ECE 445

SENIOR DESIGN LABORATORY

FINAL REPORT

---

# Automated guided vehicle for cargo delivery in factories

---

ZHENGJIE WANG
(zw65@illinois.edu)
XUHONG HE
(xuhongh2@illinois.edu)
YUYI AO
(yuyiao2@illinois.edu)
QIQIAN FU
(qiqianf2@illinois.edu)

TA: Haoran Cui, Yanbing Yang

March 17, 2025

# Abstract

Cargo delivery in large factories faces challenges like low efficiency and safety risks with manual labor. To address these issues, we design an automated guided vehicle (AGV) to reduce labor costs and improve safety level ini this process. The AGV systems include following components: navigation system, obstacle avoidance system, instruction system and mechanical and electrical control.

# Contents

# 1 Introduction

## 1.1 Problem

Cargo delivery in large factories has long been a problem due to the low efficiency, restricted working period, and high safety risks caused by manual labor. Human-operated systems, such as forklifts, often results into delays, errors, and accidents, as evaluated by injuries linked to forklifts in the U.S. [1]. Human-operated vehicles or manual transport methods often result in delays, errors, and inconsistent performance, especially in complex factory surroundings. Workers' working hours are limited and therefore cannot maintain a 24/7 operation. Additionally, heavy machinery, narrow transporting channels, and dynamic obstacles increase the risk of accidents and injuries. To solve these problems, factory owners and researchers want to design a kind of automated guided vehicle that performs better than manual labor. These challenges call for the rising demand of automated guided vehicles (AGVs), which will eliminate human error, reduce labor costs by 20–30% [2], and operate continuously day and night.

## 1.2 Solution

An automated guided vehicle needs to be designed and assembled. The vehicle needs to deliver cargo within a large factory. The vehicle needs to be equipped with a control/navigation and obstacle avoidance system. This system ensures that the vehicle can move to the ordered destination by itself safely. Moreover, the vehicle needs to lift goods for at least 10 kilograms. This AGV frees workers from moving the goods from point to point, and the only job they need to do is to place the goods in the correct position when the AGV reaches its destination. To accomplish these functions, five parts will be built and assembled on a manual forklift to transform the cart into an AGV. The main system is a Raspberry Pi, serving as a core processor of any signals. Users can access the AGV from a distance, and the order assigned by the user will be transferred to the main system through the instruction subsystem, which contains database to provide the user with the available positions the AGV can go to. Once the AGV is in motion, another two subsystems will start functioning. The navigation subsystem employes laser radar and SLAM reconstruction and positioning to navigate the route, and the obstacle avoidance subsystem uses ultrasonic sensor to detect any possible obstacles and give instant signal to avoid them. These subsystems communicate with the main system, and after processing, the Raspberry Pi will send signals to the mechanical and electrical subsystem to adjust the power supply of each motion part, controlling the motion of the cart.

