEE400D	Project Development	Tools Selection	Fahad, Mohsina, Abrar, Fariha	17	May 20 - June 5
		Simulation of Multiple Designs	Fahad, Mohsina, Abrar, Fariha	75	May 30 - August 12
		Optimal Solution Development	Mohsina, Fahad	12	July 28 - August 8
		Evaluation	Fariha, Abrar	14	August 1 - August 14
		Design Report	Fahad, Mohsina, Abrar, Fariha	37	July 18 - August 23

Fig. 24. Gantt Chart/Project Timeline for EEE400D

Phase		Tasks	Assigned to	Duration (Days)	EEE400C (Sept: 1 7 14 21 30; Oct: 1 7 14 21 31; Nov: 1 7 14 21 30; Dec: 1 7 14 21 31)
EEE400C	Project Completion	Design Implementation	Fahad, Mohsina, Abrar, Fariha	52	Sept 30 - Nov 21
		Performance Analysis	Mohsina, Abrar, Fariha	47	Oct 14 - Dec 1
		Validation	Abrar, Fahad	47	Oct 14 - Nov 21
		Project Reflection	Fariha, Mohsina, Fahad	60	Oct 14 - Dec 14
		Report	Fahad, Mohsina, Abrar, Fariha	50	Nov 1 - Dec 20
		Project Closing	Fahad, Mohsina, Abrar, Fariha	21	Dec 1 - Dec 22

Fig. 25. Gantt Chart/Project Timeline for EEE400C

7.4 Conclusion

Following a project management scheme is helpful in completing the project in due time with proper prioritization of tasks. It also helps to sort the tasks in a proper sequence. Additionally, it depicts the observation of the estimated and the actual time required. Furthermore, the distribution of tasks ensures the participation of all members and strengthens teamwork.

Chapter 8

Economical Analysis

8.1 Introduction

Economic analysis is a breakdown of a project's cost and benefit. The main elements of economic analysis are:

- Identifying and estimating costs directly related to investment
- Identifying and estimating benefits obtained from investment
- Comparing cost and benefits to justify investment

8.2 Economic Analysis

8.2.1 Budget for the Working Prototype

Table 10. Budget for the Final Design

Sub System	Component	Example Model	Unit Price (BDT)	Unit	Total Cost (BDT)
Data Collection	Force sensitive resistors (FSR)	FSR406	4+60	820+333	23,335.00
	16:1 Multiplexer	74HC4067	320	4	1,280.00
	FSR shipping + C&F				7,500.00
Processing unit	Arduino	Mega 2560	2,500.00	1	2,500.00
Gateway	Bluetooth + WiFi Module	ESP-32 Node Node MCU	720.00	2	1,420.00
Remote Health Monitoring	Heart-Rate Monitor and Pulse Oximeter Biosensor	MAX 30100	610.00	1	610
	Temperature Sensor	DS18B20	140.00	1	140.00
Medical Bed	Mattress+Plastic Sheet	Single	8,000	1	8,000.00
Miscellaneous	Jumper Wires, Breadboard, LCD Display, Resistor, LED, Button, IC Rail, Heat Shrink, AC Adapters, Wires				3,858.00
			Total Cost		**48,643.00**

Table 10 shows the total cost for the working prototype to be BDT 48,643. This excludes components that have been used in trial-and-error scenarios.

8.2.2 Estimated Cost

Table 11. Estimated cost for the working prototype, first unit, and commercialized product

Cost for working prototype With spare parts (BDT)	Estimated Budget for first unit (BDT)	Estimated Budget for the commercialized product (BDT)
53,780	50,000	35,000
• Scarcity of specific components • Bought extra components as contingency • Experimented with different parts for optimization	• Components will be restocked in host nation as post-covid restrictions end • Specific number of parts will be bought	• Components will be factory fitted • Retail/bulk-purchase price • No extra components will be unused

Table 11 shows the estimated budget for the first working unit and budget for the commercialized product. The cost for the first unit is estimated to be less than the first working prototype as there will be no trial-and-error scenarios and the specific components required will already be known. The cost for the commercialized product is estimated to be much less than the first unit as all components will be attained at retail price.

