# TRIBHUVAN UNIVERSITY

# INSTITUTE OF ENGINEERING

KATHMANDU ENGINEERING COLLEGE

KALIMATI,KATHMANDU


MINOR PROJECT PROPOSAL REPORT ON

**‘MODULAR LINE FOLLOWING BOT’**

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TO

DEPARTMENT OF ELECTRONICS, COMMUNICATION AND INFORMATION ENGINEERING

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# Acknowledgement

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# List of Abbreviation

**MPU:** Motion Processing Unit

**IMU:** Inertial Measurement Unit

**HCI:** Human-Computer Interaction

**DoF:** Degrees of Freedom

**VR:** Virtual Reality

**AR:** Augmented Reality

**PLA:** Polylactic Acid

**ESP:** Espressif Systems

**IoT:** Internet of Things

**VAR:** Virtual Augmented Reality

**MEMS:** Micro-Electro-Mechanical Systems

**DMP:** Digital Motion Processor

**TCP/IP:** Transmission Control Protocol/Internet Protocol

**CPU:** Central Processing Unit

**GPU:** Graphics Processing Unit

**Wi-Fi:** Wireless Fidelity

**RISC:** Reduced Instruction Set Computer

**IEEE:** Institute of Electrical and Electronics Engineers

**HTTP:** Hypertext Transfer Protocol

**IDE:** Integrated Development Environment

**API:** Application Programming Interface

**EEVEE:** Enhanced Efficient Virtual Environment Engine

# Chapter 1: Introduction

## 1.1 Background Theory

The rapid integration of robotics into healthcare environments is transforming traditional caregiving approaches. With rising demands for efficient patient management in hospitals, hostels, and elderly care centers, autonomous service robots are becoming an innovative solution. These robots, especially those capable of delivering medications and supplies, offer consistent, scheduled, and contactless services that reduce human error and free up valuable time for medical personnel. Among the various robotic systems being developed, line-following robots have gained attention for their simplicity, reliability, and adaptability in structured indoor environments like hospital wards or dormitories with fixed bed layouts. These robots navigate by following predefined paths, typically using infrared (IR) sensors to detect contrasting lines on the floor. Such navigation is especially useful for environments where precise, repeatable routes are needed to deliver medication trays to specific beds. The proposed system enhances this concept by introducing a three-compartment modular robot. The bottom compartment houses motion components, including motors, wheels, sensors, and batteries, making it the foundation for navigation and mobility that follows the line following mechanism. The middle compartment is dedicated to general storage, such as medical equipment, water, or additional medicine trays. The top compartment features a smart pill dispenser powered by a Raspberry Pi and a camera. This setup allows the robot to identify patients using facial recognition algorithms and dispense medicine according to a preset time schedule, minimizing the chances of human error and increasing medication adherence. To ensure robust interaction and real-time tracking, the system can integrate wireless communication modules (e.g., Wi-Fi or Bluetooth) to connect with a central server or a mobile application. This allows healthcare providers to monitor the robot's location, view pill dispensing logs, and modify schedules as needed. The use of AI in facial recognition and scheduling also paves the way for personalized patient care, enabling the robot to adapt to individual needs. Modularity in the robot's design adds another layer of practicality. Each compartment is detachable and independently upgradable, enabling easy maintenance, swift replacements, and the possibility of repurposing the robot for different tasks (e.g., food delivery, waste collection) by simply swapping modules. Lightweight yet durable materials like 3D-printed PLA or ABS plastic are ideal for building these components, ensuring comfort, stability, and structural integrity. In the broader context, this project reflects the growing intersection of robotics, AI, and healthcare—a convergence that is expected to redefine service delivery in hospitals. By aligning routine medical tasks with intelligent automation, such systems not only improve efficiency but also offer a glimpse into the future of compassionate, technology-driven patient care.

## 1.2 Problem Statement

Modern healthcare systems—particularly in resource-constrained settings such as public hospitals, mass hostels, and elderly care facilities—face ongoing challenges in ensuring timely, consistent, and personalized delivery of medication. Relying on human staff for routine tasks such as distributing pills or tracking medication schedules often results in inefficiencies, human error, and missed doses, especially during peak workloads or emergencies. While existing medical robots offer partial automation, they are typically expensive, non-modular, or dependent on proprietary software, limiting their adaptability and scalability in practical environments.

