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Auto Stock Rover: AI-Powered Stock Movement Automation for Smart Warehousing

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ABSTRACT

AutoStock Rover is an autonomous robotic system designed for efficient stock movement in warehouses. It integrates IoT, rule-based control, and AI-assisted decision-making for improved performance. The ESP8266 enables wireless communication through a web-based interface. Infrared and ultrasonic sensors support navigation and obstacle avoidance.

The rover includes a lifting mechanism for automatic pickup and delivery of items. The system mainly operates on predefined rules, with AI assisting in workflow optimization. Experimental results show accurate navigation and reliable communication. The robot successfully performs material handling tasks with minimal errors. This system reduces operational time and human effort. It is scalable and suitable for advanced warehouse automation applications.

***Keywords* - Autonomous Mobile Robot, ESP8266, IoT, Smart Logistics, Warehouse Automation**

I. INTRODUCTION

In the last few years, due to the rising trend of online retailing, manufacturing, and supply chain logistics, there has been an immense need for effective warehouse management. Conventional approaches to managing warehouses include manual labor and semi-automation for material handling. This approach causes inefficiencies in terms of cost, processing times, and errors. Furthermore, regular handling of products by hand puts employees at risk of injury and fatigue. These issues call for automation technology that enhances the efficiency and accuracy of the process while reducing the potential for human error.

Automating warehouse processes has become increasingly

Internet of Things (IoT), robotics, and big data. Automated guided vehicles (AGVs) have been adopted for performing repetitive tasks, including transporting goods, picking orders, and moving inventory. However, most of the available solutions are path-dependent and require significant investment in infrastructure, making them unsuitable for small and mid-scale warehouses.

AutoStock Rover is an autonomous robot that has been developed for performing various stock movement operations based on the use of both rule-based control and artificial intelligence decision-making. The use of IoT technologies for establishing a wireless connection makes it possible for a person to interact with the rover via a website interface, giving commands for tasks, such as picking up objects from one location and bringing them to another.

To ensure the safety of its operations and their efficient performance, the proposed system has infrared sensors for following lines in the warehouse and ultrasonic sensors that help identify obstacles. In addition, the presence of the lifting tool enables the machine to perform pick-up and placing operations, thus allowing material transport automation. The functionality of the system is realized according to predefined rules and conditions. Moreover, artificial intelligence is used to facilitate decision-making.

As compared to conventional systems, AutoStock Rover has numerous advantages, among which cost-effectiveness and scalability must be highlighted. Thus, it is more beneficial than the existing robots due to fewer expenses associated with manual labor, reduced likelihood of errors in performing tasks, and improved productivity. At the same time, it fully meets all requirements characteristic of Industry 4.0.

The rest of this paper is structured as follows: In Section II, we look at the problem statement, Section III deals with the objectives, Section IV focuses on the system architecture, Section V talks about the methodology, Section VI contains the results, and Section VII is the conclusion with future scope.

II. LITERATURE REVIEW

Modern research has shifted towards using robotics, IoT, and intelligent systems in warehouse automation and logistics services. However, the traditional methods involved the usage of either manual labor or automated procedures that were not flexible and adaptable. The shortcomings prompted the need for developing AMR systems that could conduct operations with minimum human assistance.

The contribution made by Espressif Systems includes ESP8266, a technical feature of IoT, which allows efficient wireless communication among the involved parties. Therefore, ESP8266 allows for effective data exchange in real time between web and hardware systems. Similarly, S. B. Niku explained the basic aspects of robotics that are critical when designing autonomous robots. For instance, S. B. Niku mentioned the issues such as motion control, kinematics, and the design aspects of robotics.

In addition, the developments in robotic systems are described in the research conducted by Siciliano and Khatib that focused on the role of sensors, perception abilities, and adaptive behavior of robots. Thus, the sensors play a key role in enabling the robot to operate efficiently in various environments based on real-time data exchange among different sensors. Finally, Roy and Mukherjee developed intelligent autonomous robots that could optimize their movement in warehouse operations.

The role of IoT technology in the field of smart logistics has been widely examined by Bazzi, who explained that interconnected devices help track and coordinate the activity of warehouse facilities. Moreover, it enables better monitoring and increases decision-making process effectiveness. In addition, Chen et al. considered the use of robots in industry, proving that such technologies boost efficiency and ensure constant work in logistics and production sectors.

There is a range of important issues related to robot activities, including path planning and obstacle detection. Xu and Ma analyzed algorithms providing safe navigation in changing environments and stressing the need for sensor-based adjustment systems. Furthermore, Goldberg and Kehoe introduced the topic of cloud robotics that allows central systems to help robots with computations and coordination tasks.

Nowadays, there is an evident trend of combining IoT, AI, and automation technology to create

intelligent logistic systems. Zhang et al. investigated future trends in automated warehouses and considered aspects of intelligent decision making and integration. In addition, Mathew and Jose researched the topic of integrating AI and IoT technologies and showed their effect on warehouse efficiency.

III.METHODOLOGY AND SYSTEM ARCHITECTURE

AutoStock Rover is an AI-driven automated stock movement system that integrates the use of rule-based control, AI-based supervision, and Internet-of-Things (IoT)-based communication techniques to achieve the objectives of a warehouse automation system. It converts users' task input requests into well-defined movements of the robot.

