Smart bed for pressure ulcer (bedsores) prevention

Product design and Prototyping laboratory (HT508) Mid-semester evaluation report

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Abstract

Pressure ulcers (PUs) is one of the most challenging issues in healthcare management. It leads to formation of secondary infections in patient thereby increasing the cost of therapy. Various internal and external factors are responsible for the formation of PUs. The major reasons for PUs formation are uneven pressure distribution on different locations of the body, friction, shearing between the body and mattress, temperature, malnutrition, compromised immune system in patients. Several researchers across the world are trying to address this issue by studying alternatives to the factors responsible for PUs formation. One such technique to avoid PUs is to reposition the patient at regular intervals which helps in redistribution of pressure thereby improving the blood circulation. The demand for manual intervention and time-to-time monitoring makes it practically impossible to reposition the patient especially in hospital settings. To address this issue a smart bed with in-built sensors, micro vibrations and servo motors has been proposed in this study. This report gives an overview of the study.

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Introduction

Pressure ulcers (PUs), also known as bedsores, remain a significant challenge in patient care, especially in hospitals and home settings. The incidence and prevalence of PUs are widely recognized as indicators of the quality of patient care. These ulcers occur across various healthcare environments, with studies indicating that nearly 57% to 60% of cases develop in hospitals. In long-term care facilities, the prevalence ranges from 2.4% to 23%, while in homecare settings, it varies between 9% and 20%. Although they can affect individuals across several age groups, elderly patients, i.e., those above the age of 70, are more prone to these PUs. As per a study, almost 70% of the patients above 70 can be affected with PUs. The prevalence of pressure ulcers in emergency services ranges from 5.2% at admission to 12.3% at discharge. The incidence (new cases) ranges from 4.5% to 78.4%, depending on the study population and risk factors (Sardo P.M.G et al., 2023).

Several factors, including uneven pressure distribution, reduced blood supply to dermal tissues, shearing forces, friction, moisture, temperature, malnutrition, and prolonged immobility, contribute to PU formation. The major factor responsible for the PUs is the uneven distribution of pressure during lying conditions. High pressure is exerted on the low-contact surface areas such as shoulders, elbows, hips, buttocks, and heels, which leads to improper blood circulation to the dermal layers due to compression of the blood vessels, leading to anoxia, tissue damage, cell death, and eventually PUs formation. Additionally, increased temperature due to prolonged contact with a surface leads to sweating and moisture accumulation, which leads to weakening of the skin barrier, making it more fragile and susceptible to friction and bacterial infections. The heat generated increases metabolic demand in tissues, which, when combined with restricted blood flow, accelerates tissue breakdown and ulcer formation.

One major conventional strategy to prevent PUs is repositioning patients at regular intervals, typically every two hours, as widely practiced in hospitals. However, this approach is labour-intensive, demanding continuous patient monitoring, and causes a significant burden on caregivers. Given the vast number of patients, maintaining such frequent repositioning in hospital settings becomes practically not feasible.

To address this challenge, various smart bed solutions have been developed. Some systems monitor pressure points and alert caregivers when repositioning is necessary, while others use air or water-based mechanisms to redistribute pressure continuously. However, these solutions are often costly or require manual intervention.

To address these limitations, a smart bed capable of continuously monitoring pressure distribution over time has been discussed in this report. This bed integrates micro-vibrations to enhance blood circulation and can initiate lateral movements when pressure exceeds predefined thresholds. By automating pressure redistribution, our solution aims to reduce the need for manual repositioning, offering a more efficient and accessible approach to PU prevention.

Literature Review

PUs, also known as bedsores or decubitus ulcers, remain a significant medical concern, particularly among immobilized and elderly patients. PUs are a leading cause of morbidity in bedridden and geriatric patients. Agrawal & Chauhan (2012) report that incidence rates in hospitalized patients range from 0.4% to 38%, with prevalence rates as high as 69%. Nursing home residents and home care patients also experience significant rates of pressure ulcer development. Thomas (2001) noted that PUs occur in nearly 70% of individuals over the age of 70, with spinal cord injury patients and orthopaedic patients at particularly high risk. PUs primarily result from sustained external pressure exceeding capillary perfusion pressure, leading to ischemia and subsequent necrosis of the affected tissues (Bhattacharya & Mishra, 2015). Shearing and frictional forces further exacerbate tissue damage by distorting blood vessels, impeding circulation, and increasing vulnerability to ulcer formation (Thomas, 2001). The most common sites for pressure ulcers include bony prominences such as the sacrum, ischial tuberosities, trochanters, and heels (Agrawal & Chauhan, 2012).