## 1.3 Visual Aid

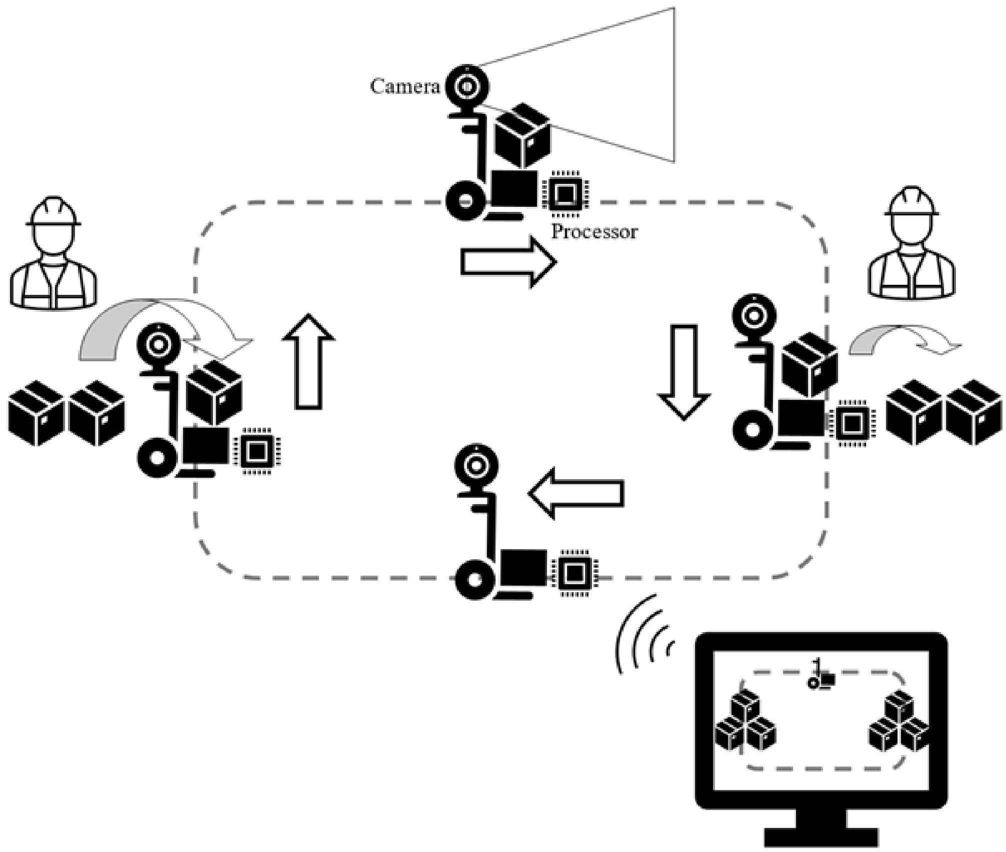


Figure 1: AGV System Overview

# 2 Design

## 2.1 Subsystem Overview

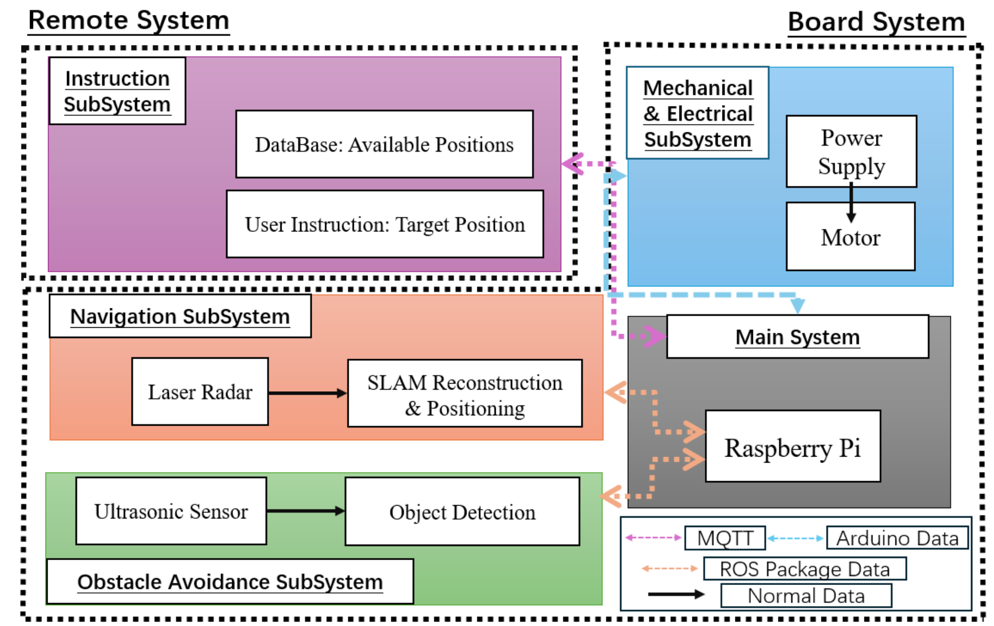


Figure 2: AGV System Overview

The AGV consists of four modular interconnected subsystems: Navigation SubSystem, Obstacle Avoidance SubSystem, Instruction SubSystem and Mechanical  Electrical SubSystem. Each subsystem is essential to ensuring the AGV operates efficiently, safely, and autonomously within the factory environment. Together, these subsystems work in harmony to create an AGV capable of reliable and efficient cargo transport.

### 2.1.1 Navigation SubSystem

The SLAM (Simultaneous Localization and Mapping) [3] algorithm is responsible for constructing a real-time map of the factory environment while simultaneously tracking the vehicle's position within it. It integrates data from sensor (we use laser rader here) to estimate the vehicle's position and update the environmental map. This subsystem provides critical spatial scene for path planning. By maintaining accurate localization, it ensures the forklift operates autonomously in the factory scenarios.

