# NovaBot: An AI-Powered Assistant Rover for the Disabled

## Graduation Project Proposal

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# Contents

# Chapter 1

# Project Information

## 1.1 Project Title

**NovaBot: An AI-Powered Assistant Rover for the Disabled**

## 1.2 Project Summary

NovaBot is an AI-powered assistant rover designed to aid individuals with physical or sensory disabilities through intelligent, multimodal interaction. It integrates advanced AI models, including a Large Language Model for conversation, speech and sign language recognition, and computer vision for environmental awareness. NovaBot can autonomously navigate, follow the user, detect obstacles, and adapt to the user's preferred mode of communication (voice, ASL, or touch). With features such as emotion and fall detection, traffic rule awareness, and live guardian monitoring, NovaBot enhances independence, safety, and companionship for users in their daily lives.

## 1.3 Project Team

| Name | Student ID | Program |
|------|-----------|---------|
| Basant Awad | 22101405 | CS |
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## 1.4 Supervisors / Advisors

| Name | Title / Position | Department |
|------|-----------------|------------|
| Dr. Ahmed Shalaby | Project Supervisor | Computer Science Department |

## 1.5 Project Category

**Category:** AI and Robotics
**Type:** Research and Development (R&D)
**Field:** Artificial Intelligence, Human-Robot Interaction, Assistive Technology

## 1.6  Keywords

Artificial Intelligence, Robotics, Assistive Technology, Computer Vision, LLM, Accessibility, Human-Robot Interaction

## 1.7  Deliverables

- NovaBot physical prototype (rover)

- NovaBot software system (AI modules + control interface)

- Guardian monitoring web/mobile dashboard

- Final report and testing documentation

- Presentation and video demonstration

## 1.8  Project Duration

| Phase | Duration | Description |
|---|---|---|
| Phase 1 – Research & Design | 2 weeks | Define problem, scope, and architecture |
| Phase 2 – System Design | 2 weeks | Prepare all UML and architecture diagrams |
| Phase 3 – Development | 6 weeks | Implement hardware, AI models, and software |
| Phase 4 – Testing | 3 weeks | Conduct integration and system testing |
| Phase 5 – Documentation & Presentation | 2 weeks | Finalize report, prepare for defense |

# Chapter 2

# Introduction

## 2.1 Background

Advances in artificial intelligence, robotics, and computer vision have made it possible to develop intelligent systems that can interact naturally with humans. Among the most impactful applications of these technologies are assistive robots: machines designed to enhance the independence and quality of life of individuals with disabilities. Many people with physical, sensory, or communication impairments face daily challenges in mobility, social interaction, and access to information. While smart devices and voice assistants have improved accessibility, they remain limited in physical interaction and contextual understanding.

NovaBot aims to bridge this gap by combining artificial intelligence, speech and sign recognition, computer vision, and autonomous navigation into one assistive rover. By integrating these technologies, NovaBot serves as both a functional assistant and a companion, capable of understanding the user's environment and communicating through multiple modalities.

## 2.2 Problem Statement

Individuals with disabilities often rely on fragmented solutions to perform daily tasks, voice assistants for reminders, wheelchairs for mobility, and caregivers for communication or safety. These systems do not communicate or adapt to the user's context, leading to dependency, reduced independence, and limited autonomy.

There is a clear need for an intelligent, unified system that can assist users in real-world environments, one that can perceive, communicate, and act with awareness of human needs and surroundings. NovaBot addresses this challenge by providing a multi-sensory, adaptive robotic assistant capable of understanding natural communication methods and responding in real time.

## 2.3 Objectives

The main objective of NovaBot is to design and implement an AI-powered assistant rover that supports individuals with disabilities through intelligent interaction and assistance.

**Specific objectives:**

- Develop a multimodal communication system integrating voice, text, and sign language recognition.

- Implement a vision-based navigation system for autonomous movement and obstacle avoidance.

- Integrate emotion and fall detection to enhance safety and empathetic response.

- Develop a guardian monitoring interface for live tracking and alerts.

- Ensure the system operates efficiently on embedded hardware suitable for real-time performance.

## 2.4 Scope

The project focuses on the design and development of an assistive robotic rover prototype that can operate in indoor environments such as homes, rehabilitation centers, and campuses. The system will include:

- A physical rover equipped with sensors and cameras for environmental awareness.

- An AI-powered software system capable of perception, communication, and decision-making.

- A user interface for configuration and guardian monitoring.

NovaBot's initial prototype will emphasize safety, communication, and assistance rather than heavy-load carrying or advanced manipulation tasks. Future iterations may extend to outdoor navigation and integration with IoT environments.

## 2.5 Significance

NovaBot represents a step toward inclusive technology, designed to empower, not replace, human capability. By merging robotics and artificial intelligence for accessibility, it contributes to social inclusion, independent living, and emotional well-being.

The project also serves as a practical demonstration of applying AI models, embedded systems, and computer vision in a real-world context, aligning with the global push for assistive innovation and human-centered design. It has the potential to inspire similar solutions in healthcare, rehabilitation, and education, especially within developing regions where accessibility tools remain limited.

# Chapter 3

# Literature Review

## 3.1 Overview

Assistive robotics has become one of the most promising fields in the intersection of artificial intelligence, computer vision, and human-computer interaction. Over the past decade, various research projects and commercial prototypes have aimed to improve the quality of life for individuals with disabilities through autonomous systems. This chapter provides an overview of existing technologies, methodologies, and research efforts that inspired and informed the design of NovaBot.

## 3.2 Assistive Robotics

Assistive robots are designed to support individuals in daily activities, promote independence, and enhance accessibility. These robots can be categorized into three main groups:

- **Mobility Assistants:** Robots that help with navigation or movement, such as smart wheelchairs and robotic guides for the visually impaired.

- **Social Assistants:** Robots that provide companionship and communication support, such as humanoid assistants and therapy robots.

- **Service Robots:** Robots that perform specific physical tasks, such as carrying objects or retrieving items.

Examples include *Pepper* by SoftBank Robotics, designed for social interaction, and *GuideCane*, which assists visually impaired users with navigation. However, many of these solutions focus on either mobility or communication, not both, and lack contextual awareness or emotional adaptability.

## 3.3 AI in Human-Robot Interaction

Recent advances in AI have enabled robots to better understand and interact with humans. Large Language Models (LLMs) such as OpenAI's GPT and Google's Gemini have shown remarkable capabilities in natural conversation and context understanding. When integrated into robotics, these models allow for dynamic and context-aware communication.

Computer vision plays a complementary role, enabling robots to interpret their surroundings and respond intelligently. State-of-the-art object detection models like YOLOv8, SSD, and EfficientDet can recognize and track multiple objects in real time, forming the foundation for navigation, obstacle avoidance, and gesture recognition.

## 3.4   Multimodal Communication

One of the core challenges in assistive technology is creating systems that accommodate diverse user needs. People with speech or hearing impairments may rely on sign language, text, or visual cues to communicate. Research on multimodal systems — combining speech, vision, and text — shows that integrating multiple input and output channels greatly enhances accessibility and user experience.

Projects such as *DeepASL* and *SignAll* have demonstrated the feasibility of automatic sign language recognition using deep learning models trained on camera feeds. Similarly, advancements in Text-to-Speech (TTS) and Speech-to-Text (STT) systems, such as Whisper and Tacotron, have made voice interaction more natural and responsive.

