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Adaptive AGV Navigation Using Edge-Driven in Small-Scale Industries

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ABSTRACT

The Adaptive AGV Navigation System is a smart material handling solution designed to automate and optimize operations in small-scale industries. It employs a **PIC16F877A microcontroller** to control and coordinate various components of the Automated Guided Vehicle (AGV), including **DC motors**, **IR sensors**, and **RFID-based modular instruction cards**. These instruction cards, read by an **EM-18 RFID reader**, provide real-time task and navigation commands, allowing the AGV to adapt its path dynamically based on operational needs.To ensure accurate control and responsiveness, the system integrates **edge computing modules**, which locally process sensor data and navigation instructions, significantly reducing latency. The AGV structure is supported by a durable **robot chassis**, powered by a **5V battery supply**, The hardware configuration, supported by modular and reprogrammable components like the **motor driver module**, allows easy system expansion and reconfiguration without extensive rewiring or infrastructure changes. This makes the solution ideal for flexible production lines, warehouse logistics, and assemblyautomation in small to medium-sized enterprises. By combining intelligent navigation, modular design, and real-time edge processing, this system offers a cost-effective and scalable AGV platform that enhances productivity, reduces manual labor, and supports the transition toward smart industrial automation.

I . INTRODUCTION

Automation and efficient material handling are essential in today’s small-scale industrial environments, where adaptability, cost-efficiency, and operational flexibility limits scalability and incurs high setup costs. To overcome these challenges, the **Adaptive**

In the context of AGVs, edge devices can perform critical tasks such as path planning, **AGV Navigation System** offers a smart, modular solution designed to provide **real-time navigation and task flexibility** for industrial automation.

The system utilizes a **PIC16F877A microcontroller** to control the AGV’s movement, sensor integration, and task execution. Modular **RFID instruction cards** are placed at strategic points in the working environment and read by an **EM-18 RFID reader** mounted on the AGV. These cards dynamically communicate navigation and operation instructions to the AGV, enabling **on-the-fly route adjustments** without reprogramming the entire system. Additionally, **IR sensors** support obstacle detection and path correction, enhancing navigation safety and efficiency.

II . LITERATURE SURVEY

Evolution of AGV Navigation Systems rely on centralized control mechanisms, fixed pathways such as magnetic strips or QR codes, and predefined route maps. These systems, while robust in large-scale environments, lack adaptability and are cost-prohibitive for SSIs. Modern advancements have introduced vision-based, LiDAR-assisted, and simultaneous localization and mapping (SLAM) techniques to enhance AGV autonomy. However, these systems often require significant computational resources,factor in resource-constrained environments.

Need for Flexibility in Small-Scale Industries, SSIs are characterized by frequent layout changes, mixed production batches, and the need for human-machine collaboration. The lack of IT expertise in many small setups further necessitates intuitive and low-maintenance solutions.

Edge computing has emerged as a transformative paradigm, enabling data processing closer to the source reducing latency and dependency on cloud .

Modular instruction cards (MICs) represent a novel approach to decentralized AGV guidance. When paired with on-device computer vision systems, AGVs can interpret these instructions locally, enabling plug-and-play path modification. MICs offer an intuitive interface for non-technical operators to modify AGV behavior on the fly, enhancing user autonomy and operational flexibility.

III . METHODOLOGY

The Adaptive AGV Navigation System was developed through a structured hardware-software integration process, with a focus on modularity, real-time responsiveness, and flexibility suitable for small-scale industries. The core of the system revolves around the PIC16F877A microcontroller, chosen for its efficient peripheral interfacing and ease of programming. The microcontroller coordinates the primary components of the AGV, including IR sensors, DC motors, and the RFID reader. The mechanical body of the AGV was constructed using a durable robot chassis powered by a 5V battery supply, ensuring stability and energy efficiency during operation.

To enable intelligent navigation, the AGV employs an RFID-based modular instruction system. EM-18 RFID readers mounted on the AGV scan pre-positioned RFID cards that contain task and navigation instructions. These inputs are processed by the microcontroller, allowing the vehicle to make real-time decisions on movement and task execution without manual intervention. IR sensors placed strategically around the vehicle provide environmental feedback for obstacle detection, which is also processed response latency and enhances the system's adaptability to dynamic industrial settings.

Motor control is achieved using an L293D motor driver module, which interfaces the DC motors with the microcontroller. Motion algorithms are implemented in embedded C to convert sensor and RFID inputs into specific movement commands. A 16x2 LCD is incorporated to provide visual status updates, including task.

IV . EXISTING SYSTEM

Navigation systems in existing AGVs are largely rule-based or deterministic, lacking cognitive capabilities to interpret varying task priorities or dynamic obstructions. Additionally, task execution in traditional AGVs is hardcoded or manually configured, making it difficult to modify or scale operations without reprogramming the entire system.