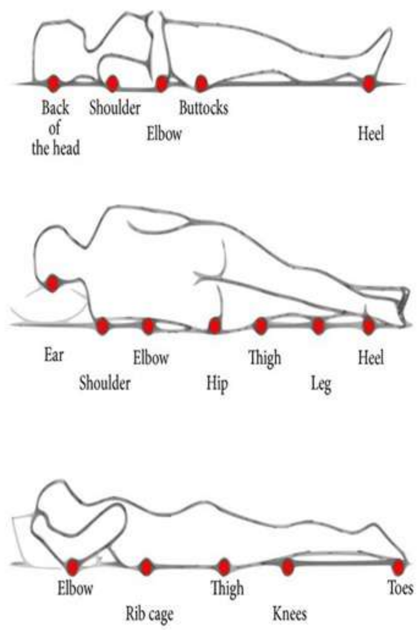


Figure 1: Areas of the body that are at risk of pressure ulcers (Source: Google)

The economic burden of PUs is considerable, with treatment costs ranking third highest among chronic conditions after cancer and cardiovascular diseases (Agrawal & Chauhan, 2012). Despite advancements in medical care, PUs continue to present challenges in prevention and treatment. Prolonged hospital stays, increased risk of secondary infections, and higher mortality rates among affected patients further underscore the importance of effective prevention and management.

PUs are classified into four stages based on the extent of tissue damage (Bhattacharya & Mishra, 2015):

- **Stage 1:** Non-blanchable erythema with intact skin.
- **Stage 2:** Partial-thickness skin loss involving the epidermis and dermis.
- **Stage 3:** Full-thickness skin loss with damage extending to subcutaneous tissue.
- **Stage 4:** Extensive tissue necrosis with involvement of muscle, bone, or supporting structures.

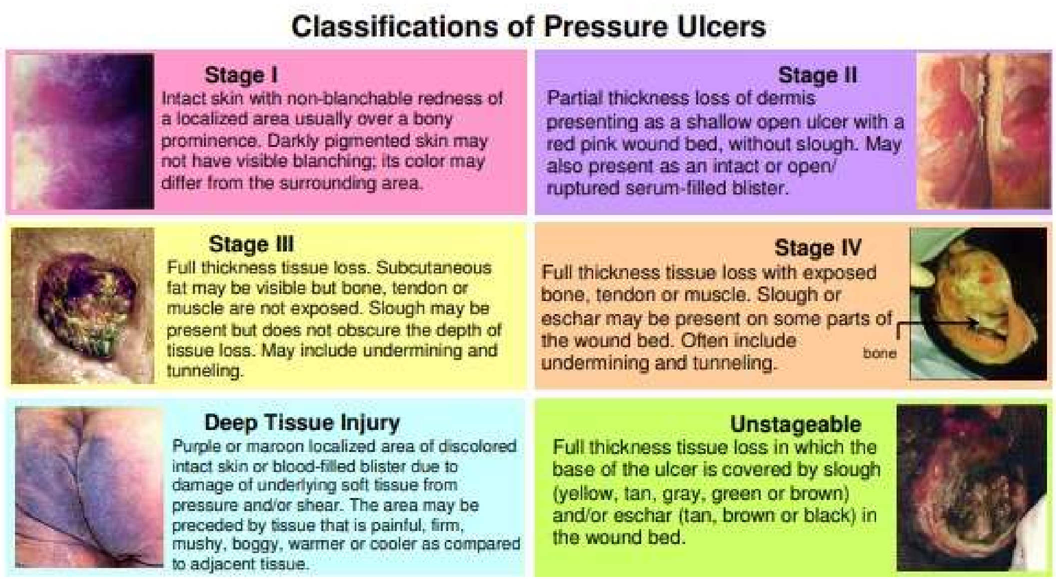


Figure 2: Classification of Pressure Ulcers (By Centres for Medicare & Medicaid Services (CMS))

Prevention remains the most effective approach in pressure ulcer management. Strategies include:

1. **Regular Repositioning:** Turning and repositioning patients every two hours to relieve pressure (Thomas, 2001).