## 3.5   Context Awareness and Emotion Recognition

Contextual understanding is essential for building empathetic and safe assistive systems. Emotion recognition systems leverage computer vision and affective computing techniques to analyze facial expressions, tone of voice, or behavioral cues. Studies show that emotionally responsive robots can improve user trust, engagement, and comfort, especially among individuals with disabilities or the elderly.

Furthermore, fall detection systems, often built using accelerometers, cameras, or pose estimation models, play a crucial role in ensuring user safety. When integrated into a mobile platform, they can trigger alerts to caregivers or guardians in real time.

## 3.6   Gaps in Existing Solutions

Although existing assistive robots and AI systems have achieved significant progress, several gaps remain:

- Most assistive robots focus on a single mode of interaction, limiting accessibility for users with multiple disabilities.

- Few systems integrate both conversational AI and computer vision for real-time environmental understanding.

- Existing commercial robots often lack affordable hardware designs suitable for real-world use in developing regions.

- Emotion, fall detection, and safety systems are typically treated as separate modules rather than integrated into a unified framework.

These limitations highlight the need for a holistic, multimodal, and context-aware robotic assistant; one that merges perception, communication, and mobility to offer meaningful, human-centered support.

## 3.7   Summary

This literature review establishes that while assistive robotics and AI have made significant strides, there remains an unmet need for an integrated, accessible, and adaptive system for people with disabilities. NovaBot aims to fill this gap by unifying multimodal communication, autonomous mobility, emotion detection, and safety monitoring into one intelligent rover. By combining these domains, NovaBot represents a step toward a new generation of assistive technology that prioritizes empathy, inclusivity, and independence.

# Chapter 4

# Project Description

## 4.1 Overview

NovaBot is an AI-powered assistant rover designed to support individuals with disabilities through intelligent communication, perception, and autonomous mobility. It combines artificial intelligence, robotics, and computer vision to provide a holistic assistive experience.

Unlike conventional assistive devices that rely on single modes of input such as voice or text, NovaBot offers a multimodal interaction system, enabling users to communicate via speech, text, or sign language. The robot adapts its communication and assistance style based on the user's disability, ensuring accessibility and inclusivity.

## 4.2 System Concept

NovaBot acts as a personal companion and assistant, capable of perceiving its surroundings, understanding user intent, and responding accordingly. The rover integrates multiple AI models and hardware subsystems that allow it to:

- Communicate naturally using speech and text.

- Recognize sign language and gestures from camera input.

- Navigate autonomously while avoiding obstacles and following its user.

- Detect and interpret human emotions for empathetic interaction.

- Identify falls or emergencies and alert the guardian system in real time.

- Provide entertainment and companionship through multimedia interaction.

## 4.3 System Components

The NovaBot system consists of three main layers: hardware, software, and cloud integration.

### 4.3.1 Hardware Layer

The hardware layer contains all physical and sensory components of the rover:

- **Chassis and Motors:** Supports omnidirectional movement for smooth indoor navigation.

- **Cameras and Sensors:** Used for object detection, human tracking, obstacle avoidance, and environmental perception.

- **Microphone Array:** Captures voice commands for speech recognition.

- **Touchscreen Display:** Provides visual interface and text-based interaction.

- **Speakers:** Output system responses, alerts, and entertainment audio.

- **Edge Computing Unit:** (e.g., NVIDIA Jetson or Raspberry Pi) processes AI inference and navigation tasks in real time.

### 4.3.2 Software Layer

This layer integrates the AI models, perception modules, and control algorithms:

- **Large Language Model (LLM):** Handles dialogue, context understanding, and reasoning.

- **Speech-to-Text (STT) Model:** Converts user speech into text commands.

- **Text-to-Speech (TTS) Model:** Produces natural voice output.

- **ASL Recognition Model:** Interprets sign language from camera feed using computer vision.

- **Computer Vision Model:** Performs object detection, emotion recognition, and environmental analysis.

- **Navigation System:** Controls autonomous movement, user following, and obstacle avoidance.

- **Safety and Alert System:** Includes fall detection and real-time guardian notifications.

### 4.3.3 Cloud Layer

The cloud layer supports monitoring, storage, and communication:

- **Cloud Database:** Stores user profiles, configurations, logs, and AI-generated context data.

- **Guardian Dashboard:** Allows remote live camera access and monitoring.

- **Data Analytics:** Tracks usage patterns and robot performance for continuous improvement.

## 4.4 System Features

NovaBot integrates a wide range of features designed to address the needs of individuals with different disabilities:

- **Multimodal Interaction:** Communication through speech, text, or ASL depending on the user's needs.

- **Adaptive Input and Output:** The robot automatically selects the most suitable input/output mode (voice, text, or visual display).

- **Autonomous Mobility:** Ability to navigate, follow the user, and avoid obstacles in real time.

- **Emotion and Mood Detection:** Enhances interaction by recognizing facial expressions and adapting responses.

- **Fall Detection:** Monitors and detects sudden falls, triggering guardian alerts immediately.

- **Guardian Monitoring System:** Live camera streaming and safety notifications accessible via web or mobile app.

- **Entertainment and Assistance:** Provides media playback, reminders, and companionship to reduce isolation.

- **Traffic Compliance:** Follows basic indoor and outdoor navigation rules for safe movement.

## 4.5  System Architecture Overview

NovaBot's architecture follows a modular design that enables distributed processing between the rover and the cloud. The architecture can be summarized as:

- **Input Layer:** Captures multimodal inputs (speech, camera feed, touchscreen).

- **Processing Layer:** Performs AI inference (LLM reasoning, object detection, emotion analysis).

- **Control Layer:** Generates movement commands and system responses based on AI output.

- **Output Layer:** Delivers responses through voice, text, or visual feedback.

- **Cloud Layer:** Handles monitoring, data storage, and remote control.

This modular approach ensures scalability, allowing the integration of new AI models and hardware upgrades without reconfiguring the entire system.

## 4.6  Summary

NovaBot integrates multiple disciplines: artificial intelligence, robotics, human-computer interaction, and embedded systems into a unified solution for assistive technology. Its core innovation lies in its ability to perceive, understand, and respond to users naturally and empathetically, regardless of their disability. The project not only advances technical learning but also contributes meaningfully to accessibility, inclusion, and human-centered design.

# Chapter 5

# Technologies and Tools

## 5.1 Overview

NovaBot integrates a wide range of technologies spanning artificial intelligence, embedded systems, and cloud computing. The selection of each technology was based on performance, compatibility, scalability, and ease of integration within a real-time assistive robotics environment.

This chapter outlines the hardware and software technologies that will be utilized throughout the design, implementation, and testing of the NovaBot system.

## 5.2 Hardware Components

### 5.2.1 Core Hardware

The hardware components are anchored by the Hiwonder JetAuto robot kit, which forms the mobile platform for NovaBot. Key features of the kit include:

- Omnidirectional movement chassis with mecanum-wheels, enabling smooth lateral movement and agile navigation in tight indoor spaces.

- A programmable edge computing unit (e.g., NVIDIA Jetson Nano or Raspberry Pi 5) pre-integrated into major JetAuto versions for ROS1/ROS2 compatibility.

- A 3D depth camera and LiDAR (e.g., SLAMTEC A1) for simultaneous localization and mapping (SLAM), obstacle detection and navigation planning.

- 7-inch touchscreen display, built-in microphone array, speaker system, and expansion board for peripherals and sensors.

