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Early Detection and Prevention of Pressure Injury and Ulcer in Prolonged Care

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ABSTRACT

This project aims to address the persistent issue of pressure injuries—commonly known as pressure ulcers or bedsores—that frequently affect immobile patients in long-term care or intensive care settings. These injuries, though largely preventable, result in significant health complications, extended recovery periods, and increased healthcare costs. The project proposes an integrated, technology-driven approach combining clinical risk assessments, smart wearable devices, and machine learning algorithms to detect and prevent these injuries proactively. Standard tools such as the Braden or Norton Scale assess risk levels, while sensor-embedded mattresses and wearable devices monitor pressure distribution, moisture, and patient movement in real time. This data is analyzed using predictive models to detect early signs of pressure injuries, triggering alerts for caregivers and enabling timely intervention. The system also includes a decision-support module that recommends individualized care strategies such as repositioning schedules and skincare routines, with all data integrated into electronic health records for comprehensive documentation and continuous care optimization. Expected outcomes include a significant reduction in pressure injury incidence, improved patient comfort and safety, enhanced caregiver responsiveness, and reduced healthcare burden. Overall, the project represents a shift from reactive treatment to proactive prevention, aiming to ensure safer, more dignified, and cost-effective care for patients requiring prolonged medical attention.

I. INTRODUCTION

Pressure injuries, commonly known as pressure ulcers or bedsores, are a serious and ongoing challenge in healthcare, particularly affecting patients in prolonged care settings such as intensive care units, long-term care facilities, and post-operative recovery wards. These injuries result from sustained pressure, shear, or friction, typically over bony prominences, and are especially prevalent among immobile patients, the elderly, and those confined to beds or wheelchairs. Despite existing clinical protocols, traditional methods of managing pressure injuries are largely reactive, relying on manual inspections and routine repositioning, which often detect injuries only after visible damage has occurred, leading to complications, prolonged healing, and increased healthcare costs. This project proposes an innovative, proactive solution that combines clinical assessment tools with smart technologies such as wearable sensors, pressure-sensitive mattresses, and machine learning algorithms to enable real-time monitoring of key risk factors like immobility, pressure points, and moisture. The system analyzes this data using predictive models to detect early warning signs of pressure injury development and generate alerts and personalized care recommendations for caregivers. Integrated with electronic health records, the solution supports automated decision-making, optimizes intervention schedules, and aligns seamlessly with existing medical workflows. By enhancing early detection and shifting the focus from treatment to prevention.

II. LITERATURE SURVEY

Pressure injuries, also known as pressure ulcers or bedsores, are localized damage to the skin and underlying tissue, typically over bony prominences, as a result of sustained pressure or pressure in combination with shear. The World Health Organization (WHO) and the National Pressure Injury Advisory Panel (NPIAP) classify these injuries into stages based on severity, with advanced stages leading to deep tissue necrosis, infection, sepsis, and increased mortality. Numerous studies have highlighted the high prevalence of pressure injuries in hospital and long- term care settings, particularly among the elderly, immobile, or neurologically impaired patients. A 2020 study published in *Advances in Skin & Wound Care* reported that approximately 2.5 million patients develop pressure injuries each year in the U.S. alone, with annual treatment costs exceeding $11 billion. These findings reinforce the urgency of adopting more effective and proactive prevention strategies.

Historically, the prevention of pressure injuries has focused on manual strategies such as repositioning patients every two hours, maintaining dry skin, and using support surfaces like foam mattresses. Clinical risk assessment tools such as the Braden Scale, Norton Scale, and Waterlow Score have been widely used to estimate the risk of pressure injury development by evaluating factors such as sensory perception, moisture, activity, mobility, nutrition, and friction/shear.

To overcome the limitations of manual monitoring and assessment tools, recent years have seen a growing interest in leveraging technology for pressure injury prevention. Pressure-redistribution mattresses with integrated sensors, wearable pressure and moisture monitors, and camera-based skin assessment tools have been introduced to enable continuous surveillance of at-risk patients. These devices provide real-time data on pressure points, body position, and environmental conditions that can influence skin integrity. For example, studies published in the *Journal of Tissue Viability* have demonstrated that continuous pressure mapping can significantly reduce the incidence of Stage 1 and 2 pressure ulcers by alerting caregivers before tissue breakdown occurs. However, the adoption of these devices has been limited due to cost, lack of integration with hospital systems, and the need for specialized training.

A growing body of literature highlights the role of artificial intelligence (AI) and machine learning (ML) in advancing pressure injury prevention. By analyzing historical and real-time patient data, such as movement patterns, risk scores, vital signs, and environmental factors, AI algorithms can predict the likelihood of pressure injury formation with greater accuracy. In a 2021 study conducted at the Mayo Clinic, researchers developed a machine learning model that accurately identified high-risk patients up to 72 hours before visible symptoms emerged. Similarly, other studies have proposed AI-driven dashboards and alert systems integrated with electronic health records (EHRs) to support timely interventions and optimize nursing workflows. Despite their promise, these systems are still in the experimental phase in many settings and require broader validation and real-world implementation.

III. METHODOLOGY

The methodology for this project is centered around designing and implementing a proactive healthcare monitoring system that can detect and prevent pressure injuries in patients requiring prolonged care. The system integrates clinical assessment tools, real-time physiological monitoring using embedded sensors, machine learning-based prediction algorithms, and alert- generation mechanisms. The architecture is designed to be modular, allowing for data acquisition, processing, decision support, and data storage, with patient safety and usability as the highest priorities.