8.3 Cost-benefit Analysis

Table 12. Profit Estimation With Respect to Number of Institutions in Contract

Estimated Profit/bed (BDT)	Estimated number of hospitals/nursing homes in contract	Estimated Profit/10 beds/contracted institutions (BDT)
6,000.00	5	3,00,000.00
6,000.00	10	6,00,000.00
6,000.00	15	9,00,000.00
6,000.00	20	12,00,000.00

A projection of the estimated profit has been listed in Table 12. Considering the commercialized product will cost a maximum of BDT 35,000 and it will be sold at BDT 41,000, the projected profit per 10 beds sold will be approximately BDT 12,00,000 if contracted with 20 hospitals or nursing homes.

8.4 Economic and Financial Aspects

Table 13. Profit Estimation From Number of Units Sold per Year

		Cost of sales (BDT)	Sales (BDT)	Profit (BDT)	Loss (BDT)
Cost of production/unit (BDT)	35,000.00	XXXXXX	XXXXX	XXXXX	XXXXX
Selling price/unit (BDT)	41,000.00	XXXXXX	XXXXX	XXXXX	XXXXX
Production/year/unit	10	3,50,000			
No. of units sold/year	10		4,10,000	60,000	0
Production/year/unit	10	3,50,000			
No. of units sold/year	5		2,05,000	0	1,45,000
Production/year/unit	10	3,50,000			
No. of units sold/year	9		3,69,000	19,000	0
Production/year/unit	24	8,40,000			
No. of units sold/year	20		9,84,000	1,44,000	0

In Table 13, as an arbitrary assumption, it is estimated that at least 10 units be produced every year to maintain the cost of components bought and make a profit. By selling each unit at BDT 41,000, the markup is 6000 per unit. The total cost of sales for producing 10 units comes to be BDT 3,50,000 and as shown in the table, selling 9 units of the proposed 10 will give a sum of BDT 3,69,000. BDT 3,50,000 of the Sales will be directly deposited into making 10 more units and the remaining BDT 19,000 will be counted as a profit for that year.

According to a realistic plan, at least 24 units would need to be produced annually to maintain the cost of the components used and turn a profit. According to the table, the total cost of sales for manufacturing 24 units is BDT 8,40,000. Selling 20 of the proposed 24 units will bring in BDT 9,84,000 in total. Of the Sales, BDT 8,40,000 will be used directly to produce 24 additional units for the following year, and the remaining BDT 1,44,000 will be recorded as annual profit.

8.5 Conclusion

A proper economic analysis is necessary to estimate the costs that would be incurred during the whole project. It is also important to make a budget for the prototype being developed. The cost-benefit analysis with the help of the budget helps to identify the financial prospects of the system and can further encourage stakeholders to actively participate in the project.

Chapter 9

Ethics and Professional Responsibilities

9.1 Introduction

Project Management Institute (PMI) [27], emphasizes that ethics is concerned with making the best possible decision that interests people, resources, and the environment. Ethical considerations and professional responsibilities are an integral part of any project management. This helps in acknowledging and minimizing the possible risk of the project. As strong moral integrity in academics is focused on and considered, the project's quality is also maintained. Therefore, the aforementioned factors shall be recognized and considered in designing the solution throughout the development of the project.

Several ethical considerations and professional responsibilities are taken into account throughout the project development process to obtain the objectives of the problem stated earlier in this report.

9.2 Identification of Ethical Issues and Professional Responsibility

9.2.1 Informed Consent

The patients using the Smart Bed would be informed about the purpose of our medical equipment which is to protect them from falling off the bed and monitor their health vitals. To achieve this, the proposed system would monitor the patients' movements, postures, and positions while they are in bed as well as record their vitals at regular intervals. In such a case, consent would be obtained from the patients and their guardians to establish a proper understanding between the patients and medical personnel.