Since NovaBot's assistive functionality requires reliable mobility, perception and adaptability, the JetAuto kit provides a strong foundation; reducing build time and offering a flexible platform that supports our AI, vision and interaction modules.

### 5.2.2 Sensors and Peripherals

In addition to the standard kit components, the following sensors and peripherals will be integrated for NovaBot:

- HD camera module (RGB + depth) for computer vision, ASL recognition, and environment monitoring.

- Ultrasonic sensors and/or IR sensors for close-range obstacle detection and fall detection support.

- Microphone array (six-microphone ring) for far-field voice recognition and audio localization (supported by some JetAuto Pro versions).

- Touchscreen display and speaker output (leveraging the JetAuto kit's optional screen) for user interface, voice output and accessibility.

## 5.3   Software Technologies

The software stack powering NovaBot includes multiple layers: AI models, computer vision libraries, control algorithms, and cloud services.

### 5.3.1   Artificial Intelligence and Machine Learning

- **Large Language Model (LLM):** Used for conversation, reasoning, and task understanding. Models such as GPT-based APIs or open-source alternatives (e.g., Llama 3) will be explored.

- **Speech-to-Text (STT):** Implemented using Whisper or Google Speech API for accurate voice transcription.

- **Text-to-Speech (TTS):** Powered by models like Tacotron or Amazon Polly for natural speech output.

- **ASL Recognition:** Built using a CNN or MediaPipe-based model trained on sign language datasets.

- **Object Detection:** Implemented using YOLOv8 for real-time frame analysis and obstacle identification.

- **Emotion Detection:** Based on facial expression analysis using OpenCV and deep learning.

- **Fall Detection:** Using pose estimation models (e.g., BlazePose) and motion analysis from camera feed.

### 5.3.2   Robotics and Navigation

- **ROS (Robot Operating System):** Provides communication between hardware nodes, sensor fusion, and navigation control.

- **OpenCV:** Used for image and video frame processing.

- **TensorFlow / PyTorch:** Frameworks for training and running deep learning models on the Jetson board.

- **Arduino / Microcontroller Code:** Controls low-level sensors, motors, and feedback systems.

### 5.3.3   Cloud and Backend Technologies

- **Database:** Hybrid architecture: PostgreSQL (SQL) for structured data and MongoDB (NoSQL) for AI context and logs.

- **Backend Framework:** Node.js or Flask API to manage data exchange between robot and cloud services.

- **Cloud Platform:** AWS, Google Cloud, or Render for deployment, storage, and guardian dashboard hosting.

- **WebSocket / MQTT:** Real-time communication between robot, guardian interface, and monitoring server.

## 5.4 Development and Testing Tools

- **Development Environment:** VS Code, Jupyter Notebook, and Arduino IDE.

- **Version Control:** Git and GitHub for collaborative development and source code management.

- **Simulation and Prototyping:** Gazebo or Webots for testing navigation algorithms before hardware integration.

- **Design Tools:** Figma for interface design and Draw.io for system and architecture diagrams.

- **Testing Frameworks:** PyTest for software modules, ROS testing utilities for motion control, and manual evaluation for real-world performance.

## 5.5 Justification of Technology Choices

Each chosen technology was selected based on performance, compatibility, and accessibility:

- **Jetson / Raspberry Pi:** Offers the balance between processing power and affordability required for edge AI computation.

- **YOLOv8 and MediaPipe:** Provide lightweight yet high-accuracy real-time detection and recognition capabilities.

- **ROS Integration:** Enables modular design and communication between perception, planning, and control nodes.

- **Hybrid Database:** Combines relational reliability with flexible storage for AI-driven and unstructured data.

- **Cloud Monitoring:** Ensures the guardian can remotely monitor NovaBot safely and in real time.

## 5.6 Summary

The technologies and tools selected for NovaBot were chosen to achieve real-time performance, scalability, and user accessibility. The combination of embedded AI, robust robotics frameworks, and cloud integration allows NovaBot to operate intelligently and autonomously, providing dependable assistance tailored to the needs of each user.

# Chapter 6

# Requirements Analysis

## 6.1 Functional Requirements

NovaBot's functional requirements define the core capabilities and functions that the system must provide to meet the needs of users with disabilities. These requirements are organized into five primary groups that address safety, health, interaction, navigation, and system management.

### 6.1.1 Safety & Emergency Response

This group of requirements governs the system's primary safety-critical functions.

- **FR-1.1:** The system shall continuously monitor the Primary User's state to detect a fall event.

- **FR-1.2:** Upon detection of a fall (per FR-1.1), the system shall automatically initiate an emergency alert sequence.

- **FR-1.3:** The system shall continuously monitor the environment for hazards, specifically [smoke, gas leaks].

- **FR-1.4:** Upon detection of an environmental hazard (per FR-1.3), the system shall alert the Primary User and initiate an emergency alert sequence.

- **FR-1.5:** The emergency alert sequence (per FR-1.2, FR-1.4) shall dispatch notifications to, in order of priority: [1. Caregivers, 2. Emergency Services].

- **FR-1.6:** The alert notification shall include the user's identity, location, and the nature of the event (e.g., "Fall Detected," "Smoke Detected").

### 6.1.2 Health & Wellness Management

These requirements define the system's functions related to user health monitoring and assistance.

- **FR-2.1:** The system shall be capable of collecting and securely recording the Primary User's vital signs (e.g., heart rate, blood oxygen, sleep patterns, stress levels).

- **FR-2.2:** The system shall generate periodic and on-demand health reports from recorded vital sign data.

- **FR-2.3:** The system shall provide a secure interface for authorized [Healthcare Professionals] to access generated health reports (per FR-2.2).

- **FR-2.4:** The system shall allow the Primary User or Caregiver to create, update, and manage medication schedules.

- **FR-2.5:** The system shall provide timely, multimodal reminders to the Primary User at scheduled medication times.

- **FR-2.6:** The system shall provide a medical query interface (RAG) to answer user questions with verified medical information.

### 6.1.3 Multimodal Interaction & Companionship

These requirements define the core AI interaction modalities and capabilities.

- **FR-3.1:** The system shall accept and process user commands via three distinct modalities: [1. Spoken Language, 2. Sign Language (SL), 3. Touch Interface].

- **FR-3.2:** The system shall provide a conversational AI agent for the purpose of companionship and emotional support.

- **FR-3.3:** The system shall analyze the Primary User's communication (e.g., voice tone, facial expression) to detect their emotional state.

- **FR-3.4:** The system shall adapt its conversational responses and tone based on the detected emotional state (per FR-3.3).

### 6.1.4 Autonomous Navigation & Visual Assistance

These requirements govern the "rover" aspect of the system: its movement and environmental awareness.

- **FR-4.1:** The system shall autonomously navigate a pre-mapped indoor environment from point A to point B.

- **FR-4.2:** The system shall detect and avoid obstacles in its path, including static (e.g., furniture) and dynamic (e.g., people, pets) objects.

- **FR-4.3:** The system shall provide a "follow" mode to autonomously follow the Primary User.

- **FR-4.4:** The system shall adhere to "traffic rules" (e.g., respecting boundaries, speed limits) as defined by the user.

- **FR-4.5:** The system shall, upon request, provide visual assistance to the Primary User by:

  - **FR-4.5.1:** Identifying and announcing specific objects.
  - **FR-4.5.2:** Reading printed or digital text.
  - **FR-4.5.3:** Providing a verbal description of the immediate scene.