2. **Support Surfaces:** Pressure-reducing mattresses, cushions, and air-fluidized beds help distribute pressure more evenly (Bhattacharya & Mishra, 2015).

3. **Skin Care and Moisture Control:** Keeping skin dry and clean prevents maceration and breakdown (Thomas, 2001).

4. **Nutritional Support:** Adequate protein intake is crucial for tissue repair and wound healing (Agrawal & Chauhan, 2012).

Management of pressure ulcers depends on the severity of the wound and includes:

- **Debridement:** Removal of necrotic tissue using surgical, enzymatic, or biological methods (Bhattacharya & Mishra, 2015).

- **Wound Dressings:** Hydrocolloid, alginate, and silver-impregnated dressings promote healing and prevent infection (Thomas, 2001).

- **Negative Pressure Wound Therapy (NPWT):** A newer approach that accelerates healing by enhancing tissue perfusion and reducing bacterial load (Bhattacharya & Mishra, 2015).

- **Hyperbaric Oxygen Therapy (HBOT):** Used in refractory cases to improve oxygenation and promote tissue regeneration (Bhattacharya & Mishra, 2015).

- **Surgical Intervention:** In severe cases, flap reconstruction is necessary to close large defects and prevent recurrence (Agrawal & Chauhan, 2012)

Table 1: Overview of existing technologies for pressure sores management

S No.	Title	Year	Advantage	Disadvantage
1.	IoT-Based Healthcare Monitoring System: Bedsores Prevention	2020	• Real-time pressure detection	• Requires constant monitoring. • Dependent on internet connectivity
2.	Evaluation of commodity force sensor for building low-cost bed sore prevention mat.	2021	• Pressure monitoring for every 30 seconds.	• Can't decide the movements of the patient. • Requires manual intervention.
3.	Medical Robotic Bed to Prevent Pressure Sores	2021	• Fully automated repositioning	• Expensive due to robotic implementation

4.	Wearable Preventive Pressure Ulcer System Using Embroidered Textile Electrodes	2023	• Non-invasive & wearable. • Activates muscles to relieve pressure	• Not effective for existing severe ulcers.

Proposed solution

To tackle the issue, we propose a smart bed with integrated sensors, automated pressure redistribution, and caregiver-friendly interfaces to prevent bedsores, improve patient care, and reduce healthcare costs. The proposed smart bed has features like:

1. **Integrated Sensors and Motors for Real-time Monitoring**

   The bed is equipped with multiple sensors to continuously track patient conditions, including:

   - **Pressure Sensors:** Detect areas of high pressure where the skin is at risk of ulcer formation.

   - **Temperature Sensors:** Identify heat build-up, which can indicate poor circulation or early signs of tissue damage.

   - **Moisture Sensors:** Monitor dampness from sweat, urine, or spills, helping to keep the bed surface dry and preventing microbial growth.

These sensors feed data into a microcontroller, which assesses risk levels in real time and triggers preventive actions.

2. **Automated Pressure Redistribution by using motors (No Manual Intervention Required)**

   Unlike traditional beds that require caregivers to manually reposition patients, the smart bed uses **automated adjustments**:

   - **Micro-Vibrations for Blood Circulation:**

     - The bed can generate **gentle micro-vibrations** if the micro-controller detects the threshold values are at moderate risk.

     - These vibrations stimulate blood flow, reducing the risk of tissue breakdown due to poor circulation.

     - Micro-vibrations are generated in the range of 25-50Hz with the help of ERM motors, lead to influx of Ca^{+2} ions which enhances the NO (nitric oxide) production that causes vasodilation and increases the blood flow (Games *et al.*, 2015).

- **Working principle of ERM (Eccentric Rotating Mass) vibration motors:** A Coin ERM (Eccentric Rotating Mass) motor is a tiny vibration motor used in mobile phones, wearables, and haptic feedback systems. It creates vibrations using an off-centre weight attached to a spinning motor.
    - Power ON → Electricity flows into the small DC motor.
    - Motor Spins → The motor shaft starts rotating.
    - Unbalanced Weight (Eccentric Mass) Moves → A tiny weight attached off-centre to the motor spins along with it.
    - Vibration Happens → Because the weight is not evenly distributed, the spinning motion creates a continuous vibration effect.
    - Power OFF → The motor stops, and the vibration stops.