9.2.2 Protecting Anonymity and Confidentiality

Since medical data about the patients would be stored in cloud storage, it is vital to maintain the confidentiality of the medical record of the patients. In addition, patients' identities would also need to be kept anonymous.

9.2.3 Avoiding Deceptive Practices

This segment is interrelated with the Informed Consent section. For the consent of the patients to be granted, it is necessary to let the stakeholders know about the purpose and the functionality of the device. For clarity, any deceptive practices must be avoided at all costs for safety, privacy, and transparency.

9.2.4 Acknowledging Proper Sources

Throughout the project planning and development, existing works have been studied and a viable solution has been developed. It is to be noted that all of the literary works and articles as well as different websites were fully credited with proper in-text citations and references in report writing to avoid plagiarism.

9.2.5 Approval from Respective Bodies

A significant aspect of the development and manufacturing of medical devices is that it requires permissions and approvals from several authorities. Since the project is a medical device being developed in Bangladesh, the main authority concerned is the Directorate General of Drug Administration (DGDA) of the Ministry of Health and Family Welfare. According to [18], the registration and circulation of medical devices are regulated by this respective body. In the article [18], DGDA regulates and circulates medical devices and the regulatory guidelines are structured upon the guidelines set by the Global Harmonization Task Force (GHTF) which is an international regulatory body for medical devices.

9.3 Application of Ethical Issues and Professional Responsibility

9.3.1 Informed Consent

A consent form will be presented to the patient before using the device on them. This form will seek approval to keep track of their body movements, record medical vitals regularly and monitor their sleep cycle for better medical checkups. The form has been attached in Fig. 26 and Fig. 27.

EEE400C
Group-10
ATC-2

BRAC UNIVERSITY
Inspiring Excellence

Participant Consent Form

We are asking you to participate in a research study related to our Final Year Design Project. This is a consent form for your participation. We will explain this study to you and answer any of your questions.

Project Title:

"Bed Fall Prediction System with Integrated Remote Health Monitoring System"

Researchers:

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Purpose of the Research:

The data collected will be used for optimization and verification of a Bed Fall Prediction System. The pressure sensing mattress will measure pressure applied at each sensor and based on that, it will identify the position of the patient. The identified position and the pressure readings will be stored to improve efficiency and accuracy of the prediction system.

Procedure:

The participants will be asked to lie down on the sensor mat in 5 different positions and have to stay on each position for around 2 min. Then, they are required to fill out general information about themselves such as height, weight, age, gender along with a short summary of the overall experience of lying on the mat. The total time of participation will be around 15 min.

Risks

There are no known or anticipated risks to the participants.

Benefits

1

Fig. 26. First Page of the Consent Form

There are no direct benefits to the participants. However, the information from this study will be used to develop a smart medical bed which is a common concern not only for the elderly patients but also for patients with impaired mobility, dementia, Alzheimer's, and Parkinson's diseases. Thus, it will reduce the physical injuries and the hospital costs due to bed fall accidents and benefit the society as whole.

<u>Privacy/Confidentiality:</u>

All identifying information will be removed and replaced with a Subject ID and all the electronic data will be stored on a password-protected, encrypted computer. Identifying information will be kept separate from the research data.

<u>Photograph/ Video Recording:</u>

Photographs/ Videos of lying positions might be captures which will be utilized for better posture identification. This is optional for participants and they may skip this part if they want.

<u>Data Sharing:</u>

De-identified data from this study may be shared with the research community or published in journal papers. Any personal information that could identify a particular participant will be removed or coded before data is shared.

<u>Participation is voluntary</u>

The participant's involvement is voluntary and they may refuse to participate before the study begins, discontinue at any time, or skip any questions/procedures that may make him/her feel uncomfortable, with no penalty or compensation.

<u>Statement of Consent</u>

I have read the above information, and have received answers to any questions I asked. I consent to take part in the study.