Furthermore, most delivery bots lack intelligent interaction capabilities. They often depend solely on line-following navigation without integrating patient identification, flexible routing, or automated scheduling, making them unsuitable for truly personalized or responsive care. Pill-dispensing mechanisms in these systems are also generally basic, lacking integration with facial recognition, scheduling, or patient feedback mechanisms.

This project addresses these limitations by developing a low-cost, modular, and intelligent line-following medical assistant robot equipped with a smart pill dispensing system. The robot combines real-time navigation, multi-compartment storage, and a top-mounted AI-driven module featuring a Raspberry Pi and camera for facial recognition and time-based pill dispensing. The modular design allows each compartment—motion, storage, and dispenser—to be independently upgraded or replaced, ensuring long-term flexibility, easy maintenance, and expandability.

By integrating low-cost hardware components with machine learning and wireless communication, this project aims to deliver a scalable solution that enhances healthcare automation. It enables accurate, personalized medication delivery while reducing staff workload, minimizing human error, and supporting future integration with mobile apps or hospital information systems. Ultimately, the system reimagines patient-care interaction by aligning routine medical services with smart, autonomous, and context-aware robotic assistance.

## 1.3 Objectives

The primary objective of this project is to design and develop a modular, intelligent line-following medical assistant robot capable of navigating hospital or hostel rooms and delivering personalized medications through an AI-powered pill dispenser. The key objectives are:

- To develop a robust line-following mechanism using infrared sensors for reliable indoor

navigation.

- To implement a modular three-compartment architecture consisting of:

  Bottom: Motion and power unit

  Middle: Storage trays

  Top: Raspberry Pi-powered smart pill dispenser

- To integrate AI-based facial recognition for identifying patients and ensuring correct pill delivery.
- To schedule pill dispensing based on real-time clock or external input for personalized and timely delivery.
- To create a centralized mobile or web-based application for monitoring robot logs, modifying pill schedules, and tracking delivery status.
- To maintain affordability, scalability, and ease of maintenance by using low-cost sensors, 3D-printed housings, and open-source software/hardware.

## 1.4 Scope

This project is focused on creating a prototype of a healthcare delivery robot optimized for structured environments like hospital wards and student hostels. The scope includes:

- Development of an autonomous line-following base that can navigate pre-defined paths.
- Designing 3D-printed modular compartments with quick-connect mechanisms for easy upgrades or replacements.
- Implementing facial recognition using a Raspberry Pi and camera to authenticate patients before dispensing medication.
- Building a basic pill dispensing mechanism controlled by a servo or motor, programmed via scheduled inputs.
- Building a basic pill dispensing mechanism controlled by a servo or motor, programmed via scheduled inputs.
- Data logging for dosage history, delivery time, and patient interaction.

## 1.5 Applications

The data glove system finds applications in various fields including:

- Virtual and Augmented Reality (VAR)
- Assistive Technology
- Gaming
- Robotics Control
- Smart Environments / IoT Applications
- Educational Tools

# Chapter 2: Literature Review

## 2.1 Literature Review

Sharma, R., & Mehta, S. (2020) [1], proposed a line-following robot for indoor navigation in structured environments such as hospital wards and academic institutions. Their design utilized infrared (IR) sensors to detect line patterns and allowed the robot to autonomously follow predetermined paths with minimal user intervention. The study demonstrated how line-following technology could be effectively used to automate routine delivery tasks within controlled spaces, significantly reducing human labor and improving task consistency. The robot's modular design also supported future integration with smart technologies like RFID and computer vision, providing a scalable foundation for service-based robotics in healthcare and institutional settings.

Patel, D., & Verma, A. (2021) [2], developed a prototype for a multi-compartment delivery bot tailored for hospital environments. Their robot featured distinct compartments for transporting medical supplies, documents, and refreshments. A key innovation was the layered structural design, with each compartment having specific dimensions and purpose. The bottom layer facilitated motion and housed the power components, while the middle and top compartments were designated for payloads. This layered approach ensured stability, modularity, and ease of maintenance. Their work supports your structural design by emphasizing ergonomic separation of functionalities across the robot's vertical build.

Singh, M., & Rathi, P. (2022) [3], implemented a pill dispensing mechanism using a servo-controlled rotating disc. Each pill slot was aligned with a timing mechanism linked to a Raspberry Pi. The dispensing process was controlled via a real-time clock (RTC) module and was further enhanced with facial recognition for personalized medication delivery. The study illustrated the effectiveness of integrating computer vision and embedded systems in automating healthcare routines. This directly supports the use of a Raspberry Pi and camera in your design, highlighting how time-based, person-specific pill dispensing increases safety and compliance in medication routines.

