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Automated Guided Vehicle with Swarm Robotics

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Abstract
This research outlines the creation and execution of an Automated Guided Vehicle (AGV) system aimed at improving cold chain logistics within small and medium-sized dairy enterprises in rural Tamilnadu. The AGV system is structured in a master-slave configuration, wherein a manually operated master AGV directs several autonomous slave AGVs to effectively transport dairy products from production facilities to cold storage units. By applying principles of swarm robotics, the system reduces the need for manual labor, enhances inventory management, and guarantees accurate deliveries, all while lowering operational expenses. The AGV is outfitted with sophisticated navigation features, allowing for safe operation in dynamic warehouse settings and the ability to circumvent obstacles. Empirical testing has revealed notable advancements in efficiency, cost savings, and the reliability of the cold chain. This study elaborates on the design, implementation, and trans-formative effects of the AGV system on dairy supply chain logistics.
Keywords: *Automated Guided Vehicle (AGV), Swarm Robotics, Cold Chain, Dairy Industry, Master-Slave Configuration.*

1. Introduction
The growing need for efficient logistics in the dairy sector, especially in rural Tamil Nadu, poses a major challenge in cold chain management. Small and medium dairy industries find it difficult to rely on manual transportation of dairy products, which leads to inefficiencies, increased operating costs and possible quality degradation. Ensuring timely, accurate delivery from production units to cold storage is important to maintain the freshness and minimum loss of products.To cope with these challenges, the implementation of automatically oriented vehicle (AGV) has become a promising solution. AGVs can automate the transportation process, reducing dependence on manual labor while improving efficiency and reliability. This research focuses on the design and development of an AGV system that uses swarm robotics in a master-slave configuration. In this system, a manually controlled master AGV coordinates multiple autonomous slave AGVs, ensuring seamless and optimized movement of dairy products. A key advantage of the system is its ability to safely and efficiently navigate dynamic warehouse environments. Equipped with obstacle detection and real-time route optimization, AGVs can operate autonomously, minimizing transport delays and reducing human intervention. This also helps maintain hygiene standards by limiting direct contact with dairy products during transport. This paper discusses the concept, implementation and impact of the AGV system on cold chain logistics in the dairy industry. The system has been successfully tested in a real-world environment, demonstrating its potential to improve supply chain efficiency, reduce operating costs and increase overall productivity. The project aims to revolutionize refrigerated transportation through automation and provide a scalable, cost-effective solution for the dairy industry in rural areas. [1-4]

2. Problem Statement
Cold chain logistics plays a vital role in maintaining

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the quality of dairy products, but small and medium dairy industries in rural Tamil Nadu face major challenges in ensuring efficient transportation. Currently, the process of transporting dairy products from production units to cold storage is largely based on manual labor, which is time-consuming, labor-intensive and delayed. These inefficiencies result in increased operating costs, product losses, and overall reduced productivity.The lack of an automated milk transportation system not only reduces efficiency, but also impacts inventory management and supply chain reliability. Additionally, cold storage environments require precise and timely handling of perishable goods to maintain optimal freshness and quality. The existing manual approach struggles to meet these demands, highlighting the need for a more streamlined and cost-effective solution. To address these issues, this study proposes to develop an automated guided vehicle (AGV) system using swarm robots. The AGV system will be in a master-servicing configuration, where a manually controlled master AGV will coordinate multiple autonomous slave AGV to efficiently transport dairy products. By integrating advanced navigation and obstacle detection, the system will ensure seamless operation in dynamic warehouse environments. The proposed AGV system aims to reduce manual labor, increase cold chain efficiency, and reduce costs, ultimately improving dairy logistics in rural Tamil Nadu. The solution aims to optimize transportation, maintain hygiene standards, and create a scalable and reliable cold storage management system through automation. (Figure 1)

3. Methodology

Our project focused on developing an automated guided vehicle (AGV) system using two robots operating in a master-servant configuration. The master robot is responsible for obstacle detection and decision-making, while the slave robots execute the master robot's commands. These robots communicate wireless using radio frequency modules and integrate various sensors to ensure effective real-time navigation and obstacle avoidance.The power system consists of a 12V lead-acid battery to provide the necessary power for the electronic components. The voltage regulator provides a stable voltage level for the Arduino Uno, sensors, and motor drivers. This setup ensures reliable operation while maintaining energy efficiency.