____________________	____________________	____________________
Name of Participant	Signature	Date
____________________	____________________	____________________
Name of Researcher	Signature	Date

2

Fig. 27. Second Page of the Consent Form

9.3.2 Protecting Anonymity and Confidentiality

Concerning the anonymity of the patient and protecting their information, each patient will be provided with a unique identification number that protects their data from deceptive practices. Additionally, this data will be encrypted to maximize security.

9.3.3 Avoiding Deceptive Practices

In reflection, any misleading practices might invalidate the purpose of this project which would also discredit our work, and hence it is necessary to maintain proper measures and sincere practices.

9.3.4 Acknowledging Proper Sources

Academic integrity is an essential component of ethics. Hence, it is necessary to address and credit the rightful sources with proper citation and referencing. To further check the quality of the write-up, a similarity check was conducted via Turnitin on this report and a 6% similarity was obtained.

9.3.5 Approval from Respective Bodies

Before taking approval from DGDA, approval is required from the respective organization from which the medical device has been researched and manufactured. As students of BRAC University, primary approval is required from the Institutional Review Board (IRB) at BRAC James P Grant School of Public Health (JPGSPH).

9.4 Conclusion

Recognising professional responsibilities and conserving ethics is essential in any scientific work. It is of high significance to ensure transparency and maintain the quality of the work. Five main aspects have been prioritized in this project. They are as follows: consent, confidentiality, ethical practices, acknowledgment, and approval. Apart from ensuring a technically viable solution, the solvency of the whole project is required in order to gain the trust of the user and the approval of the authorities in that particular field of the medical sector.

Chapter 10

Conclusion and Future Work

10.1 Project Summary

Bed fall prediction system and remote health monitoring is a project dedicated to assisting caretakers to efficiently and conveniently monitor patients with a wide range such as dementia, Parkison's disease, impaired mobility, Alzheimer's, etc. The project focuses on observing the selected five different positions and postures of the patient and their health vitals such as heart rate, oxygen saturation, and temperature. Then the algorithm runs to detect any risk of falling off the bed and any anomaly of the vitals. Upon detection of such a case, an alert will be generated and sent to the caretaker to enable them to control any mishap prior to its occurrence. This system can be implemented to care for any individual at home, or patients at hospital, and assisted care facilities, etc. Thus, a bed fall prediction with remote health monitoring would be beneficial to a wide range of patients, and taking care of them will be more accessible and manageable.

10.2 Future Work

The progress of the project can be divided into different phases to gradually scale up the level of implementation with the integration of new objectives. In the future, with adequate budget, resources and time, the prediction system can be further utilized to add bedsore detection and sleep-related diseases. Also, it can be implemented in hospital wards to observe multiple patients simultaneously on one dashboard where each patient would have a unique patient ID. Furthermore, the datasets collected during the project can be well documented and made available to encourage and facilitate similar works for the same category in the health sector.

Chapter 11

Identification of Complex Engineering Problems and Activities

11.1 Attributes of complex Engineering Problem (EP)

Table 14. Attributes of Complex Engineering Problems (EP).

	Attributes	Put tick (√) as appropriate	Justification
P1	Depth of knowledge required	✓	In-depth knowledge has been required for the mechanism of the pressure sensors and different analytical methods e.g rule-based and threshold-based to design the solution of the problem identified. Also, knowledge about circuit designing and programming the embedded system was necessary for the project. Additionally, literature study has been done to understand and analyze the frequency and cause of the targeted problem and failings of existing solutions.
P2	Range of conflicting requirements		
P3	Depth of analysis required	✓	Several literary works showed a research gap upon which multiple solutions have been identified through thorough analysis, keeping in mind the solutions do not harm any patient or the design does not contain any hazardous objects. Proper analysis of the data was further performed to come up with the optimal system that can solve the required problem efficiently.
P4	Familiarity of issues		
P5	Extent of applicable codes	✓	Several existing codes and standards such as sensor usage, electrical safety, wireless connectivity etc. are applicable to the proposed design. However, practices and codes directly related to bed fall prediction systems are unavailable because fall detection systems are more available than prediction systems. Also, most prediction systems have cameras or wearable solutions that cause privacy issues and discomfort. Non-wearable fall prediction systems lack standardized practices and code establishment.