### 6.1.5 User & System Management

These requirements define the administrative and support functions of the system.

- **FR-5.1:** The system shall securely authenticate all actors [Primary User, Caregiver, Healthcare Professional, Administrator] before granting access to system functions or data.

- **FR-5.2:** The system shall allow the Primary User to manage their data privacy and sharing preferences.

- **FR-5.3:** The system shall provide a remote dashboard for authorized [Caregivers] to view the Primary User's real-time status, location, and recent alerts.

- **FR-5.4:** The system shall support multiple, distinct Primary User profiles within a single household, with personalized settings for each.

- **FR-5.5:** The system shall allow authorized [Administrators] to perform system maintenance, apply software updates, and manage AI models.

# 6.2 Non-Functional Requirements

NovaBot's non-functional requirements define the quality attributes and constraints that ensure the system operates reliably, securely, and accessibly. These requirements span performance, reliability, security, usability, scalability, safety, compatibility, data quality, and ethical considerations.

## 6.2.1 Performance Requirements

These requirements ensure NovaBot operates efficiently and responds in real time.

- **NFR-1.1:** The system shall process voice or sign-language commands and generate responses within 2 seconds under normal operating conditions.

- **NFR-1.2:** The fall detection and hazard detection modules shall trigger alerts within 1 second of event detection.

- **NFR-1.3:** The autonomous navigation system shall maintain a location update rate of at least 10 Hz for smooth motion and obstacle avoidance.

- **NFR-1.4:** The system shall support continuous operation for at least 6 hours on a single full battery charge under mixed-use conditions.

- **NFR-1.5:** All cloud communications (alerts, logs, dashboard updates) shall be transmitted within 3 seconds of event creation.

## 6.2.2 Reliability and Availability

Ensures NovaBot's stability and resilience in continuous use.

- **NFR-2.1:** The system shall achieve an uptime of 99% during normal operation hours.

- **NFR-2.2:** The system shall be able to recover automatically from transient failures (e.g., Wi-Fi disconnects, sensor faults) within 10 seconds.

- **NFR-2.3:** In the event of a component failure (e.g., camera or motor), the system shall gracefully degrade functionality while maintaining safety-critical features (e.g., emergency alerts).

- **NFR-2.4:** All critical logs (health, safety, navigation) shall be preserved locally for at least 7 days in case of network outage.

## 6.2.3 Security Requirements

Defines data protection, authentication, and privacy measures.

- **NFR-3.1:** All communication between NovaBot and the cloud shall use end-to-end encryption (TLS 1.3 or higher).

- **NFR-3.2:** User authentication shall use multi-factor authentication (MFA) for caregivers and administrators.

- **NFR-3.3:** Personal data and health information shall be stored in compliance with GDPR / HIPAA-like standards for confidentiality.

- **NFR-3.4:** The system shall restrict access to user data based on role-based access control (RBAC).

- **NFR-3.5:** All sensitive data stored locally shall be encrypted at rest (AES-256).

### 6.2.4 Usability and Accessibility

Ensures the system is intuitive and inclusive for users with disabilities.

- **NFR-4.1:** The interface shall be designed following WCAG 2.1 accessibility standards, supporting users with visual, hearing, or mobility impairments.

- **NFR-4.2:** All user interactions shall provide multimodal feedback (visual + auditory + text) to confirm actions.

- **NFR-4.3:** The system shall offer adaptive UI scaling for low-vision users.

- **NFR-4.4:** Voice and sign-language recognition accuracy shall be $\geq 90\%$ under normal indoor conditions.

- **NFR-4.5:** The system shall provide language localization (multi-language support) for diverse users.

### 6.2.5 Scalability and Maintainability

Ensures that NovaBot can evolve, expand, and be easily maintained.

- **NFR-5.1:** The modular architecture shall allow new AI models or sensors to be integrated without redesigning the full system.

- **NFR-5.2:** The cloud backend shall support up to 100 concurrent connected devices without performance degradation.

- **NFR-5.3:** Software updates shall be deployable over-the-air (OTA) without requiring manual intervention.

- **NFR-5.4:** All code modules shall follow ROS and API documentation standards for maintainability.

- **NFR-5.5:** The system shall log all key events for debugging and allow remote diagnostics through the guardian dashboard.

### 6.2.6 Safety and Compliance

Ensures that the system meets physical and operational safety standards.

- **NFR-6.1:** The rover shall not exceed 1 m/s indoors to ensure user and property safety.

- **NFR-6.2:** Obstacle avoidance accuracy shall be $\geq 95\%$ within a 1-meter detection range.

- **NFR-6.3:** The system shall meet ISO 13482 (safety requirements for personal care robots) compliance standards where applicable.

- **NFR-6.4:** In the event of critical malfunction, the rover shall automatically stop and enter safe mode.

### 6.2.7 Portability and Compatibility

Ensures flexibility across hardware and platforms.

- **NFR-7.1:** The software stack shall be compatible with both NVIDIA Jetson and Raspberry Pi 5 architectures.

- **NFR-7.2:** The web dashboard shall be compatible with modern browsers (Chrome, Edge, Safari) and mobile devices.

- **NFR-7.3:** The backend APIs shall follow RESTful or WebSocket standards for easy third-party integration.

### 6.2.8 Data Quality and Accuracy

Ensures dependable sensor and AI inference results.

- **NFR-8.1:** The fall detection system shall achieve at least 95% detection accuracy and <5% false-positive rate.

- **NFR-8.2:** Emotion recognition accuracy shall not fall below 85% under controlled lighting.

- **NFR-8.3:** Object detection latency shall not exceed 200 ms per frame on the edge processor.

### 6.2.9 Ethical and Privacy Requirements

Ensures user dignity, transparency, and responsible AI use.

- **NFR-9.1:** The AI assistant shall clearly inform the user when recording audio or video data.

- **NFR-9.2:** The system shall not transmit or store sensitive biometric data without explicit consent.

- **NFR-9.3:** AI models shall be trained and used in compliance with ethical AI principles, avoiding bias or discrimination.

## 6.3 Business Requirements

NovaBot's business requirements define the strategic goals, stakeholder value propositions, and organizational objectives that guide the project. These requirements ensure alignment with market needs, user expectations, and the university's mission in assistive technology innovation.

### 6.3.1 Market & Social Impact Requirements

**BR-M1: Accessibility Gap Closure**

The system shall demonstrate a viable solution to the fragmentation problem identified in the problem statement, providing Primary Users with a unified, multimodal platform that reduces dependency on multiple separate assistive devices and caregivers.

**BR-M2: Inclusive Design Demonstration**

The system shall exemplify human-centered design principles and inclusive technology, serving as a reference implementation for assistive robotics in developing regions and underserved communities where accessibility solutions remain limited.

### BR-M3: Quality of Life Enhancement

The system shall measurably improve key quality-of-life indicators for target users, including independence, social engagement, emotional well-being, and safety—as validated through user feedback and comparative studies where applicable.

### BR-M4: Addressable Market Recognition

The project shall identify and document a clear target market (e.g., elderly populations, disabled individuals in rehabilitation centers, at-home care scenarios) with quantifiable demand to support potential future commercialization or licensing.

## 6.3.2   Stakeholder Value Requirements

### BR-S1: Primary User Empowerment

The system shall enable Primary Users to achieve increased autonomy and independence in daily activities, specifically in communication, mobility, health monitoring, and emergency response—without diminishing human dignity or social connection.