The AGV is designed to operate autonomously by reading task-specific instructions from RFID cards placed along its path. This approach enables dynamic task assignment and path redirection without the need for altering the physical layout, making the system highly adaptable to different workflows or layout changes.

PLCs, yet many still lack distributed intelligence and real-time adaptability,

Overall, the proposed AGV system enables flexible, intelligent, and real-time material handling operations suitable for dynamic production environments. Its edge-computing capabilities, RFID-based task management, and modular design combine to deliver an efficient, low-cost automation platform that supports the ongoing shift toward Industry 4.0 in small to medium-scale industrial sectors. Moreover, the integration of sensors and control hardware in existing solutions is often rigid, with non-modular architectures that do not support quick component replacement, plug-and-play upgrades, or on-the-go reprogramming. These shortcomings limit the applicability of conventional AGVs in SME environments that demand flexibility, modularity, and cost-effectiveness.

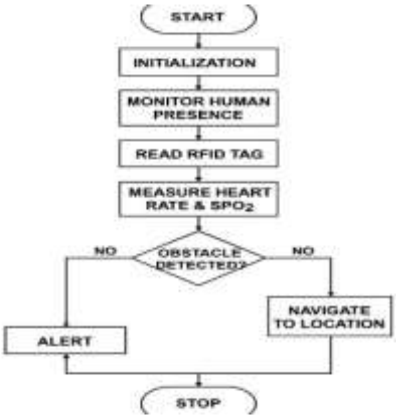

Fig 1. Flowchart of Existing AGV Model

Early AGV systems were primarily centralized in nature, with a central control unit handling path planning, obstacle avoidance, and task scheduling. . Modern implementations have partially addressed this by using onboard microcontrollers processing navigation data locally, reducing dependency on external servers.This system is particularly beneficial for warehousing, manufacturing, and e-commerce fulfilment centres, offering scalability, low maintenance, and easy integration with existing warehouse management systems (WMS) or IoT platforms. Overall, the Adaptive AGV Navigation System provides a future-proof, infrastructure-independent, and economically viable automation solution for SMEs looking to optimize material handling without high upfront investments.The overall design undergoes phase-wise testing and calibration, ensuring that each subsystem—from motor control and sensor response to RFID recognition and path execution—performs reliably under real-world industrial conditions.

V. PROPOSED SYSTEM

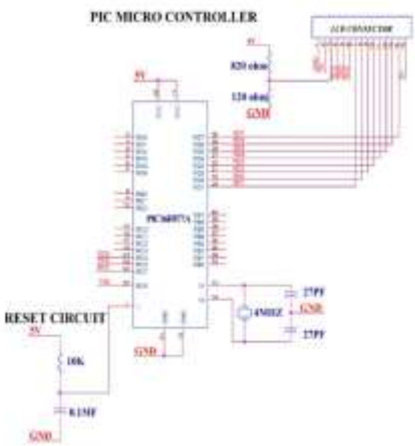

Fig 2. Circuit Diagram for Proposed AGV Model

The Proposed Adaptive AGV Navigation System is a cost-effective, intelligent, and flexible material handling solution designed for small and medium-sized enterprises (SMEs), overcoming the limitations of traditional AGV systems that rely on fixed navigation infrastructure like magnetic tracks or laser reflectors. Instead, this system leverages a PIC16F877A microcontroller-based architecture for efficient control, integrating RFID-based modular instruction cards for dynamic path guidance, IR sensors for real-time obstacle detection and collision avoidance, and edge computing modules for decentralized, low-latency decision-making. By eliminating the need for expensive permanent tracks or reflectors, the system reduces setup costs by approximately 70% compared to conventional AGVs, making automation accessible to SMEs.