P6	Extent of stakeholder involvement and needs	✓	Different types of patients and doctors of different medical specializations from small clinics and nursing homes to hospitals of large medical facilities are applicable to use of the device. Concerned bodies such as the director of a hospital have been contacted to look into the professional requirements and an online survey was carried out to seek the consumer's requirements and amendments.
P7	Interdependence		

11.2 Attributes of complex Engineering Activities (EA)

Table 15. Attributes of Complex Engineering Activities (EA).

	Attributes	Put tick (√) as appropriate	Justification
A1	Range of resources	✓	Involves the use of a range of resources such as different posture and position data of patients and required self-funding to build the working prototype.In addition, new learnings and experiences of hardware implementation was vital. Also, a budget was made and a workflow of the system was planned to complete the project. Finally, proper documentation was done to record and establish the project.
A2	Level of interaction	✓	There are multiple sub systems in this project such as data collection and data transmission and storage from both FSR and health monitoring systems. So, issues arose while trying to link one subsystem with another as they have different specifications. Also, troubleshooting had to be done in FSR segmentation due to theoretical and experimental differences. Thus, optimization of the design was required. Additionally, the FSR activation had to have threshold values assigned to it as many would detect slight pressure without a presence of the patient's pressure.
A3	Innovation		
A4	Consequences for society and the environment	✓	The project has multiple impacts on the society and environment as it positively affects the health and well-being of the patients, ensuring their safety.

			Since it is a medical device, for proper regulation and circulation, approval and permission from respective bodies are required to avoid legal issues. Also, the design has no negative impact or harmful emission to the environment. Besides, it has a positive impact on the psychological state of the targeted patients as the solution has a no-restraint design.
A5	Familiarity	✓	The rule-based project covers the research gap that has been identified during a thorough literature review of previously existing systems. For instance, multiple position detection, a comfortable device that does not intrude privacy etc. In contrast to existing bed rail solutions, it is a new experience for patients to have restraint-free protection. Also, detection systems are more familiar to patients but these cannot prevent the occurrence of the bed fall. Thus, a bed fall prediction with remote health monitoring would be beneficial to this wide range of patients and taking care of them will be more accessible and manageable.

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Appendix A.