- **Algorithm-Driven Repositioning:**
  - The bed detects prolonged pressure on a body part and automatically adjusts the surface to relieve pressure if the threshold is of very high risk.
  - It gently tilts, shifts the mattress to redistribute pressure without disturbing the patient by the help of stepper motor.
  - This prevents pressure from building up in any one location for too long.
  - **Working principle of stepper motor:** A servo motor is a special motor that moves to a specific angle based on instructions. It works using three main parts:
    - DC Motor → Provides the movement
    - Gears → Reduce speed and increase power
    - Control Circuit & Feedback System (Potentiometer) → Helps the motor know its exact position
    - The servo receives a signal (PWM) from a controller (like Arduino).
    - The pulse width (duration of the signal) tells the servo how much to rotate.
    - The feedback system (potentiometer) checks the current position.
    - If the position is wrong, the control circuit adjusts the motor to reach the correct angle.
      - The motor stays in that position until a new signal is received.

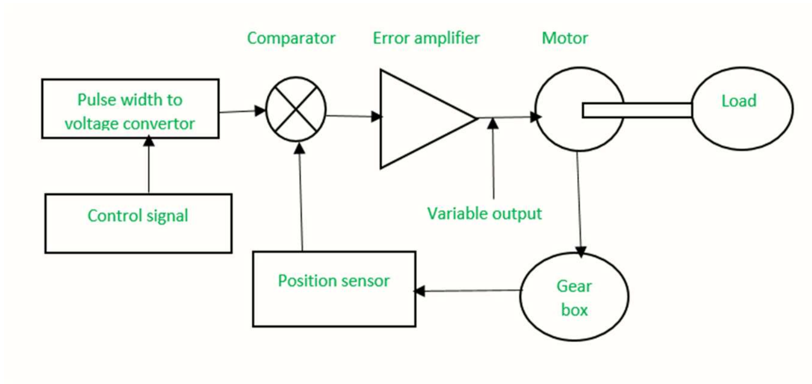


Figure 3: Working mechanism of stepper motor

These features ensure **continuous and personalized ulcer prevention** without requiring caregivers to manually turn or reposition patients, reducing labor costs and improving patient comfort.

The threshold values are set according to the data published by the National Institute of Health (NIH):

Table 2: Threshold values for pressure, temperature and humidity according to NIH

Factors	Normal Range	Micro vibrations (Moderate Risk)	Lateral movement for reposition (High Risk)
Pressure(mmHg)	<32 mmHg	32-50 mmHg for >30min	>50 mmHg for >15min
Temperature(°C)	< or = 35°C	35°C to 38°C	>38°C
Humidity (%)	30-60%	60-75%	>75%

Components of the system

Several electrical components are required for the assembly of this smart bed. The list of all the components required for this has been listed in the table below.

Table 3: List of electrical components required for the smart bed

S No.	Name of the component	Quantity required	Cost per unit	Reason
1.	BME 280	6	722/-	Temperature, humidity and pressure sensor
2.	DS3231 RTC Module	1	437/-	Time-stamp data on to SD card
3.	3V Coin vibration motor	6	58/-	Provides micro vibrations for improving the blood flow
4.	SG90 Servo motor	2	126/-	Simulate lateral bed movement (left or right)
5.	ESP32 Dev board	1	2735/-	Central control unit
6.	7.4V 2S LiPo Battery (3000mAh)	1	1994/-	Power source
7.	LM2596 Buck converter	1	262/-	Converts 7.4V → 5V for motors/servos
8.	AMS1117 3.3V LDO regulator	1	14/-	Converts 5V → 3.3V for ESP32/sensors
9.	TP4056 LiPo charger module	2	34/-	Charging of the battery
10.	MicroSD card module (SPI)	1	109/-	Store sensor data
11.	MicroSD card (8GB+)	1	562/-	Data storage
12.	TCA9548A I2C multiplexer	1	671/-	Connect 6 BME280s to ESP32, useful to choose address on data bus
13.	IRF520N MOSFET	6	41/-	Controls vibration motors
14.	5A fuse	1	49/-	Overcurrent protection

Circuit design

The circuit design for this smart bed has been made using the KiCAD circuit design module. This design gives an overview of the assembly of all the electrical components as well as their connections and working. The figure below depicts the overall circuit diagram of the proposed smart bed.