At the initial stage, each patient is evaluated using standard clinical risk assessment tools like the Braden or Norton Scale. These tools help in categorizing patients based on their risk levels by considering parameters such as sensory perception, moisture, activity, mobility, nutrition, and friction/shear. This baseline profiling allows the system to identify high-risk individuals and customize sensor sensitivity and response thresholds accordingly.

The hardware architecture is the PIC16F877A microcontroller, which acts as the central control unit for data collection and preliminary signal processing. This 40-pin microcontroller is selected for its low power consumption, built-in ADC (Analog-to-Digital Converter), multiple I/O ports, and USART communication capability. The PIC16F877A reads analog signals from the pressure and humidity sensors and converts them into digital data using its onboard ADC. It also performs basic filtering and data smoothing before transmitting the data wirelessly (via Bluetooth or Wi-Fi module) to a higher-level processing unit, such as a Raspberry Pi or cloud server, for further analysis.

A network of sensors is deployed to continuously monitor the physical parameters associated with pressure injury development. These include pressure sensors to monitor load distribution on bony prominences, humidity sensors to detect moisture levels due to sweating or incontinence, and motion sensors to assess the frequency and quality of patient repositioning. These sensors are integrated into a pressure-sensitive mattress pad and wearable devices that the patient can comfortably use over long periods.

Once sensor data is transmitted to the central processing unit, machine learning algorithms analyze it in real time to identify patterns associated with the early formation of pressure injuries. Models such as decision trees, support vector machines (SVM), or logistic regression classifiers are trained on historical datasets to predict the likelihood of pressure ulcer development. These models consider multiple input variables—pressure duration, moisture levels, movement frequency, and baseline risk score—to generate risk alerts. A weighted scoring system prioritizes critical cases and ensures the most vulnerable patients receive immediate attention.

All data—sensor readings, risk scores, caregiver interventions, and system alerts are logged in an integrated electronic health record system. This ensures that clinicians have a continuous, data- driven view of the patient's condition over time. The EHR interface allows seamless documentation, regulatory compliance, and retrospective analysis of care effectiveness. The PIC16F877A supports data time-stamping and ID- tagging at the device level, ensuring accurate and reliable data logging before transmission to the main server.

The regulated power supply plays a crucial role in ensuring stable operation for all electronic components, including the PIC16F877A microcontroller, sensors, and communication modules. The system begins with a step-down transformer that reduces AC voltage from 230V to 12V AC. The AC voltage is then converted into DC through a bridge rectifier, and the pulsating DC is smoothed using an electrolytic capacitor. To provide regulated power, the LM7805 voltage regulator outputs a steady +5V DC, which powers the microcontroller and digital sensors, while an additional LM7812 regulator provides +12V DC for higher-power components, such as the pump. The system includes decoupling capacitors for noise suppression, a power LED indicator, and protective components like fuses and a reverse- polarity diode.

This is particularly useful for adjusting the pressure zones under the patient to prevent pressure injuries. The regulated power supply ensures that both the logic circuits and the high- power components, like the pump, function reliably, while the pump driver provides precise control over pressure management based on real- time feedback from the pressure sensors. Together, these components enable a proactive and automated system for pressure injury prevention in patients requiring prolonged care.

IV. EXISTING SYSTEM

Pressure injuries, also known as pressure ulcers or bedsores, remain a significant concern in healthcare, particularly in long-term care and intensive care settings. These injuries typically occur in patients who are immobile for extended periods, often due to neurological impairments, physical disabilities, or serious illnesses. The development of these wounds not only compromises patient health but also leads to extended recovery times, higher healthcare costs, and an overall decrease in the quality of care provided. In the existing systems, the primary method of preventing pressure injuries involves manual repositioning and monitoring, which is time-consuming and dependent on the vigilance of healthcare staff.

The current standard for pressure injury prevention is primarily based on nursing interventions, which include routine repositioning of patients every two hours, use of specialized pressure-relieving mattresses, and ensuring adequate nutrition and skin care. These methods are essential, but they can often be inconsistent, as they depend on the attention and awareness of nursing staff. Furthermore, frequent manual repositioning might not always address the underlying risk factors, such as the uneven distribution of body weight, moisture buildup, or lack of movement. Existing systems that integrate pressure sensors in beds or mattresses are mostly reactive rather than proactive, often alerting caregivers after a certain threshold has been reached, rather than predicting or preventing injury before it occurs.

Wearable sensor technology is another avenue explored in existing systems. Devices like accelerometers and inertial sensors are used to detect patient movements and their position, giving caregivers valuable insight into whether the patient has been in the same position for too long. While these technologies offer some advantages, they often lack integration with more comprehensive systems that include both pressure monitoring and mobility tracking.

The data from these sensors may be collected and stored, but is often not utilized effectively to drive proactive care decisions. For example, while an accelerometer can detect movement, it cannot directly measure pressure levels at specific body points, which is a critical factor in preventing pressure ulcers. Certain industries and commercial buildings utilize Supervisory Control and Data Acquisition (SCADA) systems for power monitoring. These systems can track voltage levels, current, and power consumption in real-time.