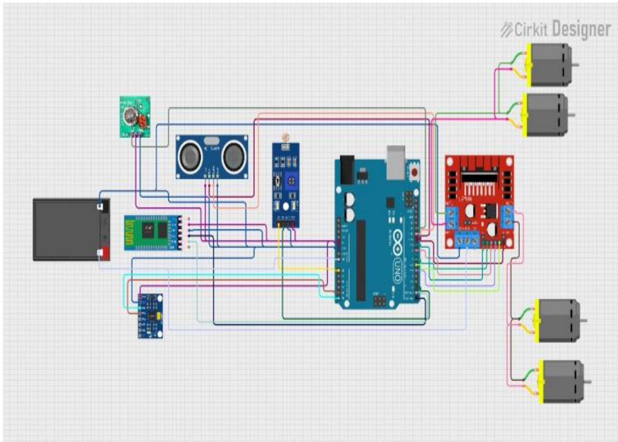

Figure 1 **Master Robot Configuration**

Each robot treatment unit is Arduino Uno, which is responsible for the sensor entrance processing and engine control. The RF module is used for wireless communication between host robot and robot, thus realizing real -time coordination between them. The master robot processes data from its sensors and sends movement commands to the slave robots accordingly. For movement, the robot uses L298N motor drivers to control the wheels to ensure smooth movement. The engine receives a control signal from Arduino Uno to provide accurate real -time data navigation and direction based on sensor -based real -time data. Several sensors are integrated into the system to achieve effective navigation and obstacles. The IMU (Inertial Measurement Unit) helps maintain balance and stability during movement. Infrared sensors detect the predefined path, while ultrasonic sensors identify surrounding obstacles. These sensors work together to ensure precise, collision-free movement. Software development involves programming the master robot to read sensor data, process motion logic, and send commands to slave robots. The slave robot is programmed to receive these commands and perform the corresponding movements. Testing and troubleshooting are performed to ensure smooth communication and responsiveness between the

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robots. The implementation and test phase includes assembly of hardware components, calibration sensors and motor control features. Navigation tests ensure that robots can identify obstacles and adjust their paths accordingly. (Figure 2)

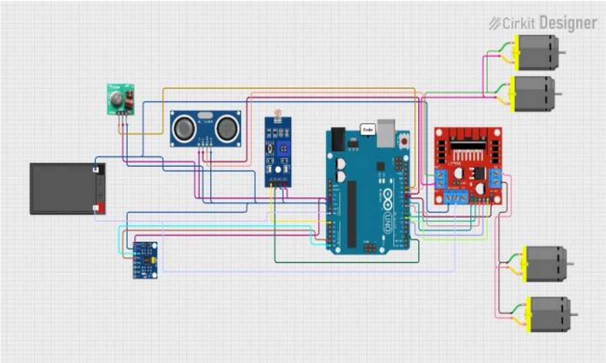

Figure 2 Slave Robot Configuration

Perform RF communication tests to verify the reliability of data transmission between the master and slave robots.To optimize performance, we fine-tuned the sensor sensitivity and improved the obstacle detection algorithm. All problems related to engine control or RF communication will improve the efficiency of the system. Future enhancement function can include high -level road plans, laser radar integration and real -time cloud monitoring to better adapt to a dynamic environment. In conclusion, this master-slave AGV system provides an effective solution for automated material handling in warehouses and other industrial environments. By integrating Arduino, RF modules and various sensors, the system provides reliable and precise movements, improving operational efficiency in industrial automation. [5]

3.1. Battery

A durable 12V, 7Ah lead-acid battery powers the AGV system, ensuring reliable and continuous operation. To meet the power requirements of various electronic components, a voltage regulator or buck converter is integrated, which steps down the voltage as needed. The battery provides stable energy for Arduino, RF module, L298N engine drive, IMU, ultrasonic sensor, has a sensor and other necessary electronic devices to ensure continuous navigation, obstacle detection and material transport. 7AH capacity supports expansion, while maintaining efficiency, making the AGV system a profitable and reliable solution for the production of milk milk processing chain milk. [6]

3.2. RF Module

Reliable RF transceiver modules enable seamless wireless communication between the master and slave AGV in the system. The RF module operates at [specified frequency, such as 433MHz] to ensure stable long-distance connection and achieve effective coordination. The master AGV sends control signals to the slave AGV, allowing them to move synchronously and respond to environmental changes in real time. This module plays a vital role in executing commands such as obstacle avoidance, motion control, and task completion without direct human intervention. By providing low latency and interference-resistant communication, RF modules improve the efficiency, responsiveness, and reliability of AGV systems, making them an essential component of swarm-based automation in cold chain logistics.