Related Codes

Bed Fall Prediction System Code

- Code for Data Collection

```
int s0 = 38;
int s1 = 39;
int s2 = 40;
int s3 = 41;
int M1 = A0, M2 = A1, M3 = A2, M4 = A3;
int muxEn[] = {37, 36, 35, 34};

int sensor[63] = {0};
void setup() {
  Serial.begin (9600);
  pinMode(s0, OUTPUT);
  pinMode(s1, OUTPUT);
  pinMode(s2, OUTPUT);
  pinMode(s3, OUTPUT);
  Serial2.begin(9600);
}

void printMux() {

Serial.println("Now");
```

```
}
void loop() {
  //Loop through and read all 16 values
 for (int i = 0; i < 16; i ++) {
  sensor[i + 1] = readMux(i, M1, muxEn[0]);
  sensor[i + 17] = readMux(i, M2, muxEn[1]);
  sensor[i + 33] = readMux(i, M3, muxEn[2]);
  sensor[i + 49] = readMux(i, M4, muxEn[3]);
 }

 printMux();
 //=============SEGMENT================
 int segStatus[11] = {0};
 int segCount[11] = {0};
 int segCountCompare[11] = {0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0};
 int segments[11][10] = {{1, 2, 6, 7, 11, 12, 0, 0, 0, 0},
  {16, 17, 21, 22, 26, 27, 31, 32, 0, 0},
  {36, 37, 41, 42, 46, 47, 0, 0, 0, 0},
  {3, 8, 13, 18, 23, 28, 33, 38, 43, 48},
  {4, 5, 9, 10, 14, 15, 0, 0, 0, 0},
  {19, 20, 24, 25, 29, 30, 34, 35, 0, 0},
  {39, 40, 44, 45, 49, 50, 0, 0, 0, 0},
  {51, 52, 53, 54, 0, 0, 0, 0, 0, 0},
  {59, 60, 0, 0, 0, 0, 0, 0, 0, 0},
  {61, 62, 0, 0, 0, 0, 0, 0, 0, 0},
  {55, 56, 57, 58, 0, 0, 0, 0, 0, 0}
 };
```

```
  for (int i = 0; i < 11; i++) {
    for (int j = 0; j < 10; j++) {
      if (sensor[segments[i][j]] > 300) {
        segCount[i]++;
      }
    }
  }
  for (int i = 0; i < 11; i++) {
    if (segCount[i] >= segCountCompare[i]) {
      segStatus[i] = 1;
    }
  }
  //====================Posture Detection=====================
  if ( !segStatus[0] && !segStatus[1] && !segStatus[2] && !segStatus[3] && !segStatus[4] &&
!segStatus[5] && !segStatus[6] ) {
    Serial2.println("BED is EMPTY");
    Serial.println("0");
  }
  else if (segCount[10] >= 2 && segCount[5] >= 4 && (segCount[4] >= 3 || segCount[6] >= 2)) {
    Serial2.println("Patient at R.RISK");
    Serial.println("1");
  }
  else if (segCount[9] >= 1 && segCount[5] >= 2  && segCount[4] >= 2 && segCount[6] >= 2)
{
    Serial2.println("Patient at RIGHT ");
    Serial.println("2");
  }
  else if (segCount[7] >= 3 && segCount[1] >= 3 && (segCount[0] >= 2 || segCount[2] >= 2)) {
```

```
    Serial2.println("Patient at L.RISK");
    Serial.println("5");
  }
  else if (segCount[8] >= 0 && segCount[1] >= 3 && segCount[0] >= 2 && segCount[2] >= 2) {
    Serial2.println("Patient at LEFT ");
    Serial.println("4");
  }
  else if (segCount[3] >= 4 && segCount[8] >= 1 && segCount[9] >= 1) {
    Serial2.println("Patient at Middle");
    Serial.println("3");
  }
}

int readMux(int channel, int muxNumber, int en) {
  int controlPin[] = {s0, s1, s2, s3};
  int muxChannel[16][4] = {
    {0, 0, 0, 0}, //ch0
    {1, 0, 0, 0}, //ch1
    {0, 1, 0, 0}, //ch2
    {1, 1, 0, 0}, //ch3
    {0, 0, 1, 0}, //ch4
    {1, 0, 1, 0}, //ch5
    {0, 1, 1, 0}, //ch6
    {1, 1, 1, 0}, //ch7
    {0, 0, 0, 1}, //ch8
    {1, 0, 0, 1}, //ch9
    {0, 1, 0, 1}, //ch10
```

```
    {1, 1, 0, 1}, //ch11
    {0, 0, 1, 1}, //ch12
    {1, 0, 1, 1}, //ch13
    {0, 1, 1, 1}, //ch14
    {1, 1, 1, 1} //ch15
  };
  digitalWrite(en, HIGH);
  for (int i = 0; i < 4; i ++) {
    digitalWrite(controlPin[i], muxChannel[channel][i]);
  }
  digitalWrite(en, LOW);
  return analogRead(muxNumber);
}
```