Ali, S., & Khan, M. (2019) [4], presented a facial recognition system using OpenCV and Raspberry Pi for identity verification in controlled environments. Their system achieved over 90% accuracy under normal lighting conditions and used Haar Cascade classifiers for detection and LBPH for recognition. This work underpins the facial recognition component in your robot's topmost compartment, affirming that low-cost, real-time vision-based recognition can be feasibly implemented on edge devices like the Raspberry Pi.

Tiwari, H., & Nair, R. (2018) [5], developed a smart dispensing system using servo motors for precise control over pill release. Their prototype focused on timed dispensing based on patient schedules stored in an SD card, managed via an Arduino system. This work strengthens the concept of using servo mechanisms to ensure mechanical precision in pill delivery and advocates for reliable storage-driven scheduling, which could complement the Raspberry Pi's computational tasks in your design.

Kamble, A., & Jadhav, R. (2021) [6], explored ergonomic designs for mobile medical robots with integrated bottle holders and tray-based delivery. Their robot's bottom compartment housed both motor components and additional storage optimized for safe transport of fragile items like liquid containers. This aligns with your proposed bottom compartment design, providing validation for integrating two half-liter bottle slots alongside the motion system, with considerations for vibration isolation and stability.

Chen, L., & Zhang, Y. (2020) [7], emphasized the importance of camera placement in robotic systems for optimal recognition performance. In their study, elevating the camera above the main structure by even half an inch significantly improved field-of-view and facial detection accuracy, especially in confined indoor environments. This supports your idea to extend the camera half an inch above the top layer, ensuring clearer patient identification.

# Chapter 3: Related Theory

## 3.1 Hardware

**MPU6050 Sensor:** The MPU6050 is a widely used 6-axis MEMS-based Inertial Measurement Unit (IMU) that integrates a 3-axis accelerometer and a 3-axis gyroscope within a single chip.It is capable of detecting linear acceleration in the range of ±2g to ±16g and angular velocity from ±250°/s to ±2000°/s, making it highly suitable for motion tracking and gesture recognition applications. A notable feature of the MPU6050 is its onboard Digital Motion Processor (DMP), which performs real-time sensor fusion using algorithms such as Kalman or complementary filtering. This significantly reduces noise and drift in gyroscopic data, enabling stable orientation tracking through the calculation of quaternions or Euler angles (roll, pitch, and yaw). The sensor communicates with microcontrollers through the I²C interface, supporting clock speeds between 100 kHz and 400 kHz for efficient data exchange. Its compact design, reliability, and real-time capabilities make it ideal for wearable systems. It enables precise and responsive motion capture for interactive systems in gesture-based applications.

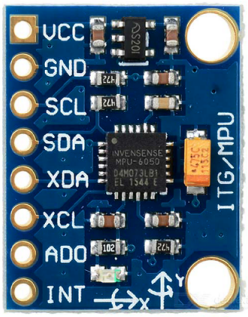



Figure 3.1: **MPU6050 Sensor**

**Arduino Mega:** The Arduino Mega is an open-source microcontroller board based on the ATmega2560, designed for projects requiring extensive input/output operations and greater memory capacity. It features 54 digital I/O pins, 16 analog inputs, and four UARTs for serial communication, making it suitable for complex hardware interfacing. With 256 KB of flash memory and a 16 MHz clock speed, it can handle multiple sensors and real-time data processing efficiently. In this project, the Arduino Mega serves as the central controller, managing input from multiple MPU6050 sensors and switches to ensure accurate and synchronized gesture-

based interactions within the game environment.