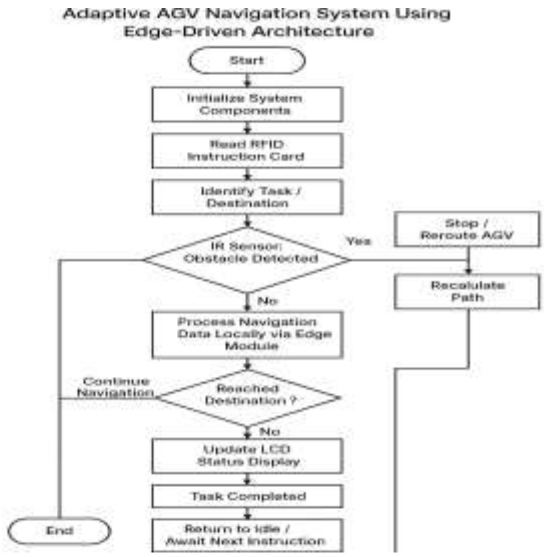

Fig 3.Flowchart of Proposed System

Its reprogrammable navigation allows quick adaptation to changing warehouse layouts without physical reconfiguration, while IR sensors ensure safe operation in dynamic environments. Additionally, the use of edge computing enhances responsiveness by path-planning logic with sensor fusion, prioritizing shortest-path navigation while accounting for real-time obstacles. Testing and calibration are conducted in phases—first in a controlled lab environment to validate RFID navigation and obstacle avoidance, followed by real-world deployment in SME warehouses to assess scalability and robustness. By combining low-cost embedded hardware, modular RFID waypoints, and edge-based autonomy, this implementation delivers a plug-and-play AGV solution that SMEs can deploy with minimal infrastructure changes, ensuring affordability, adaptability, and reliability in dynamic material handling scenarios.

VI. IMPLEMENTATION

The implementation of the proposed Adaptive AGV Navigation System involves a hardware-software co-design approach to ensure seamless functionality in real-world industrial environments. The PIC16F877A microcontroller serves as the central processing unit, interfacing with RFID readers mounted on the AGV to scan modular instruction cards embedded along the navigation path, enabling dynamic route adjustments without fixed tracks. IR sensors are strategically placed around the AGV's perimeter for obstacle detection, feeding real-time data to the microcontroller, which triggers adaptive rerouting or emergency stops when obstructions are detected. For localized decision-making, an edge computing module processes sensor and RFID data onboard, minimizing latency and eliminating reliance on cloud-based systems.

The AGV's DC motors are controlled via an H-bridge driver, ensuring precise movement based on microcontroller-generated PWM signals, while a wireless communication module (such as Zigbee or Wi-Fi) allows fleet coordination and remote monitoring. The system's software algorithm integrates

In summary, the proposed system presents a robust, intelligent, and modular AGV solution that significantly reduces infrastructure and maintenance costs. Its combination of RFID-driven flexibility, IR-based obstacle awareness, edge-based path planning, and reprogrammable navigation makes it exceptionally suited for small-scale industries transitioning toward Industry 4.0. By addressing key limitations of traditional AGVs, this system not only improves automation efficiency but also democratizes access to intelligent intralogistics solutions.cost-effective, deploying intelligent AGVs in smaller setups will be more feasible. Overall, these enhancements will make AGVs more adaptive, scalable, and cost-efficient.

VII. FUTURE ENHANCEMENT

In the future, adaptive AGV (Automated Guided Vehicle) navigation using edge-driven technology can be significantly enhanced to meet the evolving demands of small-scale industries. One key enhancement involves integrating advanced AI-based decision-making systems to enable real-time obstacle avoidance and dynamic path optimization. The use of 5G and IoT can facilitate faster communication between AGVs and edge devices, improving responsiveness and coordination. Additionally, incorporating machine learning can allow AGVs to learn from past navigation patterns, enhancing efficiency over time.

Edge-driven systems can also support predictive maintenance by analyzing operational data locally to reduce downtime. Furthermore, seamless integration with warehouse management.

VIII. PROJECT OUTCOME

Fig 4 . Prototype of Proposed AGV Model

The implementation of the Adaptive AGV Navigation System has demonstrated significant improvements in the flexibility, cost-efficiency, and operational performance of automated material handling in small-scale industrial environments. By replacing solution economically viable for small-scale industries, conventional fixed-path navigation methods with a modular RFID instruction card system, the AGV exhibited the ability to dynamically alter its route based on real-time environmental inputs and task requirements.

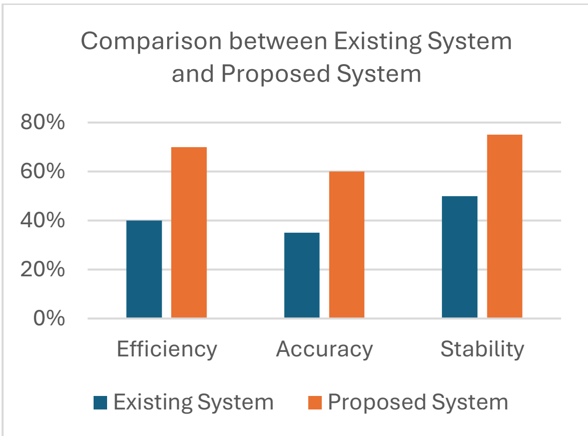

Fig 5 . Existing system vs Proposed system

Key hardware components—including the PIC16F877A microcontroller, EM-18 RFID reader, IR sensors, and DC motors—were integrated seamlessly through a well-structured control architecture. The incorporation of edge computing devices, such as the Raspberry Pi or ESP32, enabled on-device data processing, reducing latency and improving the system's response time to sensor inputs.

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