3.3. HC-05 Bluetooth Module

The HC-05 Bluetooth module is integrated for short-range wireless communication, allowing external devices to interact with the AGV system. The module operates in the 2.4 GHz ISM band and supports both Master and Slave modes, providing flexible pairing with controllers or monitoring systems. It has a range of up to 10 meters and provides a secure 128-bit encrypted connection for transmitting control commands and status updates. Low power consumption, built-in error handling and stable data transmission make it an effective choice for AGV remote control and monitoring applications.

3.4. L298N Motor Driver

The L298N motor driver controls 12V DC motors in AGV systems, providing smooth, precise motion. It operates in the range of 5V to 35V and can handle up to 2A per charge. channel. Integrated with Arduino Uno, it uses PWM control for speed regulation and H-Bridge functionality for bidirectional movement. The Enable and Input pins manage motor speed and direction, allowing forward, reverse, and turning actions. A built-in heat sink ensures stable operation, while flyback diodes protect against voltage spikes. This module improves AGV maneuverability and enables efficient warehouse navigation and automated cold chain logistics in the dairy industry. [7]

3.5. 30 RPM 12V DC Gear Motor

AGV movement requires a 30rpm 12V DC gear motor that provides high torque and controlled speed for precise navigation. Operating at 12V, it delivers 30 RPM (revolutions per minute) for smooth and stable movement. The speed reduction mechanism increases torque, making it ideal for moving loads in storage conditions. It is integrated with the L298N motor driver and Arduino Uno, allowing PWM-based speed control and bi-directional rotation. The metal gearbox increases durability and ensures efficiency with low energy consumption. This motor is essential for AGV stability, smooth operation and efficient automation of cold chain logistics [8]

3.6. Ultrasonic Sensor

Ultrasonic sensors are key components of AGV systems that allow them to detect obstacles and avoid collisions. It works by emitting high-frequency sound waves and measuring how long it takes for the echo to return, thereby calculating the distance to nearby objects. Integrated with Arduino Uno, it helps AGVs navigate safely by detecting obstacles in real time. The detection range of this sensor is 2cm to 400cm with high accuracy. Its low power consumption, fast response time and reliability make it ideal for autonomous navigation, ensuring smooth movement and preventing collisions in cold chain logistics warehouse environments. (Figure 3)

4. Design

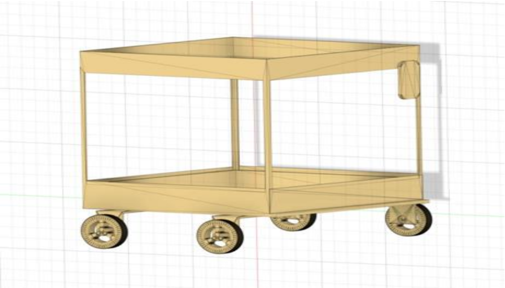

Figure 3 Isometric View

4.1. Structural Framework

The warehouse transport machine has a sturdy and compact frame that ensures durability and effective mobility. Its rectangular design optimizes warehouse operations, allowing it to transport multiple items without compromising stability. The two-tier shelving system provides ample storage, and raised side panels prevent items from slipping during movement. Additionally, the lower enclosed compartment securely houses critical electronic components, such as the Arduino Uno, RF module, IMU sensor, ultrasonic and IR sensors, protecting them from dust and accidental impact. (Figure 4)