### BR-S2: Caregiver Support

The system shall reduce caregiver burden through automated monitoring, remote alerts, and task assistance, allowing caregivers to focus on emotional support and complex care decisions rather than routine surveillance.

### BR-S3: Healthcare Professional Integration

The system shall provide healthcare professionals with secure, actionable health data and insights, enabling evidence-based care decisions and facilitating remote patient monitoring where applicable.

### BR-S4: Guardian Confidence & Trust

The system shall establish trust through transparent operation, clear communication, explainable AI decisions, and demonstrated reliability—earning confidence from guardians and family members who oversee the Primary User's welfare.

## 6.3.3   Technical Excellence & Innovation Requirements

### BR-T1: Integrated AI Showcase

The system shall demonstrate state-of-the-art integration of multiple AI disciplines (NLP via LLM, computer vision, emotion recognition, autonomous navigation) into a cohesive, real-time robotic platform—advancing the team's technical expertise and portfolio.

### BR-T2: Edge AI Deployment

The system shall validate efficient edge computing practices by running complex AI models (object detection, emotion recognition, NLP inference) on embedded hardware (Jetson/Raspberry Pi) within strict latency and power budgets.

### BR-T3: Modular Architecture Validation

The system shall prove the viability of a modular, extensible architecture that allows independent development, testing, and integration of AI modules, sensors, and cloud services—facilitating future enhancements and third-party integrations.

**BR-T4: Real-Time Multimodal Performance**

The system shall validate the feasibility of processing and responding to multimodal user inputs (speech, sign language, touch) in real time on resource-constrained platforms, setting performance benchmarks for future assistive robotics systems.

## 6.3.4 Scalability & Sustainability Requirements

**BR-SC1: Prototype-to-Product Pathway**

The system architecture and development process shall be designed to facilitate transition from academic prototype to deployable product, with clear documentation, modular code, and identified scalability bottlenecks and mitigation strategies.

**BR-SC2: Multi-Device Scalability**

The cloud backend and communication infrastructure shall be architected to support multiple concurrent NovaBot instances (initially prototyped with 1-5 units, designed for 100+ in future iterations) without degradation in performance or reliability.

**BR-SC3: Technology Stack Sustainability**

The chosen technologies (ROS, TensorFlow, PostgreSQL, Node.js) shall have active community support, documented best practices, and clear upgrade paths to ensure long-term maintainability and evolution of the system.

**BR-SC4: Cost Optimization**

The system shall demonstrate cost-effectiveness through leveraging affordable, commercial-off-the-shelf hardware components (Jetson Nano, Raspberry Pi, JetAuto kit) rather than custom-built solutions, validating a sustainable business model for developing regions.

## 6.3.5 Educational & Research Contribution Requirements

**BR-E1: Interdisciplinary Learning Platform**

The project shall serve as a comprehensive, hands-on learning platform for the team, integrating concepts from AI/ML, robotics, embedded systems, cloud computing, HCI, and project management—demonstrating mastery of modern software engineering practices.

**BR-E2: Research Publication Opportunities**

The project shall generate research contributions worthy of academic publication, particularly in areas such as multimodal AI for accessibility, lightweight emotion recognition on edge devices, or ASL recognition in real-world settings.

**BR-E3: Open-Source Potential**

The system design and documentation shall be structured to enable potential open-sourcing of key modules (e.g., ASL recognition pipeline, fall detection algorithm, navigation stack) to benefit the broader assistive robotics and open-source community.

### BR-E4: Case Study & Best Practices Documentation

The project shall produce comprehensive documentation suitable for publication as a technical case study, detailing architecture decisions, lessons learned, performance metrics, and best practices for multi-AI-model integration on embedded systems.

## 6.3.6 Regulatory, Safety & Compliance Requirements

### BR-R1: Safety-Critical System Certification

The system shall demonstrate compliance with relevant safety standards for personal care robots (ISO 13482 where applicable) and maintain a safety-first design philosophy throughout development, with rigorous testing for edge cases and failure modes.

### BR-R2: Data Privacy & Regulatory Compliance

The system shall be architected to support GDPR, HIPAA-like, and evolving regional data protection standards, ensuring that user health and biometric data collection, storage, and sharing align with legal requirements and ethical principles.

### BR-R3: Ethical AI Governance

The system shall implement transparent, auditable AI decision-making processes and establish clear governance for training data, model bias mitigation, and user consent—demonstrating responsible AI practices suitable for vulnerable populations.

### BR-R4: Transparency & Accountability

The system shall explicitly inform users when recording data, using AI algorithms, or sharing information with guardians/professionals; provide explanations for system decisions; and maintain detailed audit logs for accountability and regulatory review.

## 6.3.7 Strategic Positioning & Long-Term Vision Requirements

### BR-V1: University Reputation & Mission Alignment

The project shall enhance Alamein International University's reputation as a leader in AI, robotics, and socially responsible technology innovation, aligning with the institution's mission to support underrepresented and disabled communities.

### BR-V2: Industry Partnership Foundation

The project shall establish a foundation for potential partnerships with healthcare organizations, NGOs, disability advocacy groups, or technology companies, demonstrating proof-of-concept for real-world assistive solutions.

### BR-V3: Student Employability & Career Growth

The project shall provide the team members with portfolio-quality deliverables, demonstrated expertise, and publication/presentation opportunities that enhance career prospects in AI, robotics, and humanitarian technology sectors.

**BR-V4: Innovation Sustainability**

The project shall document technical and organizational insights that position the team or institution to undertake subsequent phases (e.g., outdoor navigation, IoT integration, multi-user households) or related research initiatives in assistive robotics.

# 6.4 Business Rules

Business rules define operational constraints, decision policies, and governance principles that shape how NovaBot functions and evolves within its business and organizational context.

## 6.4.1 Authentication & Access Control

### BR-01: User Authentication

Each user and guardian must register and authenticate before accessing NovaBot's services. The system validates identity and permissions for all interactions.

### BR-02: Guardian Access Control

Guardians can only view and monitor the specific users linked to their accounts. Remote control privileges are restricted for safety.

### BR-13: Data Access Rights

Guardians have read-only access to data. Only the user can authorize control or configuration changes.

## 6.4.2 Communication & Accessibility

### BR-03: Accessibility Mode Detection

NovaBot automatically identifies or applies the user's preferred communication mode (voice, text, or sign language). The user may manually change the mode in settings.

### BR-04: Fallback Communication Mode

If any input/output module fails (e.g., microphone or camera), NovaBot switches to the default text interface to maintain accessibility.

## 6.4.3 Safety & Emergency Response

### BR-05: Emergency Alert Rule

Upon detecting a fall or emergency, NovaBot must immediately alert the guardian dashboard with live camera feed, timestamp, and location data.

### BR-06: Obstacle and Safety Rule

NovaBot halts movement when an obstacle is detected within 0.5 meters and resumes only when the path is clear. Safety overrides all user commands.

**BR-07: User Following Distance**

The rover must maintain a configurable following distance from the user (default 1.5 meters) to ensure safe navigation.

**BR-15: Fail-Safe Mode**

In case of hardware or software malfunction, NovaBot enters a fail-safe mode that stops motion and notifies the guardian.

### 6.4.4 Data Privacy & Security

**BR-08: Data Privacy and Encryption**

All user data (voice, video, logs) must be encrypted before storage or cloud upload. Data sharing requires explicit consent.

