ECE 445

SENIOR DESIGN LABORATORY

DESIGN DOCUMENT

ORION MED

An Autonomous Cart That Delivers Medicine in Elder-care Wards

---

Team No. 26

WENHAO ZHANG

(wenhaoz5@illinois.edu)

YUXIN ZHANG

(yuxinz11@illinois.edu)

XIANGYI KONG

(xkong13@illinois.edu)

TA: Zhuoer Zhang

Professor: Rakesh Kumar

September 19, 2025

Abstract

This document shows both the high-level control and the submodules implementation of ORION MED, an autonomous medicine delivery cart for elder-care wards. The system consists of nurse-computer interface, line-following navigation, medicine verification, and obstacle avoidance to reduce nurses' workload and improve safety. Core requirements, subsystem functions, and ethical considerations are also indicated in the documentation to ensure reliable and responsible deployment in healthcare environments.

Table of Contents

1. Introduction

1.1 Problem

The global population is aging which leads to a rapid increase in demand for elder care services. However, the trained labor force for such services doesn't keep pace, which results in a shortage of staff and extensive workload. However, a significant portion of a nurse's time is spent on routine but necessary tasks, like fetching medicine from storage locations. The repetitive tasks cause the nurses to have limited time to provide personalized care. Without interventions, the gap between the required labor force and current trained staff for elder care will continue to increase, which will negatively impact the quality of care and patient well-being. Compared to generic delivery carts, ORION MED integrates medicine verification before transmitting between different pharmacies, which reduces the chance of medication errors. It also uses a low-cost, track-guided navigation system with ground markers instead of expensive LiDAR or SLAM, which makes it more reliable and practical.

1.2 Solution

The deal with the challenge, we propose ORION MED which is a line-following autonomous medicine cart. The cart will navigate along a predefined path between a central nurse station and several fixed pharmacy stations (these are all included in a predefined map). Nurses can use their PC to input the target stations number and medicine type. The cart will navigate to the specific station, then verify the correct medicine via onboard sensors, and return to the nurse station. This system helps nurses to reduce the time spent on repetitive tasks and ensures them to provide more personalized care for patients. The solution integrates locomotion, load detection, medicine verification, and communication system together.