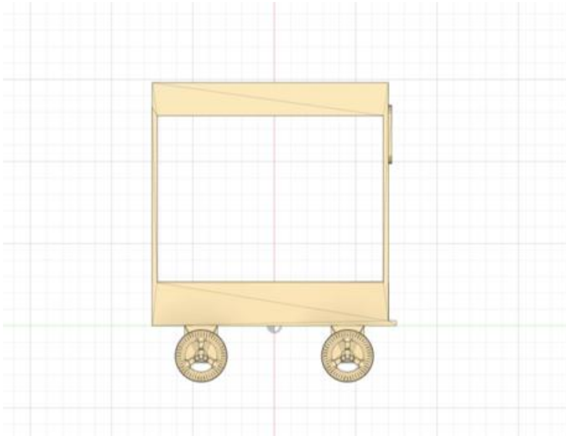

Figure 4 Side View

4.2. Mobility and Navigation

The robot has a four-wheel system designed to ensure that this is true even if the carrier is reloaded. The combination of fixed and rotary wheels can enhance operability and make it easy to navigate the warehouse environment. If necessary, the basic suspension system can be integrated to effectively treat unbalanced surfaces. Infrared sensors detect the predefined path, while ultrasonic sensors identify surrounding obstacles. These sensors work together to ensure precise, collision-free movement. Software development involves programming the master robot to read sensor dataThe robot uses IMU sensors for a stable movement, while ultrasound and infrared sensors contribute to the detection of obstacles and the compliance functions of the STIs, ensuring a semi -autonomous or complete autonomous navigation. [9]

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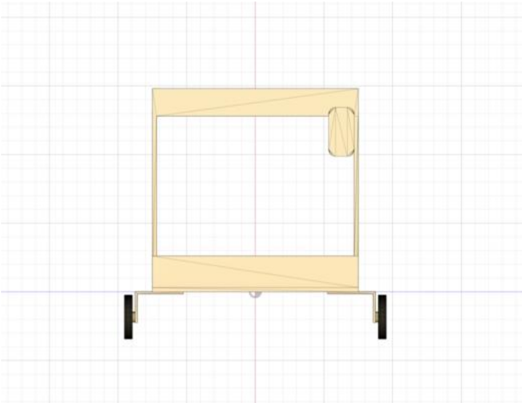

Figure 5 Front View

4.3. Storage and Compartments

The robot incorporates a two-level storage system that allows multiple items to be transported simultaneously. The open design ensures fast loading and unloading, reducing operational downtime. The upper part has a slightly raised edge to prevent the sport from slipping during exercise. The enclosed bottom area houses critical electronic components such as the motor drive, battery and sensors, protecting them from dust and accidental impacts. (Figure 6) [10]

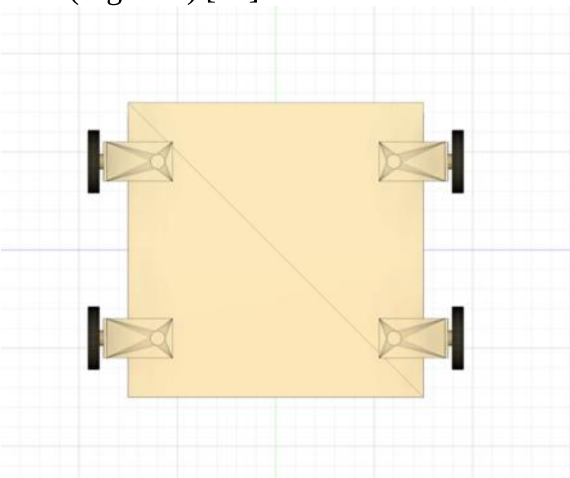

Figure 6 Bottom View

4.4. Safety and Ergonomics

Designed with a low center of gravity, the robot remains stable even with heavy loads, reducing the risk of tipping over. Includes a manual override handle to allow workers to manually move the robot when needed. Additionally, the protective housing ensures that essential electronic components remain shielded from environmental factors such as dust and impact, increasing the robot's durability and lifespan.

Conclusion and Results

The development of the automated guided vehicle (AGV) for storage transport successfully integrates robust mechanical design, autonomous navigation and efficient material handling functions. The AGV's structural framework and mobility system designed using SolidWorks ensures stability, durability and trouble-free transport of goods within a warehouse environment. The two-tier storage system enhances payload capacity, while the compact and robust design allows smooth navigation through warehouse aisles.The AGV is fully integrated with an RF-based master-slave communication system, enabling coordinated movement between multiple robots. IMU, ultrasonic and infrared sensors provide real-time obstacle detection to ensure safe navigation. Using an Arduino uno and an l298n motor driver allows for precise motor control, while a 12v lead acid battery and voltage regulator provide a reliable power source for uninterrupted operation. The implementation of autonomous navigation principles enables AGVs to effectively detect obstacles, optimize routes and transport materials without manual intervention. By utilizing the principles of swarm robotics, AGVs can synchronize with other robots to improve the efficiency of warehouse logistics. The project demonstrated successful material transport, improved operational efficiency, and reduced reliance on manual labor, making it a valuable asset in the modern warehouse.

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