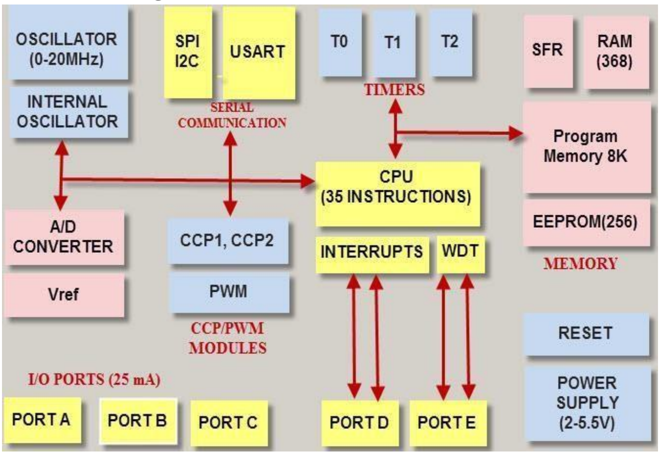
However, SCADA systems are expensive, complex to implement, and require specialized knowledge to operate. This makes them unsuitable for small-scale users, such as residential buildings or small businesses.

V. PROPOSED SYSTEM

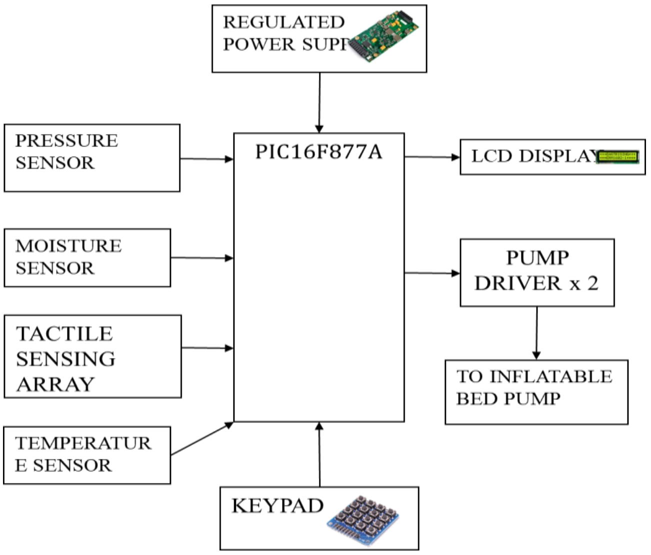
This system introduces a smart healthcare solution that combines sensor technologies, microcontroller-based control, and intelligent decision support. It utilizes a network of pressure sensors, accelerometers, and inertial sensors embedded in patient beds and wearable devices to continuously monitor the patient's posture, movement, and localized pressure points. These readings help identify patients who are at risk of developing pressure ulcers due to extended immobility or excessive localized pressure. By analyzing these parameters in real-time, the system ensures continuous surveillance without requiring constant human supervision, drastically improving the standard of patient care.

At the core of the system is the PIC16F877A microcontroller, which serves as the main control unit, interfacing with sensors and other electronic components. It collects analog data from sensors, processes it, and communicates essential information to caregivers or connected systems. When risk thresholds are detected, the system sends automated alerts suggesting necessary repositioning actions. The microcontroller also interfaces with a pump driver module that regulates an air-flow mattress to dynamically adjust the pressure applied to different body regions. Along with this, a regulated power supply unit ensures stable and consistent voltage for the entire system, preventing power surges that could affect monitoring accuracy or patient safety.

It is also designed for integration with Electronic Health Record (EHR) systems, allowing for seamless documentation and care continuity. This integrated, proactive approach not only minimizes the risk of developing pressure injuries but also optimizes nursing workflows, reduces manual monitoring burden, and improves overall patient well-being. By shifting from reactive treatment to preventive care, the system aims to revolutionize how pressure ulcers are managed in hospitals, ICUs, and long-term care environments.

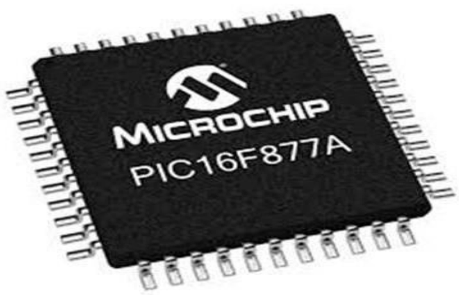


VI. WORKING OF PROPOSED SYSTEM

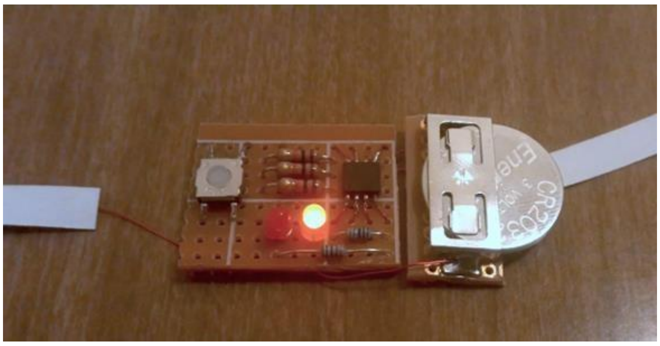


The Smart Patient Monitoring and Responsive Bed Control System is an advanced healthcare solution designed to monitor patients in real-time and respond to critical conditions without manual intervention. The system is powered through a step-down transformer that converts AC current to 12V DC. This is further regulated to a 5V output via a single power supply module. The 5V is distributed to the PIC16F877A microcontroller, which serves as the central controller. It also powers connected components including a 16x2 LCD display, a switch control panel, six internal bed sensors, three external sensors, and a relay-driven actuator system for bed movement.