1.3 Visual Aid

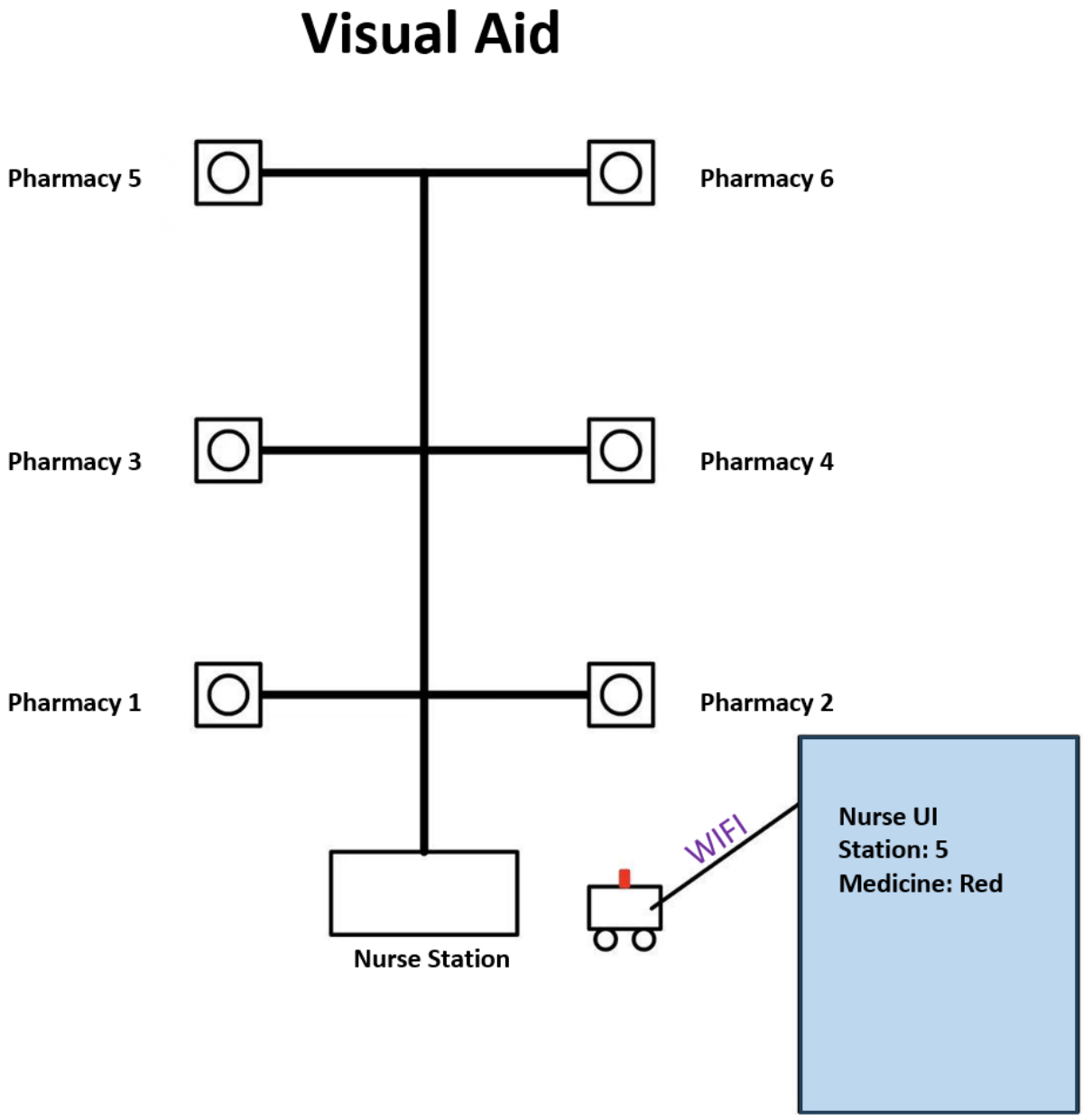

Figure 1. System diagram of Orion Med showing the nurse station, pharmacy stations, and autonomous cart communication with the nurse UI via Wi-Fi.

The diagram illustrates the ORION MED system. The nurses use a UI to send commands through WIFI to the cart starting from nurse station. The cart will follow the black path to reach one of the several pharmacies, each pharmacy will be identified by a unique ground marker pattern. After picking up correct medicine, the cart will return to nurse station.

1.4 High-Level Requirements

1. The cart must be able to autonomously travel from the nurse station to any of the several pharmacy stations and return with at least 80% success rate over 20 trials.

2. The medicine verification subsystem must correctly classify medicine (by color label) with at least 80% accuracy.

3. The obstacle avoidance system must detect and stop in front of obstacles within 20 cm, with a maximum reaction time of 1 second.