### 6.4.5 AI Ethics & Behavior

**BR-09: AI Ethical Interaction**

The AI assistant must only respond in a supportive and safe manner. It cannot provide harmful, biased, or non-assistive replies.

**BR-10: Emotion-Based Adaptation**

NovaBot may adjust its tone and responses based on detected emotions, but cannot override user commands or perform unsolicited actions.

### 6.4.6 System Maintenance & Operations

**BR-11: System Updates**

Software and firmware updates are allowed only when NovaBot is idle and connected to a secure network. Update logs must be saved automatically.

**BR-12: Battery Management**

The system issues low battery alerts below 15% and prevents task initiation if remaining power is insufficient for completion.

**BR-14: Operational Integrity**

The robot must complete sensor calibration (LiDAR, camera, etc.) before initiating autonomous movement.

# Chapter 7
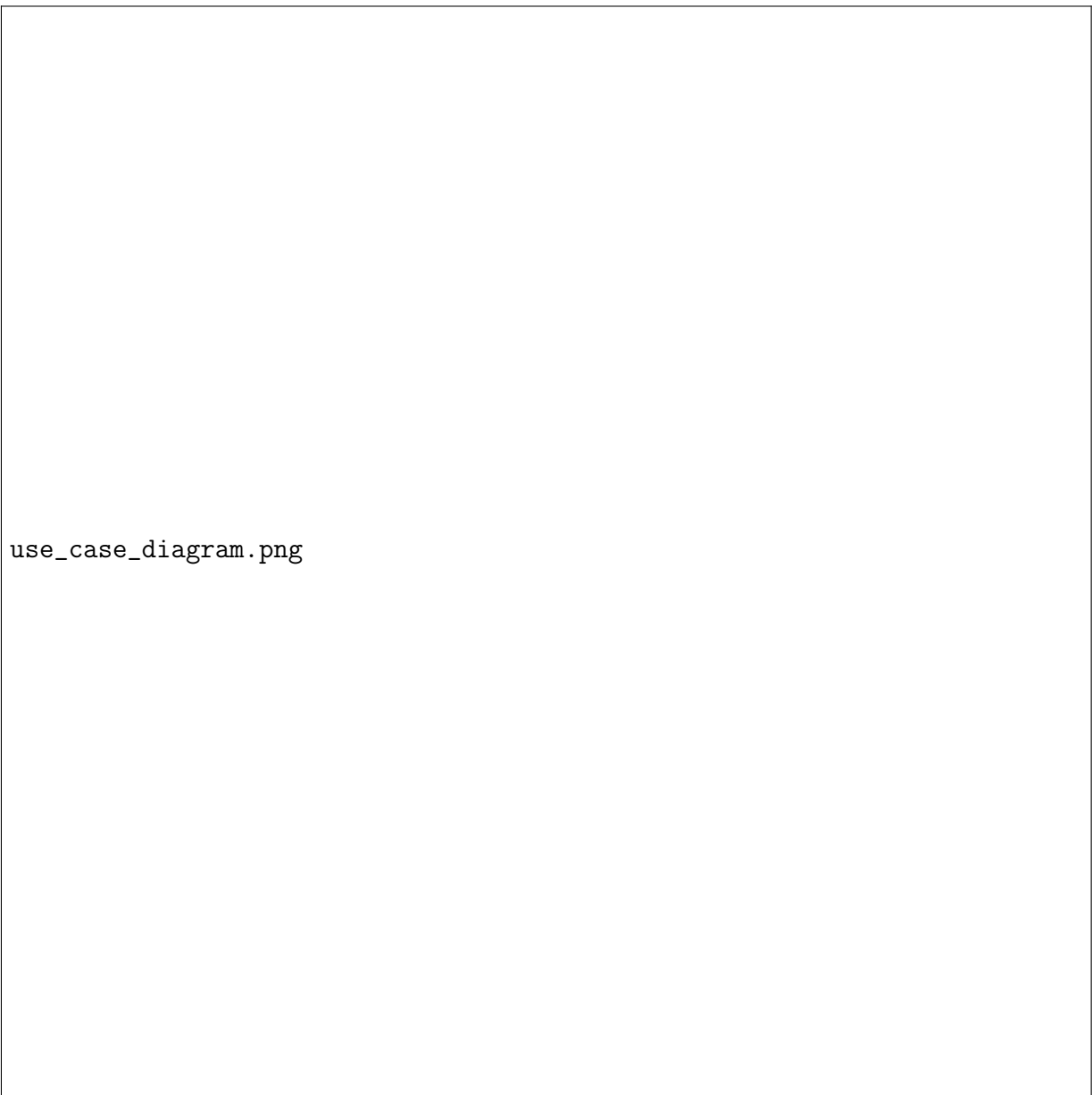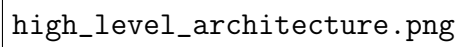
# System Design

## 7.1   Use Case Diagram

use_case_diagram.png

Figure 7.1: NovaBot Use Case Diagram
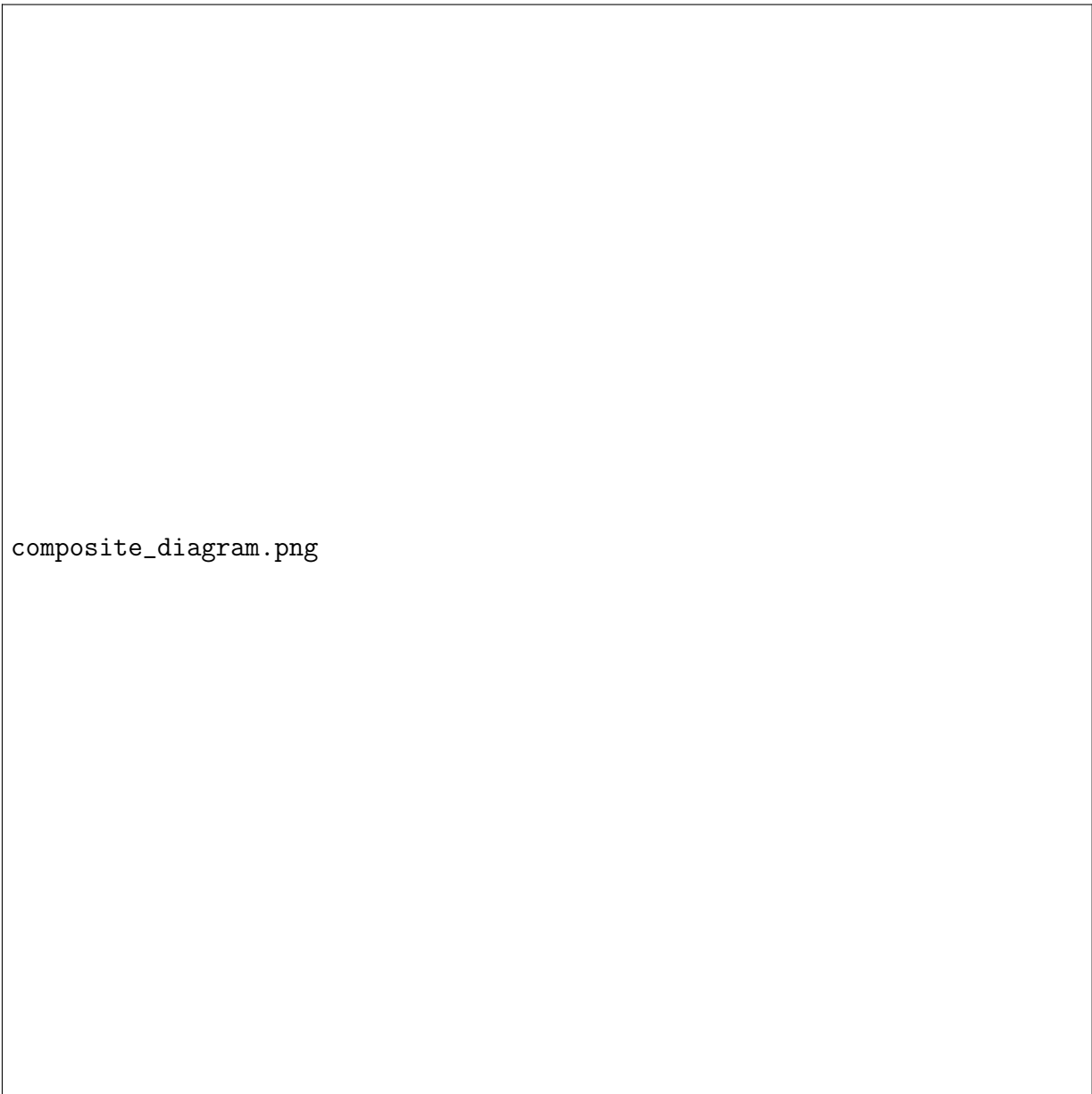
## 7.2 Architecture Diagrams