### 2.1.2 Obstacle Avoidance System

The obstacle avoidance system ensures the AGV can move safely through the factory environment by detecting and avoiding both static and dynamic obstacles. Using ultrasonic sensors[4], the system continuously emits sound waves and measures their reflections to identify if there's an obstacle or not and determine their distance from the AGV. The system then sends signal to the AGV to stop until the obstacle disappears.

### 2.1.3 Instruction SubSystem

The Instruction subsystem is to enable communication between the AGV and the control center in computer. Message Queuing Telemetry Transport (MQTT) [5] is used as the communication protocol. MQTT broker is the server that receives all messages from the clients and sends the messages to the appropriate clients. Whhen AGV is carrying a cargo, it will request the control center and will receive the information and move to the correct cargo shelf.

### 2.1.4 Mechanical Electrical SubSystem

The mechanical and electrical subsystem incorporates three electrical motors, controlling the motion of lifting, turning, and accelerating. The three motors are connected to a STM32 microcontroller, sharing the signal from the main system. Digital and analog signals are transferred and assigned to each of these motors, controlling the motion of the AGV to accomplish the order given by the user or the algorithm in the processor.

## 2.2 Subsystem Requirements

### 2.2.1 Navigation SubSystem

The navigation subsystem must generate a real-time map with an accuracy of ±10 cm and maintain localization drift under 2% over a 10-meter trajectory. It must process data from laser radar with a refresh rate of at least 10 Hz to ensure efficient responsiveness and store the data locally. The subsystem will provide continuous position updates and map data for route planning. If the system fails to maintain accurate localization and map updates, the vehicle would be unable to navigate autonomously within the factory.

### 2.2.2 Obstacle Avoidance Subsystem

The Obstacle Avoidance Subsystem is responsible for detecting and avoiding both static and dynamic obstacles to ensure safe AGV operation. It continuously scans the surroundings using multiple ultrasonic sensors, which emit high-frequency sound waves and measure the time taken for echoes to return, allowing precise distance estimation. This data is processed to identify obstacles and determine their location relative to the AGV. Requirements 1: The system must detect obstacles within a minimum range of 3 meters Requirements 2: The Obstacle Avoidance Subsystem interfaces with the Mechanical Electrical SubSystem by transmitting stop signals when an obstacle is detected within a 50 cm range.

### 2.2.3 Instruction SubSystem

The Instruction subsystem ensure the communication process between the AGV and the control center. When a cargo need to be transfered to final desitnation, the control center will send the Instruction to AGV to ensure it move to start point and then move to the final destination and the correct cargo shelf. MQTT is used as the communication protocol between the AGV and the control center, which is a lightweight and low consumption protocol. Its Quality of Service ensures reliable message delivery, making it suitable for AGV system.

#### 2.2.4 Mechanical Electrical SubSystem

The lifting motion's electrical motor, as well as the lifting plate's strength, should be able to provide a force that can at least lift goods of 10 kilograms. The turning part is designed to make a 90-degree turn within a 3 meters radius. The accelerating motor should provide a minimum operating speed of 1m /s when unloaded, and 0.5 m/s when fully loaded.

### 2.3 Tolerance Analysis

A critical risk in using ultrasonic sensors for obstacle detection is measurement accuracy and response time, particularly in a dynamic factory environment where reflective surfaces, environmental noise, and sensor blind spots could affect performance. The system relies on three ultrasonic sensors positioned at the front, front-left, and front-right of the AGV to detect obstacles in multiple directions. This configuration allows the AGV to identify obstacles in its path and react accordingly by stopping when an object is detected within a 50 cm range. However, ultrasonic sensors may suffer from signal reflection and absorption issues, especially in environments with metallic surfaces or irregularly shaped objects. Reflections from highly smooth surfaces can cause false detections, while soft materials may absorb the sound waves, leading to undetected obstacles. Additionally, cross-interference between the three ultrasonic sensors could result in inaccurate readings, especially if they operate at similar frequencies.