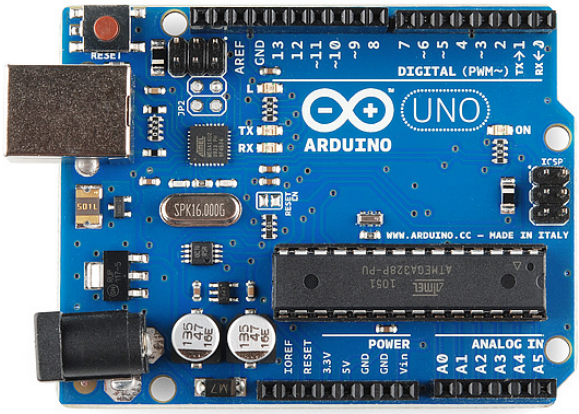



Figure 3.2: **Arduino Uno Board**

**ESP8266**: The ESP8266 is a low-cost, high-performance Wi-Fi microcontroller based on a 32-bit RISC CPU core (Tensilica L106), operating at 80–160 MHz. It integrates TCP/IP protocol stack and supports IEEE 802.11 b/g/n standards, enabling wireless connectivity with low power consumption ( 80 mA active mode). It enables devices to connect to wireless networks and communicate over the internet or within local networks. The ESP8266 supports multiple modes such as station, access point, and both simultaneously, making it highly versatile for wireless communication. It can be programmed using the Arduino IDE and is capable of handling HTTP requests, data transfer, and remote control functionalities. The ESP8266 is used to explore wireless communication possibilities between the hardware controller and the game system, potentially allowing untethered interaction.

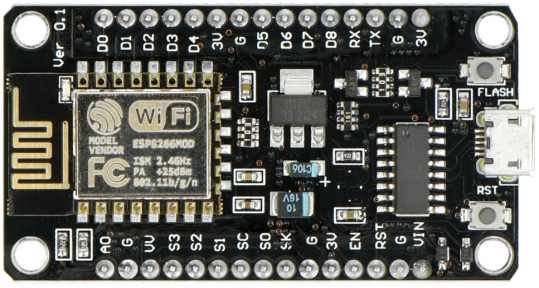



Figure 3.3: **ESP8266 Wi-Fi Module**

**Flex Sensors:** Flex sensors are passive resistive devices that change their resistance based on the amount of bend applied to them. Typically constructed using a flexible substrate coated

with conductive ink, their resistance increases as the sensor is bent. This property allows them to detect the degree of bending or curvature, making them suitable for applications involving motion capture, wearable electronics, and gesture recognition. When integrated with microcontrollers, the analog resistance change can be converted into meaningful input data. In this project, flex sensors are considered for detecting finger movements by measuring the degree of bend in each finger.

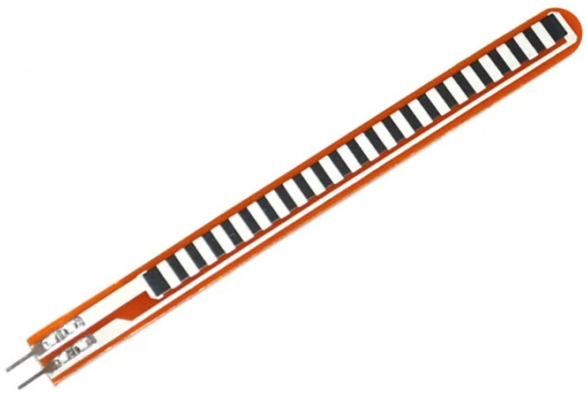


Figure 3.4: **Flex Sensor**

## 3.2 Software

**Arduino IDE:** The Arduino Integrated Development Environment (IDE) is the core programming tool for the Arduino Uno microcontroller in this project. Using C/C++, it configures the microcontroller to process digital signals from switches and analog data from MPU6050 sensors. Essential libraries like Wire.h and MPU650.h manage I²C communication, while serial protocols handle data transmission to the rendering engine. The IDE's debugging tools, including serial monitors, are crucial for verifying signal integrity and latency. Firmware algorithms integrate sensor fusion and debouncing logic for accurate gesture detection. This open-source platform significantly aids rapid prototyping and hardware-software integration for real-time interactive systems.

**Rendering Engine:** The Rendering Engine is a fundamental software component that generates real-time visual output based on physical hand gestures captured by the hardware. Initially considering Unreal Engine, this prototype utilizes Blender's integrated EEVEE and Cycles engines for rendering and simulation. The engine displays a first-person perspective with visible virtual hands, mirroring gestures like finger bends and wrist rotations instantly. This real-time visual feedback is vital for player immersion and interaction. The engine processes data from the microcontroller, supplied through middleware, to dynamically adjust hand poses and object interactions. Its capability to reflect hardware input with minimal latency ensures intuitive and

responsive gameplay, serving as the core of the gesture-controlled gaming experience. Optimized for low latency with GPU acceleration, it manages environmental elements and physics simulations via Blender's Python API.