### 7.2.1 High-Level Architecture

27

high_level_architecture.png

Figure 7.2: High-Level System Architecture

## 7.2.2 Composite Diagram

composite_diagram.png

Figure 7.3: Composite Structure Diagram
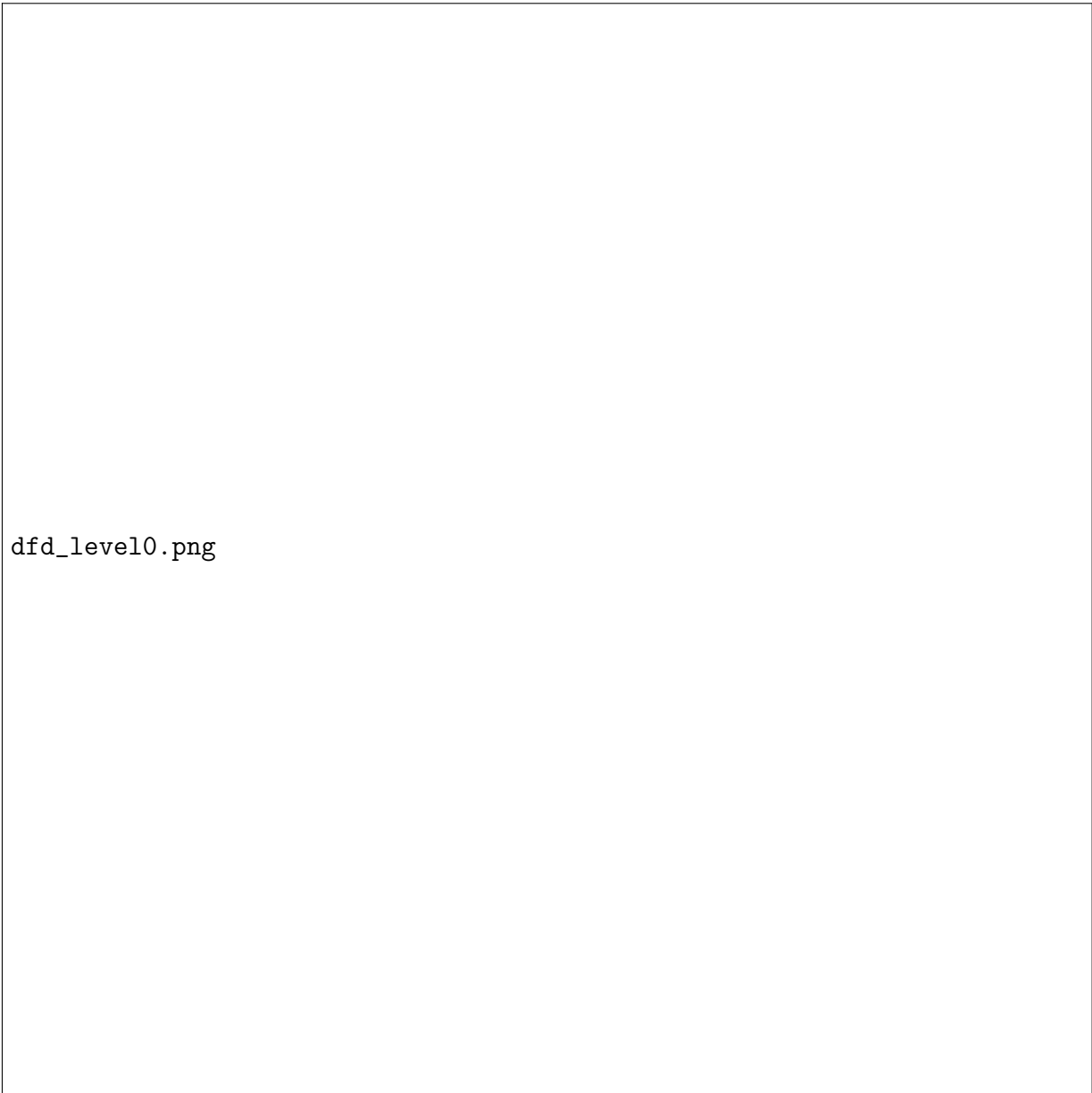
# 7.3 Data Flow Diagrams