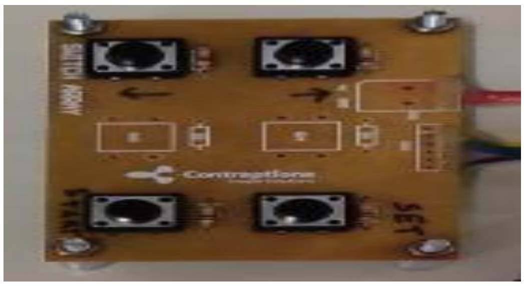
1. Sensor Input and Microcontroller Integration The system uses a combination of nine sensors six placed inside the bed and three outside. The internal sensors track the patient's mobility and physical actions, while the external sensors measure environmental parameters like temperature, moisture, and pressure. These inputs are crucial in assessing the patient's condition and are displayed in real-time on the LCD screen. The PIC16F877A microcontroller collects and processes this sensor data continuously, allowing for fast and intelligent decision-making.



The microcontroller collects data from all nine sensors and processes it to determine the patient's real-time condition. The information is then displayed on the LCD screen, providing immediate insights to caregivers.

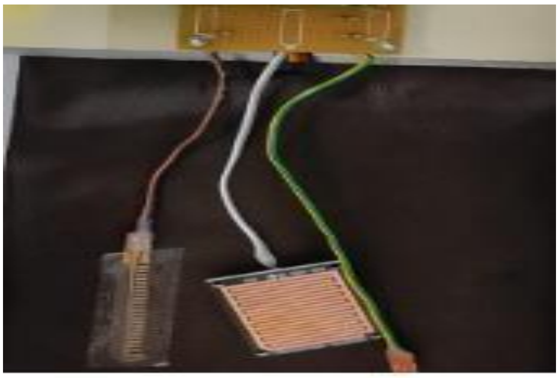


2. Manual Sensitivity and Mode Configuration The system includes a switch array connected to the microcontroller, featuring a set/start button. This interface allows healthcare staff to manually adjust system settings such as sensitivity levels and nutritional modes depending on patient requirements. These configurations influence how the microcontroller interprets sensor input and determine the response thresholds for triggering alerts or automated actions.

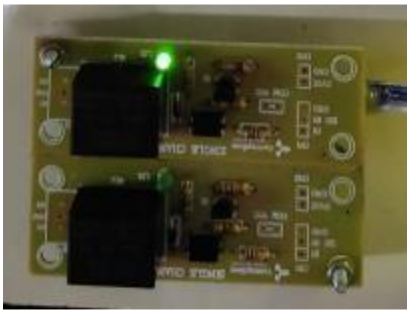


3. Health Assessment via Clinical Tools An integrated logic system compares real-time sensor values against clinically provided benchmarks using tools like the Braden Scale. The "actual values"—entered by doctors—serve as reference health metrics for individual patients, while "current values" are captured from the sensors in real-time. When deviations occur—such as high moisture or pressure with low mobility— the system identifies the patient as being at chronic risk.

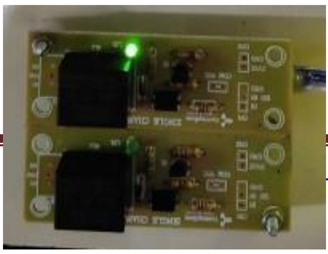
To provide detailed monitoring, the system includes current and voltage sensors that measure electrical parameters in real time. These sensors send data to the microcontroller, which processes and stores the readings for analysis. This helps in understanding power consumption patterns and detecting fluctuations.



4. Automated Bed Control via Relay and Pump If the system detects a critical mismatch between actual and current health indicators, it automatically activates a relay. This relay triggers a motorized pump mechanism that adjusts the bed's posture to reduce pressure and enhance circulation. This automated movement reduces the risk of pressure ulcers and improves patient comfort and safety without requiring nurse intervention.



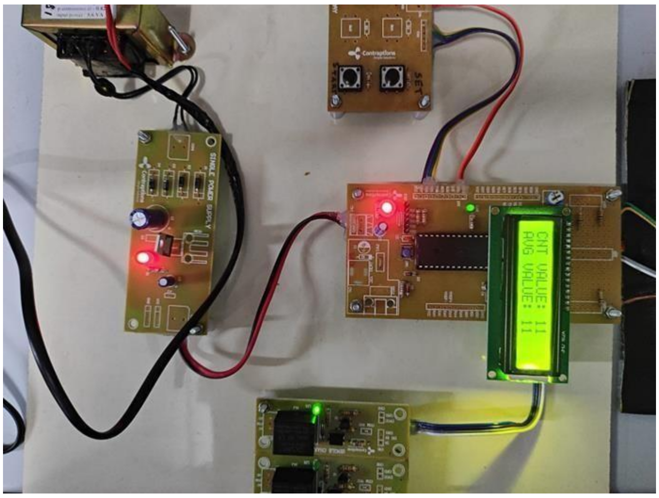
5. Data Display and Monitoring Throughout operation, sensor data and system status are continuously updated and displayed on the LCD module. This provides immediate visual feedback to caregivers and allows them to verify system operation. In future enhancements, the system could integrate a data logging mechanism using a Real-Time Clock (RTC), and also support GSM/IoT-based alerts to notify medical staff remotely about patient conditions.