**Blender:** Blender is an open-source 3D creation suite which is utilized for designing and developing game assets. This includes 3D modeling, UV mapping, texturing, and rigging, crucial for creating realistic hand models and interactive objects. Blender's EEVEE and Cycles engines provide real-time previews and high-fidelity final renders, respectively. Its Python scripting capabilities facilitate customization and workflow automation. Blender functions as both a design tool and a visual integration layer, ensuring in-game visuals accurately reflect physical gestures captured by the hardware with minimal latency through automated workflows linking it to the Arduino's output.

**Python:** Python serves as the middleware layer, connecting hardware data with the rendering engine. Custom scripts, utilizing libraries like PySerial, parse serial data from the Arduino, converting raw sensor values into actionable game inputs. Python's integration with Blender via the bpy module maps gestures to in-game animations and automates tasks. It can also be used externally to interpret sensor data and relay it to the rendering engine via custom protocols. Python's versatility and extensive library support are crucial for efficient data translation and seamless interaction between the wearable hardware and the virtual environment, enabling real-time mapping of physical movements to game commands.

# Chapter 4: Feasibility Study

## 4.1 Technical Feasibility

The project demonstrates strong technical feasibility by combining electronics, communica tion, and information processing in a practical and achievable manner. The Arduino Mega microcontroller acts as the brain of the system, providing sufficient processing power and I/O pins to accommodate multiple sensor inputs, including MPU6050 sensors, tactile push buttons, and optional flex sensors. These electronic components assist in accurately detecting hand gestures and finger movements. For communication, the ESP8266 module is considered for wireless data transfer between the hardware system and the game engine, facilitating real-time interaction with low delay. Serial communication protocols (either wired or wireless) will be utilized to ensure smooth and continuous data exchange from the Arduino to the computer running the game.

The information processing aspect involves translating raw sensor inputs into meaningful com mands for the game. This includes gesture detection using both switch activations and motion readings from the MPU. All of this will be managed using standard Arduino programming, with open-source libraries that expedite development. The modular hardware setup allows for f lexible testing, updates, and part replacement if necessary. Our design supports iterative devel opment, meaning we can test and improve as we build. Key strengths of the project include its adaptability, cost-effective components, and future scalability, making it a reliable and feasible system to implement with the tools and skills available to our team.

## 4.2 Economic Feasibility

The proposed system demonstrates strong economic feasibility with a cost-effective approach to hardware development and implementation. Most of the required electronic components and sensors are readily available in the local market and within our college resources. The primary components, like Arduino Mega, ESP8266, MPU sensors, and connecting wires, are economically accessible, with relatively low procurement costs compared to specialized gam ing interface systems. The use of PLA filament provides a budget-friendly prototyping solu tion, allowing multiple design iterations without significant financial investment. Open-source software platforms like Arduino IDE and Unreal rendering Engine further reduce development expenses by eliminating expensive proprietary software licensing costs.

The project's modular design enables incremental development, meaning team members can progressively invest in components as needed, spreading out potential expenses. Potential cost

savings are achieved through utilizing existing college laboratory equipment and leveraging team members' existing technical skills, which minimizes additional training or external con sultation expenses. The overall economic viability is enhanced by the project's scalable na ture, potential for future refinement, and the use of widely available, low-cost technological components. The minimal financial requirements make this project an economically attractive research and development initiative within the current institutional infrastructure.