## 7.3.1 Level 0 DFD

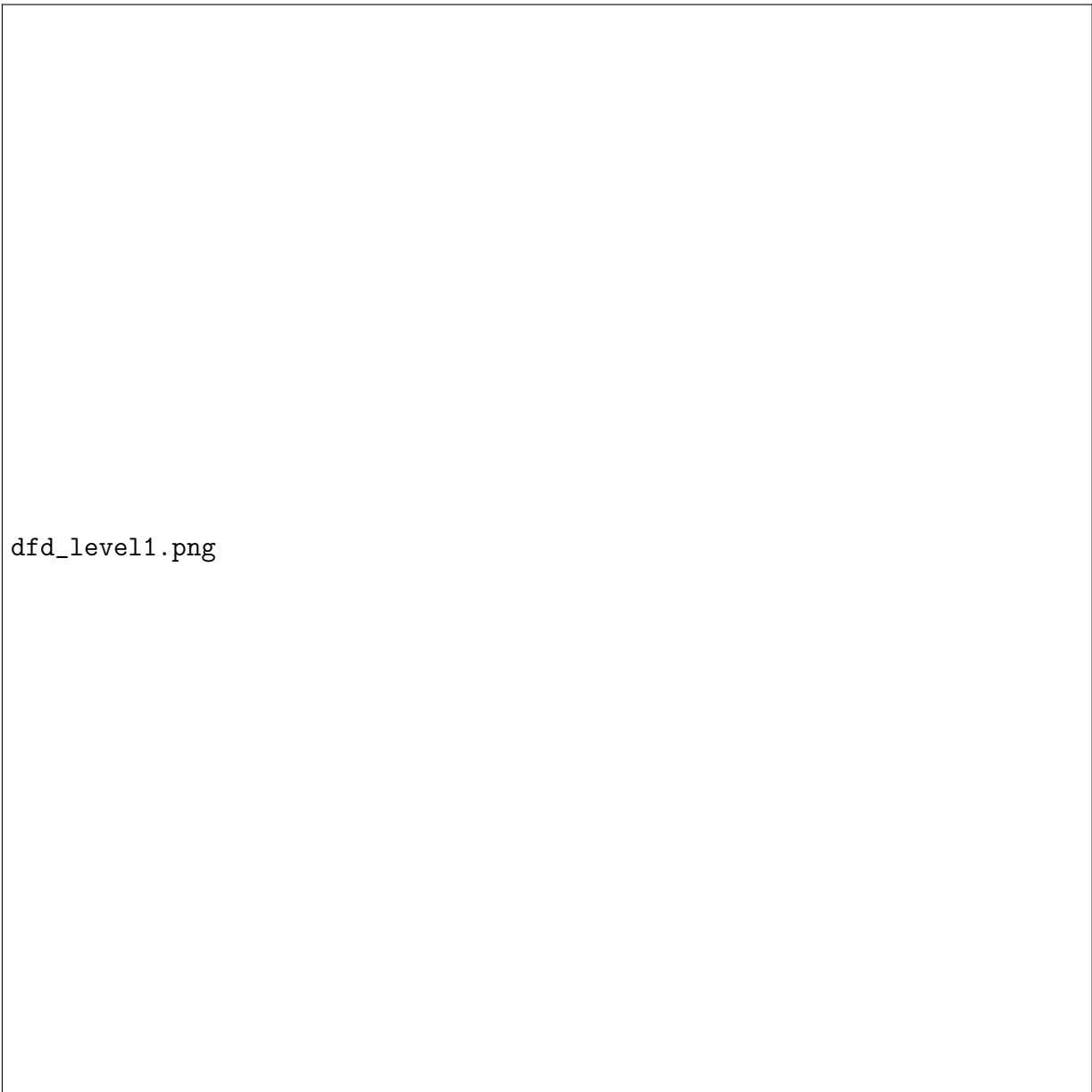`dfd_level0.png`

Figure 7.4: Data Flow Diagram – Level 0

## 7.3.2 Level 1 DFD

dfd_level1.png

Figure 7.5: Data Flow Diagram – Level 1

## 7.4 Sequence Diagrams
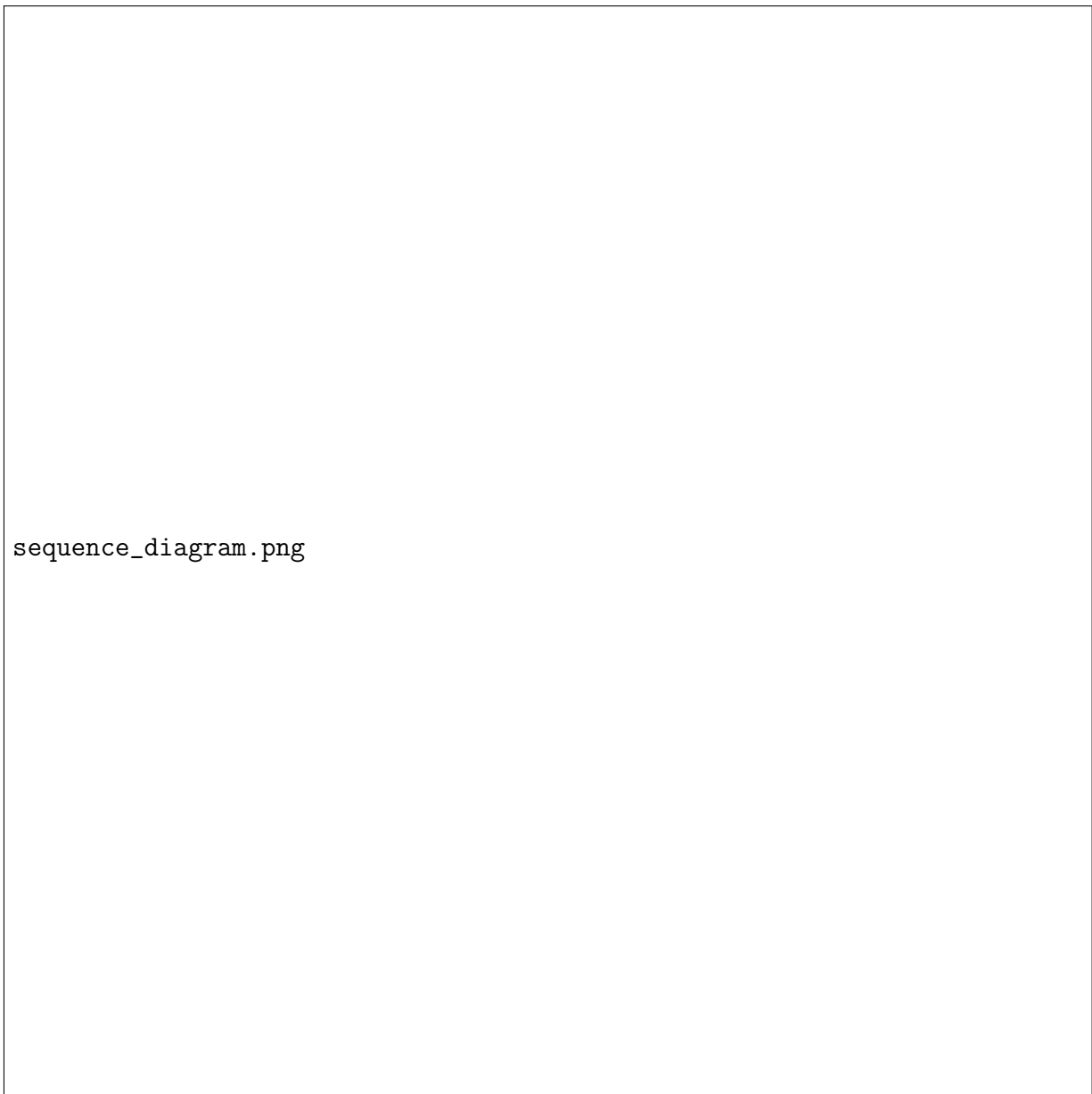


sequence_diagram.png

Figure 7.6: Sample Sequence Diagram

## 7.5 Class Diagram

## 7.6 Entity Relationship Diagram (ERD)

## 7.7 User Stories

## 7.8 Traceability Matrix

| Requirement ID | Description | Design Component | Test Case ID |
|---|---|---|---|
| REQ-1 | Voice recognition | Speech-to-text module | TC-01 |

| REQ-2 | Object detection | Vision module | TC-05 |

# Chapter 8

# Testing Methodologies

8.1    **Testing Requirements**

8.2    **Test Cases**

8.3    **Unit Testing**

8.4    **Integration Testing**

8.5    **System Testing**

8.6    **Acceptance Testing**

8.7    **Evaluation Metrics**

8.8    **Testing Tools**

# Chapter 9

# Project Management

**9.1   Timeline / Gantt Chart**

**9.2   Team Roles**

**9.3   Risk Management**

# Chapter 10

# Ethical and Legal Considerations

**10.1  Timeline / Gantt Chart**

**10.2  Team Roles**

**10.3  Risk Management**

# Chapter 11

# Conclusion

# Chapter 12

# References