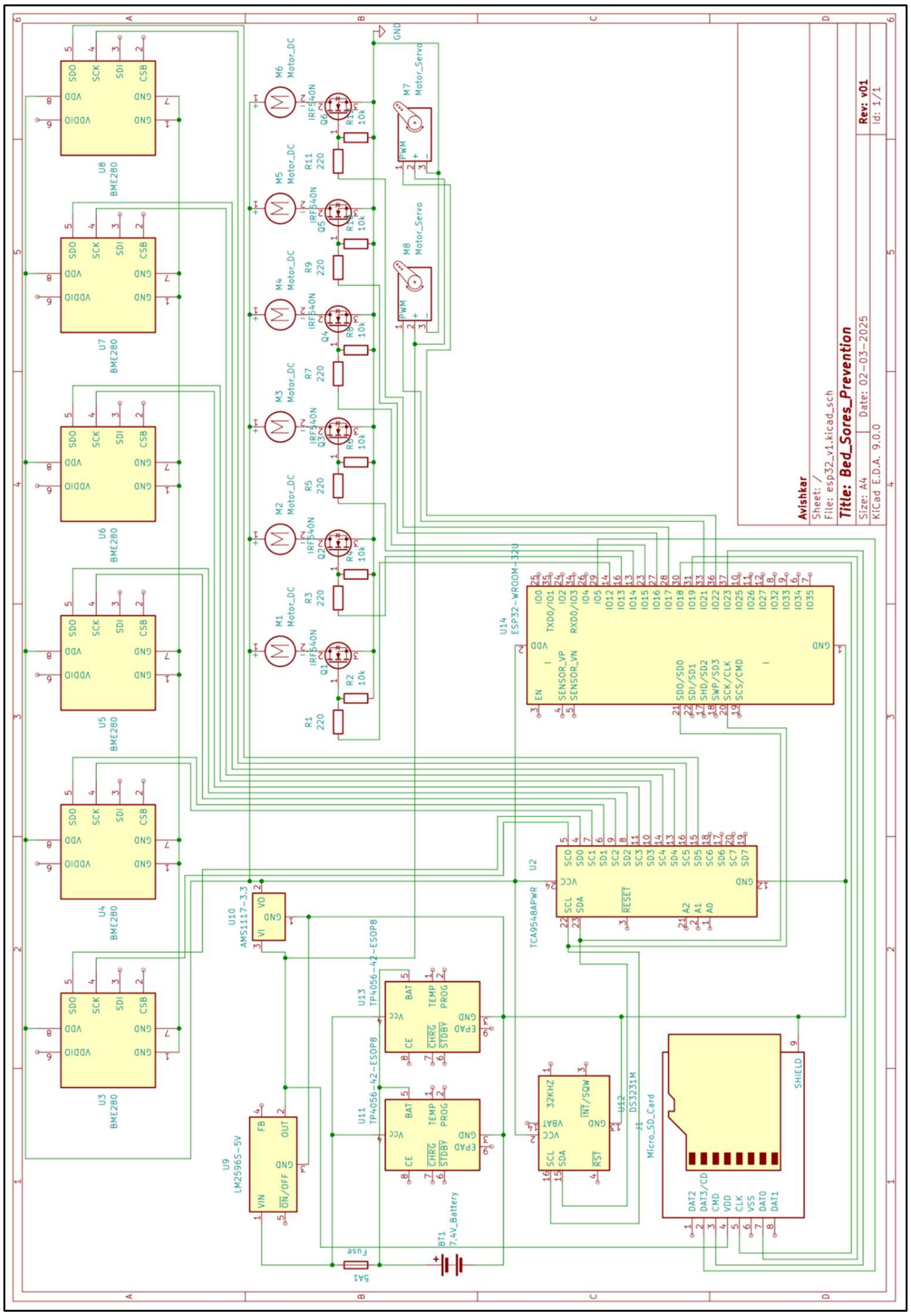
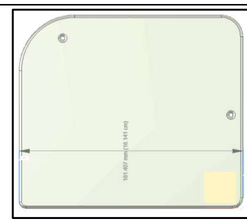
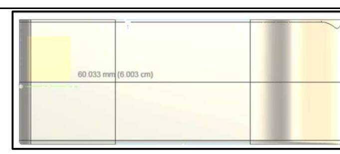
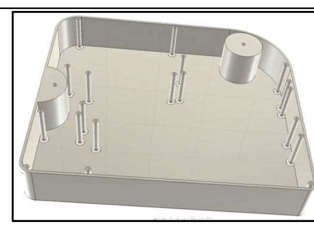
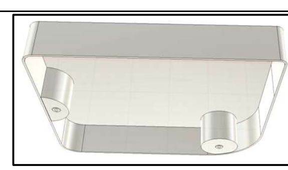