# Chapter 5: Methodology

## 5.1 System Block Diagram

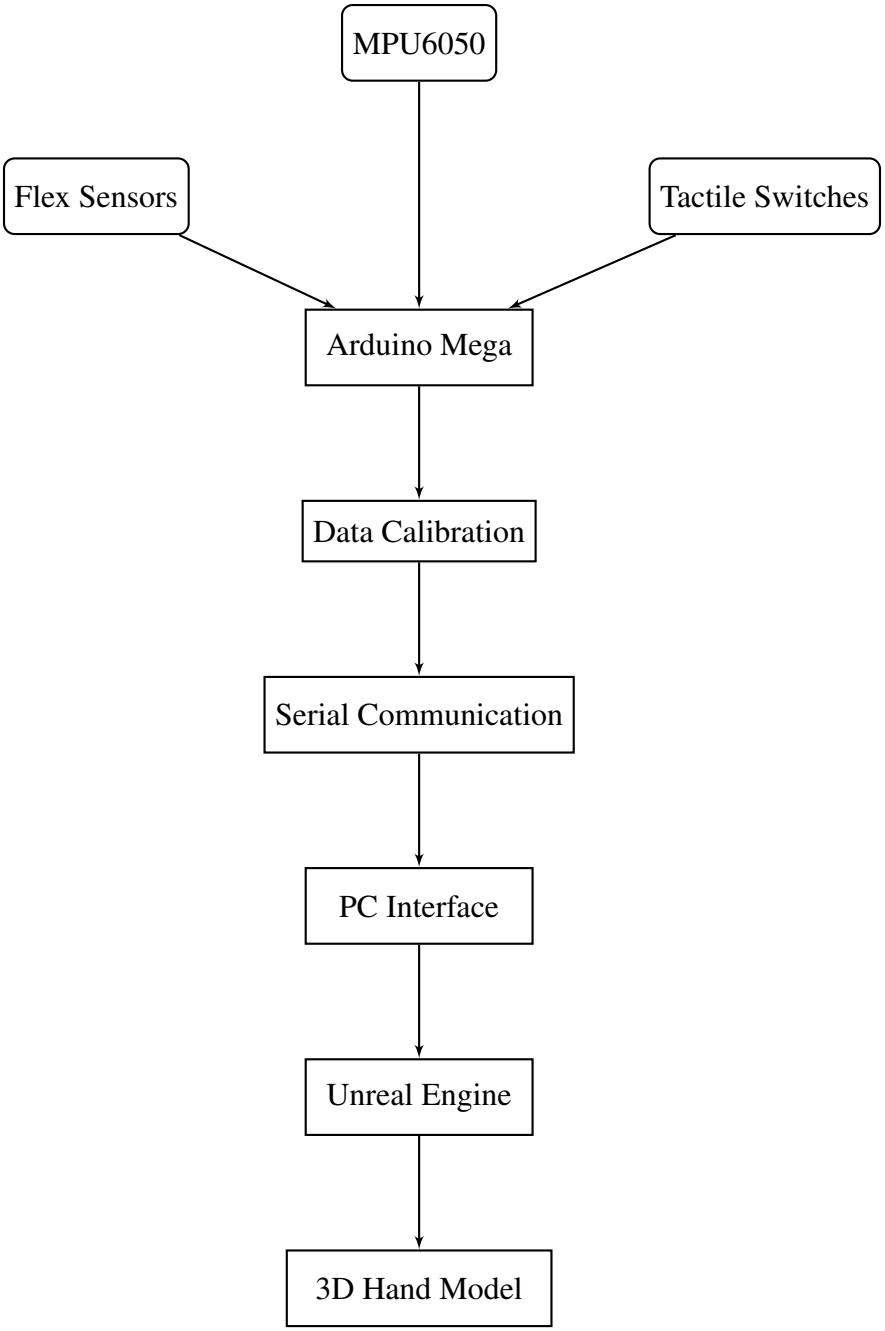



Figure 5.1: Detailed Block Diagram of Hand Motion Replicator System

## 5.2 Algorithm

1. System Initialization
    - Configure MPU6050 for 6-DoF motion tracking
    - Initialize analog inputs for flex sensors
    - Set up digital inputs for tactile switches
    - Configure serial communication parameters
2. Sensor Data Acquisition
    - Read accelerometer and gyroscope data from MPU6050
    - Measure resistance values from flex sensors
    - Monitor state of tactile switches
    - Apply calibration offsets
3. Data Processing
    - Filter sensor noise using moving average
    - Calculate hand orientation from IMU data
    - Convert flex sensor values to finger angles
    - Detect finger press events
4. Data Transmission
    - Package processed data into structured format
    - Implement error checking
    - Transmit data packets via serial communication
5. Virtual Model Update
    - Parse received data packets
    - Update hand skeleton parameters
    - Apply inverse kinematics for finger movements
    - Render updated hand model