2. Design

2.1 Block Diagram

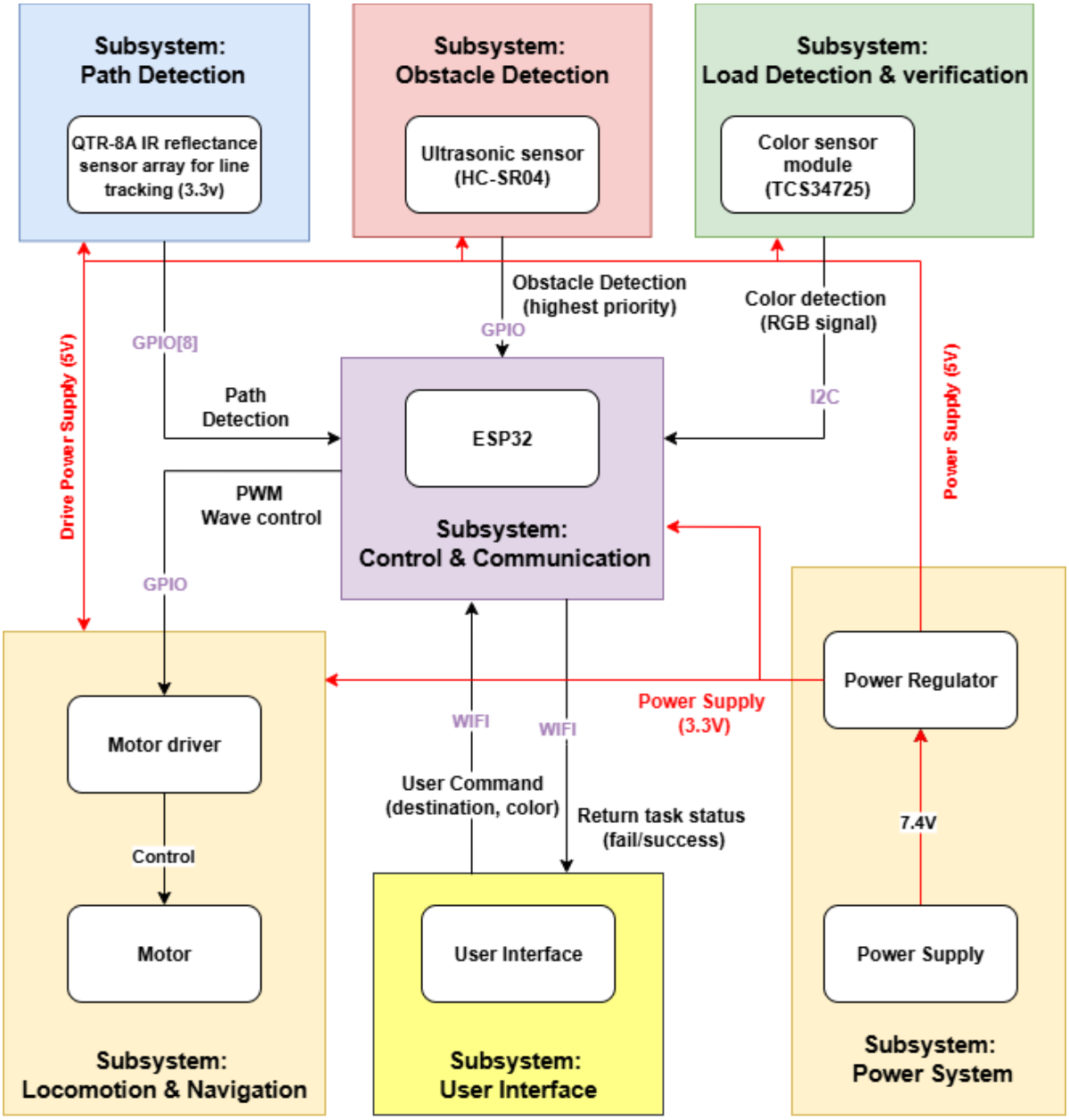

Figure 2. Block diagram of Orion Med, illustrating the interaction between subsystems: locomotion and navigation, path detection, obstacle detection, load detection and verification, user interface, control and communication, and the power system.

2.2 Subsystem Overview

2.2.1 Locomotion & Navigation:

The locomotion and navigation subsystem moving the cart along predefined path. It uses DC motors and a motor driver to generate forward and turning motion (Left, right and around). IR sensors are used to monitor the black path continuously and feed back to the control system to ensure the cart is in the middle of the path. This subsystem communicates with the control system with PWM signals.

2.2.2 Load Detection:

The load detection subsystem is used to ensure that the medicine package is placed on the cart. The RGB color sensor, TCS3425, is used to detect the presence of medicine packages by using the reflected light intensity. To avoid false triggers, the system will only confirm a load if the sensor reads a stable color signal for a defined time period. This subsystem will confirm the medicine information before delivery.