- Code for Gateway using ESP32 Development Board

```
#define BLYNK_TEMPLATE_ID "TMPLkjViI52P"
#define BLYNK_DEVICE_NAME "Bed Fall Prediction Model"
#define BLYNK_AUTH_TOKEN "JMA3nK3_Ycsa-zfip2cqK75kQASNh7MZ"

#define BLYNK_PRINT Serial
#include <Blynk.h>
#include <WiFi.h>
#include <BlynkSimpleEsp32.h>

char auth[] = BLYNK_AUTH_TOKEN;
char ssid[] = "OnePlus Nord";  // Your WiFi credentials.
char pass[] = "crd02658";
```

```
#define RXp2 16
#define TXp2 17
void setup() {
  // put your setup code here, to run once:
  Blynk.begin(auth, ssid, pass);
  Serial.begin(115200);
  Serial2.begin(9600, SERIAL_8N1, RXp2, TXp2);
}
void loop() {
  Blynk.run();
  if (Serial2.available()) {
    String d = Serial2.readStringUntil('\n');
    Serial.println(d);
    if (d.length() > 10) {
      Serial.println("Data:" + d);
      Serial.println("Data ind: " + String(d.equals("0")));
      Blynk.virtualWrite(V6, d);
      if (d.indexOf("Patient at L.RISK") > -1) {
        Blynk.logEvent("bed_fall_alert", "Patient X is at risky left position!!");
      }
      if (d.indexOf("Patient at R.RISK") > -1) {
        Blynk.logEvent("bed_fall_alert", "Patient X is at risky right position!!");
      }
    }
      }
}
```

Health Monitoring System Code

- Code for Heart rate, Oxygen Saturation and Body Temperature

```
#include <OneWire.h>
#include <DallasTemperature.h>

#define SENSOR_PIN  51 // ESP32 pin GPIO32 connected to DS18B20 sensor's DQ pin
OneWire oneWire(SENSOR_PIN);
DallasTemperature DS18B20(&oneWire);

float tempC; // temperature in Celsius
float tempF; // temperature in Fahrenheit

#define BLYNK_TEMPLATE_ID "TMPLkjViI52P"
#define BLYNK_DEVICE_NAME "Bed Fall Prediction Model"
#define BLYNK_AUTH_TOKEN "JMA3nK3_Ycsa-zfip2cqK75kQASNh7MZ"
#include <Wire.h>
#include "MAX30100_PulseOximeter.h"
#define BLYNK_PRINT Serial
#include <Blynk.h>
#include <WiFi.h>
#include <BlynkSimpleEsp32.h>

#define REPORTING_PERIOD_MS 3000

char auth[] = BLYNK_AUTH_TOKEN;
```

```
char ssid[] = "OnePlus Nord";  // Your WiFi credentials.
char pass[] = "crd02658";
PulseOximeter pox;
float BPM, SpO2;
uint32_t tsLastReport = 0;

void onBeatDetected() {
  Serial.println("Beat!");
}

void setup() {
  Serial.begin(115200);
  Blynk.begin(auth, ssid, pass);
  DS18B20.begin();
  Serial.print("Initializing pulse oximeter..");

  if (!pox.begin()) {
    Serial.println("FAILED");
    for (;;);
  } else {
    Serial.println("SUCCESS");
  }
  pox.setOnBeatDetectedCallback(onBeatDetected);
}
void getTemp(){
  DS18B20.requestTemperatures();       // send the command to get temperatures
  tempC = DS18B20.getTempCByIndex(0);  // read temperature in °C
```

```
  tempF = (tempC*9) / 5 + 32 ; // convert °C to °F
  Serial.println(tempF);
  Serial2.println(tempF);
}

void loop() {
  pox.update();
  Blynk.run();
  getTemp();
  delay(50);

  if (millis() - tsLastReport > REPORTING_PERIOD_MS) {

    BPM = pox.getHeartRate();
    SpO2 = pox.getSpO2();
    if (SpO2<95){
      Blynk.logEvent("hms_alert","Patient X's spO2 level is dangerously low");
    }
    if (BPM>100){
      Blynk.logEvent("hms_alert","Patient X's heartrate is beyond 100");
      }
    Blynk.virtualWrite(V5,SpO2);
    Blynk.virtualWrite(V4,BPM);
    Serial.print("Heart rate:");
    Serial.print(BPM);
    Serial.print("bpm / SpO2:");
    Serial.print(SpO2);
```

```
    Serial.println("%");
    tsLastReport = millis();
  }
  else {
     Blynk.virtualWrite(V7, d.toFloat());
    }

}
```