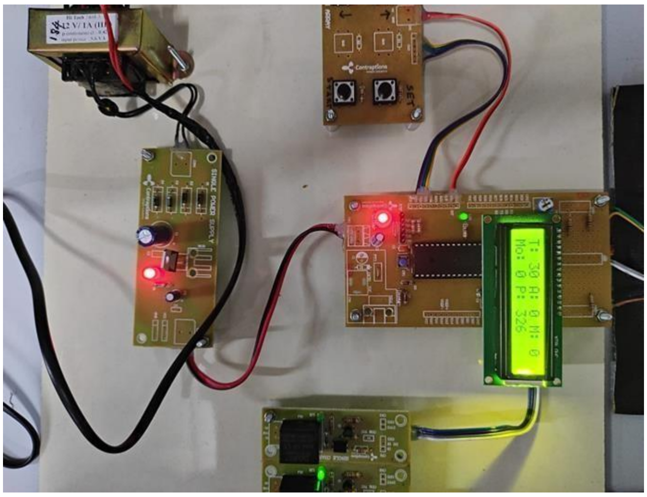


VII. SIMULATED OUTPUTS

To simulate the Early Detection and Prevention of Pressure Injury and Ulcer in Prolonged Care system, the following steps are included:

- **Power Supply Simulation**: A step-down transformer converts AC to 12V, and a regulator gives 5V DC to power the PIC16F877A microcontroller, LCD, sensors, switches, and relay.
- **Switch Control**: A "SET" button is used to start manual mode. Sensitivity and nutrition levels can be increased or decreased using switches.
- **Sensor Readings**:
  - **Inside the bed**: 6 sensors detect movement and activity.
  - **Outside the bed**: 3 sensors detect temperature, moisture, and pressure. All readings are shown on a 16x2 LCD display.
- **Braden Scale Check**: The system compares doctor-given values with live sensor values.
  - If the live value is higher, it means the patient is at risk.
  - The relay is turned ON to automatically adjust the bed.
- **Relay Output**: The relay operates a motor or pump to turn the bed when needed. This helps reduce pressure on the patient.
- **LCD-Display**: The LCD shows power status values. An alerts.





Here's the Embedded C Code for the simulation:

Simulation

```
#include<htc.h>


__CONFIG(0x1F72);
```

```
#define TACTILE_ARRAY_6 RC5
#define PUMP_A RD0
#define PUMP_B RD
#include "string.h"
#include "lcd.h" #include
"adc.h" #include "menu.h"
#define TEMPERATURE 0
#define PRESSURE 1

#define MOBILITY 2

#define MOISTURE 3

#define ACTIVITY 4

unsigned char pump_alternate_freq, mobility, braden[4], tactile_array_1_history, tactile_array_2_history, tactile_array_3_history, tactile_array_4_history, tactile_array_5_history, tactile_array_6_history;

int call_count, time, pump_timer, show_time, temperature, moisture, activity, pressure, current_braden_value, average_braden_value, outta_bed, menu_toggle = 1;

void parametersScan()

{
```

```
#define _XTAL_FREQ 16000000

#define BUFF_SIZE 8

#define TACTILE_ARRAY_1 RC0
#define TACTILE_ARRAY_2 RC1
#define TACTILE_ARRAY_3 RC2
#define TACTILE_ARRAY_4 RC3
#define TACTILE_ARRAY_5 RC4
temperature = ADC_Read_10_Bit(0);
moisture = (1023 - ADC_Read_10_Bit(1)) / 2;
pressure = ADC_Read_10_Bit(2);

if((TACTILE_ARRAY_1 == 1 && tactile_array_1_history == 0) || (TACTILE_ARRAY_1 == 0 && tactile_array_1_history == 1))

{

    __delay_ms(300);

tactile_array_1_history = !tactile_array_1_history; mobility++;
time = 0;

}

if((TACTILE_ARRAY_2 == 1 && tactile_array_2_history == 0) || (TACTILE_ARRAY_2 == 0 && tactile_array_2_history == 1))

{

    __delay_ms(300);

tactile_array_2_history = !tactile_array_2_history; mobility++;
time = 0;

}

if((TACTILE_ARRAY_3 == 1 && tactile_array_3_history == 0) || (TACTILE_ARRAY_3 == 0 && tactile_array_3_history == 1))

{

    __delay_ms(300);

tactile_array_3_history = !tactile_array_3_history; mobility++;
time = 0;

}

if((TACTILE_ARRAY_4 == 1 && tactile_array_4_history == 0) || (TACTILE_ARRAY_4 == 0 && tactile_array_4_history == 1))

{

    __delay_ms(300);

tactile_array_4_history = !tactile_array_4_history; mobility++;
time = 0;

}

if((TACTILE_ARRAY_5 == 1 && tactile_array_5_history == 0) || (TACTILE_ARRAY_5 == 0 && tactile_array_5_history == 1))

{

    __delay_ms(300);

    tactile_array_5_history = !tactile_array_5_history;
```

```
        mobility++;
time = 0;

}

if((TACTILE_ARRAY_6 ==
1 &&
tactile_array_6_history
== 0) ||
(TACTILE_ARRAY_6 == 0
&&
tactile_array_6_history
== 1))

{

        __delay_ms(300);

tactile_array_6_his
tory =
!tactile_array_6_hi
story; mobility++;
time = 0;

}

if((TACTILE_ARRAY_1 ==
1 || TACTILE_ARRAY_2
== 1
|| TACTILE_ARRAY_3 ==
1 || TACTILE_ARRAY_4
== 1
|| TACTILE_ARRAY_5 ==
1 || TACTILE_ARRAY_6
== 1)
&& outta_bed == 0)

{

          d
e
l
a
y
_
m
s
(
3
0
0
); outta_bed = 1;
}

else if(TACTILE_ARRAY_1 == 0 && TACTILE_ARRAY_2
== 0 && TACTILE_ARRAY_3 == 0 && TACTILE_ARRAY_4 ==
0 && TACTILE_ARRAY_5 == 0
&& TACTILE_ARRAY_6 == 0 && outta_bed == 1)

{

        __delay_ms(300);
outta_bed = 0; activity++;
}

}

int calculateBradenValue()

{

if(temperature > 700)
{

braden[TEMPERATURE] = 1;

}

else if(temperature > 680)

{

braden[TEMPERATURE] = 2;

}

else if(temperature > 650 )

{

braden[TEMPERATURE] = 3;

}     —

else if(temperature <= 640 && temperature > 550)

{

braden[TEMPERATURE] = 4;

}

else
```

```
{
braden[TEMPERATURE]
= 1;
}
if(pressure > 320)
{
braden[PRESSURE] = 1;
}
else if(pressure > 310)
{
braden[PRESSURE] = 2;
}
else if(pressure > 290)
{
braden[PRESSURE] = 3;
}
else if(pressure < 270)
{
braden[PRESSURE] = 4;
}
if(moisture > 400)
{
braden[MOISTURE] = 1;
}
else if(moisture > 300)
{
braden[MOISTURE] = 2;
}
else if(moisture > 200)
{
braden[MOISTURE] = 3;
}
else if(moisture < 100)
{
braden[MOISTURE] = 4;
}
if(mobility < 2)
{
braden[MOBILITY] = 1;
}
else if(mobility < 6)
{
braden[MOBILITY] = 2;
}
else if(mobility < 10)
{
braden[MOBILITY] = 3;
}
else if(mobility > 12)
{
braden[MOBILITY] = 4;
}
if(activity < 2)
{
braden[activity] = 1;
}
```

```
else if(activity < 3)
{
braden[activity] = 2;
}
else if(activity < 4)
{
braden[activity] = 3;
}
else if(activity > 5)
{
braden[activity] = 4;
}

return braden[TEMPERATURE] + braden[PRESSURE] +
braden[MOBILITY] + braden[MOISTURE] +
braden[ACTIVITY] + ((menu_var[0] + menu_var[1]) /
2);
```

```
    }
    else
        return;
  if(!pump_alternate_freq)
  {
        PUMP_A = 0;
PUMP_B = 0;
  }
    else if(call_count >= pump_alternate_freq)
    {
if(PUMP_A)
        {
            PUMP_A = 0;
            PUMP_B = 1;
        }
        else
        {
            PUMP_A = 1;
            PUMP_B = 0;
        }
        call_count = 0;
    }
  }
```

```
 }

void runPump()

{

   if(pump_timer > 40)

   {

      call_count++; pump_timer = 0; void main()

{
TRISC = 0xFF; TRISA = 0xFF; TRISE0 = 1;
   TRISE1 = 1;

   TRISD0 = 0;
   TRISD1 = 0;

PUMP_A = 0;

PUMP_B = 0; ADC_Init(8,0);
   Lcd4_Init(); MenuInit(2);
SetMenuLabels("SENSITIVITY:NUTRITION");

SetMenuDefaults("1:1");
SetMenuMaxs("4:4");
SetMenuMins("1:1");   Lcd4_Clear();
   Lcd4_Set_Cursor(0,0);
Lcd4_Write_String_Centred("BRADEN              VALUE");
   Lcd4_Set_Cursor(1,0);
Lcd4_Write_String_Centred("CALCULATION");

   __delay_ms(500);



while(!START); while(1)
   {

parametersScan();
pump_timer++;           time++;
show_time++;         runPump();
SetMenu();    if(show_time    >=
100)
{

show_time = 0; Lcd4_Clear();
menu_toggle = !menu_toggle;

current_braden_value    =    calculateBradenValue();
if(!average_braden_value)
   average_braden_value = current_braden_value;

average_braden_value   =   (average_braden_value    +
current_braden_value + 1) / 2;

if(current_braden_value < 10)

{

   pump_alternate_freq = 1;

}

else if(current_braden_value < 12)

{

   pump_alternate_freq = 2;

}

else if(current_braden_value < 16)

{

   pump_alternate_freq = 3;

}

else if(current_braden_value < 20)

{

   pump_alternate_freq = 4;

}

else

{

   pump_alternate_freq = 0;

}

mobility = 0;

activity = 0;

time = 0;

}
```

```
if(menu_toggle)

{
Lcd4_Set_Cursor(0,0); Lcd4_Write_String("T: "); Lcd4_Write_Int(temperature / 16); Lcd4_Write_String(" A: "); Lcd4_Write_Int(activity); Lcd4_Write_String(" M: "); Lcd4_Write_Int(mobility); Lcd4_Set_Cursor(1,0); Lcd4_Write_String("Mo: "); Lcd4_Write_Int(moisture); Lcd4_Write_String(" P: "); Lcd4_Write_Int(pressure);
}

else

{

    Lcd4_Set_Cursor(0,0); Lcd4_Write_String("CNT VALUE: "); Lcd4_Write_Int(current_braden_value);
    Lcd4_Set_Cursor(1,0); Lcd4_Write_String("AVG VALUE: "); Lcd4_Write_Int(average_braden_value);
}

    __delay_ms(5);

  }

}
```