2.2.3 Medicine Verification:

The medicine verification subsystem ensures correct medicine packages are placed on the cart. It receives the RGB signal from the reflected lights of the packages by using the RGB sensor. Each package will be wrapped in red/green/blue packages to make it distinguishable. After detection, the result will be sent to the control system which will compare the result with the input of nurses. This process avoids delivery errors.

2.2.4 Control & Communication:

The control and communication subsystem is the core of the ORION MED system. ESP32 microcontroller is used to run the finite state machines (FSM) to manage the control for different states which includes navigation, verification, and obstacle detection. It communicates with nurses GUI using wireless communication (WIFI). After receiving the command, the control subsystem will update the state. In addition, the ESP32 microcontroller processes the senor data and sends PWM signal to control motors.

2.2.5 Power Supply & Safety:

The power supply and safety system provides stable power supply for all the other subsystems. It includes regulated 5V and 3.3V power supply to support motors, sensors and the ESP32 microcontroller. The battery management circuits also ensure safe charging and discharging. Also, this system includes an emergency button which can immediate shutdown of motor power. To prevent potential hazards, protective enclosures are used.

2.2.6 Obstacle detection:

The obstacle detection subsystem is used to ensure the cart moves in a safe environment. It uses an ultrasonic sensor, HC-SR04, to detect unexpected obstacles. If the subsystem detects unexpected obstacles, it will send a signal to the control and communication subsystem to stop moving. This subsystem can avoid collisions and improve safety in elder-care wards.

2.3 Subsystem Requirements

2.3.1 Locomotion & Navigation subsystem:

The locomotion and navigation subsystem must ensure that it always remains roughly within the middle of the path to maintain accuracy. The cart is required to stay within ±1.5 cm of the centerline even when moving at speeds up to 0.2 m/s. In addition, it must consistently reach the correct pharmacy stations, with an overall navigation accuracy of at least 90%.

2.3.2 Load Detection subsystem:

The car will send a valid signal indicating it successfully gets loaded with the correct object only if the sensor successfully detects a stable RGB color signal for at least 1.0 second, reducing false triggers.

2.3.3 Medicine Verification subsystem:

Under normal indoor lighting, the color sensor should classify red, green, and blue labels with at least 90% accuracy.

2.3.4 Control & Communication:

The system should process FSM state updates smoothly and provide GUI status updates at a rate comfortable for monitoring. The wireless connection should remain reliable within a normal indoor operating range.

2.3.5 Power Supply & Safety subsystem:

The system must provide continuous 5V at ≥3A (motors + drivers) and 3.3V at ≥1A (ESP32 + sensors), and the system should cut off motor power within 100 ms of E-stop activation. Obstacle sensors must detect obstacles within 20 cm ±2 cm.

2.3.6 Obstacle detection subsystem:

The obstacle detection subsystem must guarantee that the cart halts when unexpected objects appear in its path. Specifically, the cart should stop within 20 cm of an obstacle to avoid collisions.

2.4 Tolerance Analysis

A critical challenge for our project is how to have stable line-control at moderate speeds (0.1 - 0.2m/s). The cart should response to the line deviations without having oscillations. This system uses a QTR-8A IR sensor, the sensor spacing is 1cm and refresh rate is 200 Hz. This sensor allows the cart to detect deviations as small as 0.5 cm. Assuming the maximum drift velocity is 10 cm/s. The control and communication subsystem needs to correct within 0.05 seconds. This is feasible with the ESP32's processing capability.

3. Ethics and Safety

The project strictly follows the IEEE Code Ethics. It will always emphasize prioritizing public welfare while also disclosing potential limitations. In addition, the Orien Med will only assist by transporting items. Nurses will still be the people responsible for medicine administration. Safety is also considered within the design. We include the emergency stop button, regulated power supply, no wiring exposure, etc. Moreover, we also implement obstacle detection to prevent unexpected collisions. By incorporating both ethical responsibility and rigorous safety standards, ORION MED will ensure both its functionality and safety within the working environment.