To mitigate these risks:

- The sensors should operate at slightly different frequencies or incorporate sequential triggering to minimize interference.
- Signal filtering techniques, such as median filtering, should be implemented to discard outlier readings caused by reflections.
- The system should integrate redundant checks where an obstacle is only confirmed if detected by at least two consecutive readings within 50 ms to reduce false positives.

# 3 Ethics and Safety

The development and deployment of AGVs for industrial use may raise ethical and safety considerations.

## 3.1 Ethical Considerations

### 3.1.1 Public Welfare and Safety

Human safety has a higher importance than AGVs, especially in shared workspaces. This is most important during the whole development process, and should follow the 7.8 IEEE Code of Ethics, and ACM Code of Ethics and Professional Conduct [6][7]. A breach could lead to accidents or harm due to system failures or inadequate collision avoidance. To avoid this, it is possible to implement safety mechanisms (e.g., LiDAR, emergency stop systems) and evaluate them through limit tests like accelerated scenario-based evaluation.

### 3.1.2 Data Privacy

AGVs' motion is partly based on collecting operational data (e.g., worker movements), and may have risks in violating privacy if mishandled. A possible solution can be aligning with the client and employer best interests principle [8].Encrypt sensitive data and comply with GDPR or equivalent regulations.

## 3.2 Safety Standards and Regulatory Compliance

During the development, it is significant to note the restrictions published by the local government. Some relative regulations are listed here. ISO 3691-4 specifies AGV safety requirements, including obstacle detection and emergency braking[9]. The National Electrical Safety Code (NESC) ensures safe electrical infrastructure for AGVs, particularly in high-risk environments [10]. ISO 34502 outlines scenario-based safety evaluations for autonomous systems[11].

## 3.3 Potential Safety Risks

Potential safety risks in this AGV development are mostly about the risk of physical harm, system failures, and environmental hazards. For instance, in the deployment of an autonomous mobile device, there is a significant risk of collisions with humans, particularly vulnerable people such as children and the olds, leading to injuries. Similarly, in industrial environments, the use of AGVs may also cause collision risks due to sensor failures or algorithmic errors. Additionally, in high-temperature factory environments, such as those involving heat-treating furnaces, the lack of proper protective gear like heat-resistant gloves can lead to burns or other injuries.

# References


[1] OSHA. "Forklift Accident Statistics." (), [Online]. Available: https://www.safetymanualosha.com/forklift-fatalities/.

[2] Deloitte. "The Future of Smart Manufacturing." (2021), [Online]. Available: https://www.deloitte.com/global/en/Industries/industrial-construction/perspectives/Digital-transformation-in-the-fom.html.

[3] J. A. Placed, J. Strader, H. Carrillo, N. Atanasov, V. Indelman, and L. Carlone, "A Survey on Active Simultaneous Localization and Mapping: State of the Art and New Frontiers," *IEEE Transactions on Robotics*, vol. 39, no. 5, pp. 1234–1250, 2023. DOI: 10.1109/TRO.2023.10075065. [Online]. Available: https://ieeexplore.ieee.org/document/10075065.

[4] Atanas Dimitrov Dimitar Minchev, "Ultrasonic Sensor Explorer," in *Proceedings of the IEEE Conference on Sensors*, IEEE, May 2016. [Online]. Available: https://ieeexplore.ieee.org/document/7542987.

[5] OASIS. "MQTT Version 5.0." (2019), [Online]. Available: https://docs.oasis-open.org/mqtt/mqtt/v5.0/mqtt-v5.0.html.

[6] ACM. "ACM Code of Ethics." (2018), [Online]. Available: https://www.acm.org/code-of-ethics.

[7] IEEE. "IEEE Code of Ethics." (2020), [Online]. Available: https://www.ieee.org/about/corporate/governance/p7-8.html.

[8] ACM. "Software Engineering Code of Ethics." (1997), [Online]. Available: https://ethics.acm.org/code-of-ethics/software-engineering-code/.

[9] ISO. "ISO Standard 83545." (2023), [Online]. Available: https://www.iso.org/standard/83545.html.

[10] IEEE. "IEEE NESC Standards." (2025), [Online]. Available: https://standards.ieee.org/products-programs/nesc/.

[11] GlobalSpec. "Standard 34502." (2022), [Online]. Available: https://standards.globalspec.com/std/14572778/34502.