NET_NO_PIN_ESCAPE
NET_NET_SHORT END

VIII . FUTURE ENHANCEMENTS

1. Wireless Sensor Networks (WSN)

In the current setup, sensors may rely on physical wiring, which can limit patient mobility and cause clutter around the bed. By upgrading to Wireless Sensor Networks (WSN), the entire system becomes more efficient and less invasive. Wireless modules can collect data from multiple sensors and transmit it to a central processor without using wires. This makes installation easier, especially in large hospitals with many patients. It also reduces the risk of wires tangling, getting disconnected, or being damaged. Wireless systems are ideal for maintaining hygiene in sterile hospital environments. Additionally, maintenance becomes easier since individual modules can be diagnosed and replaced without rewiring. This enhancement promotes better scalability, allowing the system to be easily extended to monitor more patients or areas.

2. **IoT-Based Cloud Connectivity**

Cloud integration is a powerful enhancement that extends the reach of the system beyond hospital walls. By leveraging Internet of Things (IoT) platforms, the data collected from sensors can be uploaded to a secure cloud server in real-time. This allows doctors, nurses, or even family members to monitor the patient's condition remotely using smartphones or tablets. With cloud analytics, long-term trends can be observed and used to refine care strategies. If abnormal patterns are detected, instant alerts can be sent even when caregivers are off-site. This also supports post- discharge monitoring at home, ensuring continuity of care. Cloud storage enables the system to maintain large historical datasets, which can be useful for medical research and audits. Backup and data recovery are easier with cloud support, ensuring data is not lost due to system failures.

VIII. Machine Learning for Risk Modeling

Integrating machine learning (ML) into the system enhances its ability to predict pressure injuries before they occur. ML algorithms can be trained on historical pressure data, patient movement patterns, and physiological signals to identify high-risk scenarios. As the system gathers more data over time, the model continuously improves, offering increasingly accurate predictions. For example, the model may detect subtle decreases in mobility or changes in posture that precede ulcer development. It can then alert caregivers with a risk score and suggest proactive actions. ML can also help personalize care plans based on each patient's unique risk profile. This makes the system more intelligent and responsive, going beyond fixed thresholds. It enables data-driven decisions instead of relying solely on manual observations. Integration of AI transforms the system from a reactive alert system to a predictive diagnostic tool.

IX. Automated Repositioning Mechanism

Currently, repositioning is suggested through alerts, requiring manual caregiver intervention. Future enhancement could integrate the system with a motorized smart bed or actuator-based mechanism that automatically repositions the patient. Based on pressure readings, the system can adjust the patient's posture every few hours or when pressure exceeds safe thresholds. This automation ensures consistent care, even in understaffed settings or during night shifts. It significantly reduces the dependency on human labor, especially in critical care units. The movement can be slow and controlled to ensure patient comfort and safety. Smart beds can also monitor feedback from sensors to verify successful repositioning. Such automation not only helps in preventing ulcers but also reduces caregiver fatigue. In advanced implementations, the system can even log repositioning times and success rates in patient records.

X. Smart Alert System with Escalation Protocol

The current alert system can be improved by implementing a multi-level notification and escalation process. If a caregiver fails to respond to an alert within a defined time frame, the system can escalate it to other team members via SMS, calls, or even integration with a hospital's nurse call system. Alerts can be prioritized based on risk severity and patient condition. Visual and audio indicators can be differentiated—for example, high-priority alerts could use red flashing indicators and loud alarms. Integration with wearable smartwatches or pagers can ensure that mobile caregivers receive alerts instantly. In critical conditions, the system could alert emergency response teams or supervising doctors. This ensures that no high-risk situation goes unnoticed due to human error or workload delays. An intelligent alert system can also log response times, creating accountability and performance metrics for hospital staff. It can be programmed to send reminders if an action is overdue.

XI. Multi-Patient Centralized Monitoring Interface

A centralized monitoring dashboard can be developed to allow caregivers to observe multiple patients simultaneously. The interface would display real-time data like pressure distribution, repositioning status, alert history, and patient- specific recommendations. Each patient's bed can be represented in a grid layout with color codes indicating current risk levels (e.g., green for safe, red for critical). This would help nurses prioritize which patients need immediate attention. Filters and search options can help quickly access specific patient data or beds in a particular ward. The system could also show graphs of historical pressure trends or compliance with repositioning schedules. Alerts can be managed from this single interface, making hospital operations smoother. This is especially useful in ICUs or long-term care homes where staff need to monitor many patients.