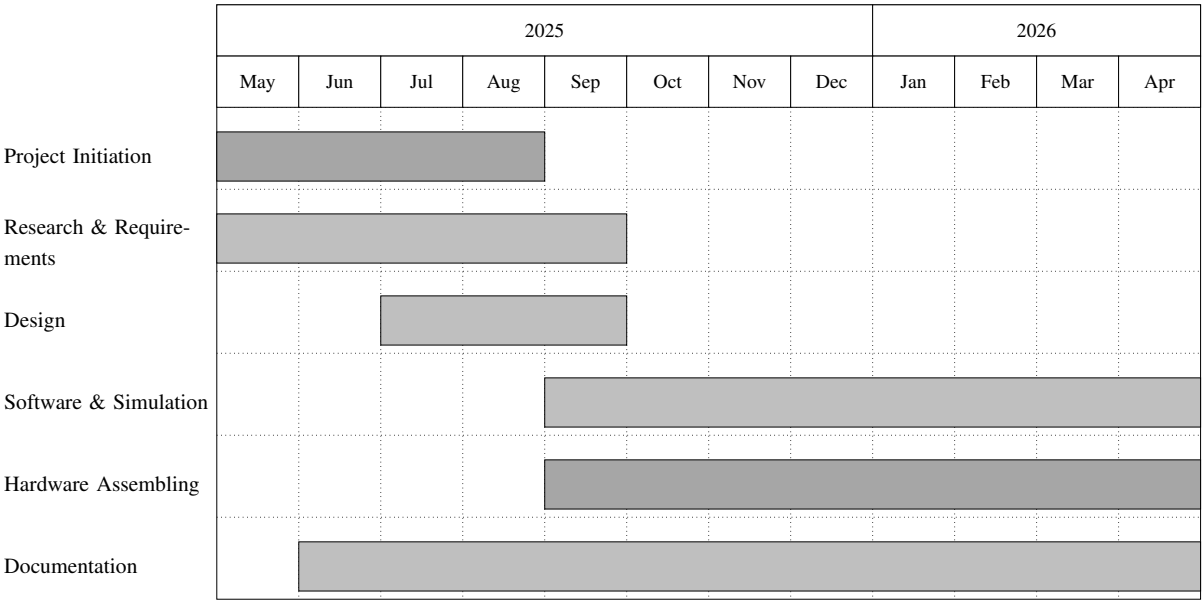
# Chapter 6: Expected Output

- **Real-time Hand Motion Tracking:**
  The system will accurately track and measure hand movements using the MPU6050 sensor for orientation (±2° accuracy), flex sensors for finger bending (0° to 90° range), and tactile switches for touch detection. The combined sensor data will provide comprehensive hand position and gesture information with minimal latency (¡100ms).

- **Virtual Hand Replication:**
  The tracked hand movements will be replicated in real-time on a 3D hand model in Unreal Engine. The virtual hand will accurately mirror all finger movements, hand rotations, and touch interactions with smooth articulation and natural movement visualization. The system will maintain a consistent frame rate above 30 FPS to ensure fluid motion reproduction.

- **Interactive Response System:**
  The system will provide immediate feedback through the virtual hand model, responding to user inputs with less than 50ms latency. This includes accurate finger bend representation (±5° accuracy), precise hand orientation tracking, and immediate response to touch inputs with over 95% reliability. The communication system will maintain a stable 60 Hz update rate to ensure seamless interaction between the physical and virtual hands.

# Gantt Chart


2025
2026
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
Project Initiation
Research & Require-ments
Design
Software & Simulation
Hardware Assembling
Documentation

# Cost Estimation

## Components and Cost Distribution

| S.N | Components | Quantity | Price | Availability |
|---|---|---|---|---|
| 1 | Momentary tactile push button | 25 | 1000 | Daraz Nepal |
| 2 | MPU 6050 | 5 | 2500 | Daraz Nepal |
| 3 | ESP 8266 | 1 | 900 | Daraz Nepal |
| 4 | Arduino with usb cable | 1 | 1700 | Daraz Nepal |
| 5 | Wire diameter 0.4mm ballpoint spring | 10 | 700 | Daraz Nepal |
| 6 | Flex sensor | 10 | 7000 | Daraz Nepal |
| 7 | PLA(1kg) | 1 | 3000 | Daraz Nepal |
| 8 | Gloves | 2 | 800 | Daraz Nepal |
| 9 | Superglue(vega) | 3 | 330 | Daraz Nepal |
| 10 | Enamel wire(50m) | 1 | 1300 | Daraz Nepal |
| 11 | Connecting wire | 40 | 900 | Daraz Nepal |
| 12 | Joystick controller with cable | 1 | 1700 | Daraz Nepal |
| 13 | Li-ion battery(3.7v) with charger | 4 | 4000 | Daraz Nepal |
| | | **Total Cost** | **NRs. 25,830** | |

Table 6.1: Components and Cost Distribution

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