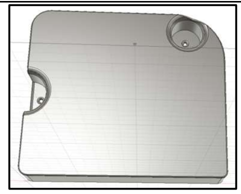
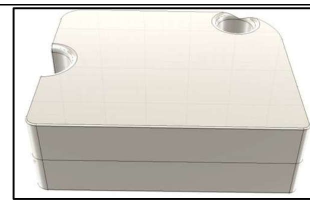
Figure 4: Circuit design for the proposed smart bed

Casing design

A casing has been designed to incorporate the electronic components except sensors, vibration coils, and servo motors, to provide a covering to all the components of the proposed smart bed. The casing design has been made using Fusion360 software. The casing has two halves (top and bottom). The dimensions of the casing are 18.141cm x 15.679cm x 6.003cm (length x width x height). The table below gives the different views of the casing design.

Table 4: Different views of the casing design

View	Image
Length of the casing	
Width of the casing	
Height of the casing	
Inside view of bottom half of the casing	
Inside view of top half of the casing	

Outside view of top half of the casing	
Representation after assembly of two halves of the casing	

Further workplan

As of now, problem identification, research gaps exploration, expert consultation, literature review, circuit design and casing design have been completed. Further plan include the following:

- **Simulation of Force and Load:** Analyzing the forces acting on the mattress to determine the appropriate motors required for optimal functionality.
- **Procurement of Materials:** Acquiring necessary components and materials for prototype construction.
- **Assembling and Soldering:** Implementing the designed circuit by assembling and soldering electronic components.
- **Programming and Coding:** Developing and implementing the control program for the smart bed's operation.
- **Parameter Optimization:** Fine-tuning various functional parameters to enhance performance and efficiency.

The estimated time for completing the construction of this prototype is second week of April 2025. The buffer period in the third week of April 2025 has been allocated to address any unforeseen issues that may arise during implementation.

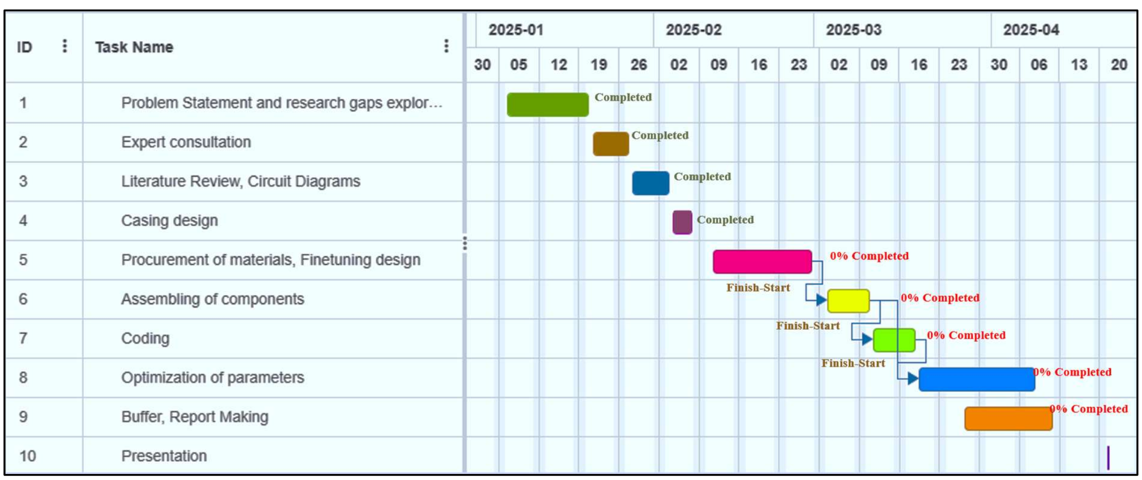


Figure 5: Gantt chart representing the overall work plan

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