XII. Seamless Integration with Electronic Health Records (EHR)

An important enhancement is the integration of the system with existing Electronic Health Record (EHR) systems used by hospitals. All pressure- related data, repositioning logs, and sensor alerts can be automatically synced with patient records. This eliminates the need for manual documentation, saving time and reducing errors. Doctors and nurses can access this data directly from the patient's health profile, allowing for a more informed diagnosis and better treatment decisions. EHR integration also ensures compliance with medical protocols and supports medico-legal documentation. It can be used to track the effectiveness of preventive measures over time. When patients are transferred or discharged, their pressure history travels with them seamlessly. This continuity of care improves outcomes, especially in cases involving multiple departments or follow-up treatments.

XIII. Enhanced Battery Backup and Power Management

For uninterrupted operation during power outages, the system can be enhanced with a more robust battery backup and an intelligent power management unit. Lithium-ion battery packs with sufficient capacity could power the system for several hours. Charging circuits and voltage regulators must be optimized to maintain power stability across all modules, including sensors and microcontrollers. Watchdog timers can ensure the system resets automatically in case of a crash, preventing data loss or corruption. Energy-efficient components and sleep-mode programming for sensors can extend battery life. Solar panels could also be considered for areas with unreliable electricity, particularly in rural healthcare settings. The system could include a battery status indicator and alert caregivers when levels are critically low. Intelligent power management ensures that even during failures, the most essential features (e.g., alerts, data logging) remain active.

XIV. Auto-Calibrating Sensor Network

Sensor drift and environmental variations can affect data accuracy over time. An auto- calibrating mechanism can be built into the system to address this issue. Pressure, temperature, and humidity sensors can periodically recalibrate based on baseline readings or reference conditions. For instance, if a bed is empty, the system can take that as a "zero" reference point for pressure sensors. This recalibration ensures that every reading is relative to the most accurate context, minimizing false alerts. The system can also log calibration data to check for sensor degradation over time. Automatic detection of faulty sensors, followed by notification to maintenance staff, can reduce downtime. Auto-calibration also adapts to changes like mattress type, patient weight, and body shape, which could otherwise skew results.

XV. Voice-Activated Control

Voice assistants can be integrated into the system to enable caregivers to control and retrieve system information hands-free. In high-pressure environments like ICUs, this feature saves time and avoids contamination risks from touch interfaces. Caregivers can ask the system questions like "What is the pressure status of Bed 3?" or give commands like "Acknowledge alert for Patient 7." The system could respond with audio or visual feedback. Voice recognition software must be trained for common medical terminology and background noise resistance. For security, voice authentication or role-based access can be implemented. This kind of interface improves ease of use, especially for multitasking staff. It also supports caregivers with limited technical skills by providing a natural and intuitive way to interact.

IX. CONCLUSION

Pressure injuries, commonly referred to as bedsores or pressure ulcers, remain a persistent challenge in healthcare, particularly among patients who are bedridden or have restricted mobility. These injuries not only lead to severe pain, infections, and longer hospital stays but also add substantial costs to healthcare systems. Despite the availability of clinical guidelines and routine care practices, their effectiveness largely depends on timely execution by caregivers—something that can be hindered by understaffing or human error. This project aims to overcome such barriers through a technology-assisted proactive approach. By integrating sensors, real-time monitoring, and intelligent alert systems, the solution addresses the root cause: unrelieved pressure over bony prominences.

The use of clinical assessment tools like the Braden Scale is augmented by constant digital observation, leading to a significantly enhanced prevention model. This hybrid approach of traditional clinical judgment and continuous technological surveillance forms the backbone of a smarter, more effective pressure injury management system. One of the key strengths of Power Pulse is its ability to track power supply fluctuations and maintain real- time logs of outages. This not only helps in analyzing power stability but also supports preventive maintenance and troubleshooting. The system's capability to integrate with alternative energy sources like solar panels enhances its sustainability, allowing users to monitor efficiency and detect faulty grids or low-performing panels. Additionally, data-driven decision-making is made possible through Excel-based real-time reporting, which records power on/off durations, consumption trends, and efficiency metrics.

Incorporating a microcontroller like the **PIC16F877A** into the system adds further efficiency and modularity. This microcontroller governs the data collection from sensors, handles signal processing, and executes control operations like issuing alarms or controlling actuators. Its low power consumption and ease of programming make it a suitable candidate for embedded health applications. Alongside, the regulated power supply and pump driver circuits ensure that the sensors and actuators function reliably without risk of malfunction due to power instability. All these components work together to build a robust and autonomous system capable of operating around the clock. The reliability and low-cost nature of the PIC microcontroller enable scalable deployments in hospitals and homecare units. This scalability ensures that the benefits of the system are not confined to large institutions but can extend to smaller care settings where resources are limited. Thus, the project brings high-end healthcare technology within reach for a broader population.

The project represents a significant advancement in addressing one of the most preventable yet damaging conditions in prolonged care settings. Its intelligent design, incorporating real-time monitoring, data analytics, and caregiver alerts, ensures that patients receive timely and personalized care. The modular structure, low-cost hardware, and user-friendly interface make it practical for wide-scale adoption. Future enhancements such as voice integration, cloud analytics, and remote caregiver dashboards further increase its potential. The journey from detection to prevention highlights a paradigm shift towards anticipatory healthcare, where risks are managed before they turn into crises. By bridging the gap between technology and patient-centric care, this project offers a scalable, efficient, and humane solution to pressure injury prevention, ultimately aiming to uphold the dignity, safety, and well-being of patients under long-term medical supervision.

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