AutoStock Rover receives inputs from the user using a web-based application. This input comprises the requirements that need to be fulfilled by the rover for completing the assigned tasks. For example, the task inputs can comprise information like location of pickup, location of delivery, task conditions, and constraints. Task input can thus be represented as:

$$U = \{Lp, Ld, C, T\}$$

Where U is a set of task inputs, Lp is the location of pickup, Ld is the location of delivery, C is task conditions or constraints, and T is the time to execute the task. On the basis of these inputs, AutoStock Rover generates an action set through a rule-based decision function:

$$A = f(U)$$

This action set is then followed to accomplish the assigned task and comprises steps such as:

$$A = \{a1, a2, a3, \ldots, an\}$$

The heart of the system is the ESP8266 microcontroller that serves as a CPU for all communication, processing of sensor data, and controlling actuators. The microcontroller receives orders from the web interface through Wi-Fi connection and processes real-time feedback from sensors in order to provide reliable task completion. Pre-defined algorithms and conditions serve as guidelines for rovers operation, thus allowing predictable results for any situation.

The navigation system employs infrared (IR) sensors for following the pre-defined path and ultrasonic sensors for detecting objects and avoiding collisions. While following the line, the IR sensors provide real-time information to the microcontroller about deviation from the path. Obstacles detected by the ultrasonic sensors result in stopping or changing the route.

For the purpose of automatic picking up and delivering of the items, a special lifting device is installed in the robot's construction. The lifting device detects pre-defined conditions in both pick-up and deliver places where the item should be located and delivered to correspondingly. Once it arrives at one of these places, the item is either lifted or put down.

The AI guidance is included at a supervisory level, where its use helps improve system performance without compromising the performance of the rule-based control systems. In addition, it plays a crucial role in optimizing task sequencing and coordinating between tasks. This system's performance can be measured using metrics like task completion and task execution efficiency. Assuming that P stands for system performance metrics, then the action flow will be updated as follows:

$$A\_updated = f(U, P)$$

It enables small changes to the task execution process without interfering with the stability of the whole system.

The current system operates on a scalable web-based architecture. At the front-end side, it involves user interaction through assigning tasks to the rovers and monitoring the activities. On the other hand, the back-end part involves controlling and communicating tasks with hardware.

Overall, the designed system can be used as a cost-effective and scalable warehouse robot solution.

Table I below shows the main modules needed in the proposed system, along with their purposes.

Table I: Major Components of the Proposed System

Component	Function
User Interface	Allows users to assign tasks and monitor rover status in real-time
Control System (ESP8266)	Processes commands, sensor data, and controls overall rover operations
Navigation System	Uses IR sensors for line-following and path tracking
Motor Driver (L298N)	Controls movement of DC motors (forward, reverse, turning)
Lifting Mechanism	Performs pickup and drop operations using electromagnet/servo
Communication Module	Enables IoT-based wireless communication between rover and web system
Rule-Based Engine	Executes predefined logic and decision rules for task completion
AI Guidance Module	Assists in optimizing task flow and improving execution efficiency
Database / Backend	Stores task data, system status, and execution logs

METHODOLOGY

1. Task Representation

The given task can be represented as:

$U = (Lp, Ld, T, C)$

where:

- Lp: pickup point,
- Ld: delivery point,
- T: time required for task completion, and
- C: task conditions.

2. Action Generation Function

The task is performed using a set of actions, which is defined by:

$A = f(U)$

where $A = \{a_1, a_2, \dots, a_n\}$

It includes a series of actions such as move, turn left, stop, pick up, and deliver.

Action a_i comprises:

- Motion control (forward motion, left turn, right turn),
- Stopping conditions,
- Pick up, and
- Deliver.

3. Robot Navigation Scheme

The robot follows a path marked on a paper sheet using IR sensors. The navigation scheme is given as:

- If the left sensor senses the line, then the robot will adjust its direction to the left.
- If the right sensor senses the line, then the robot will adjust its direction to the right.
- If the central sensor senses the line, then the robot will move forward in the same direction.

If none of the sensors sense the line, then the robot will stop.

4. Operation of Pickup and Drop Process

The processes of picking up and dropping occur according to predetermined positional conditions:

- At the moment when the robot approaches the location for picking up (Lp), the lifting system starts working.
- At the moment when the robot approaches the destination location (Ld), the lifting system stops operating.

Thus, automated manipulation becomes possible.

5. Principle of Work Based on Rules

Operation takes place according to the following set of rules:

$R = \{r_1, r_2, \dots, r_n\}$

Each rule reflects the following conditional actions:

- r_1: Line → Move forward
- r_2: Deviation → Change course
- r_3: Arrival at the location for picking up → Operate lifting mechanism
- r_4: Arrival at the destination location → Stop lifting mechanism

Thus, the operation of the system becomes predictable.

6. Overcoming Time Constraints

Let Ti be the time taken for action ai.

Total time taken can be calculated as follows:

$T\_total = \Sigma T_i$

In the case when:

$T\_total > T\_available$,

movement speed is increased.

7. Performance Evaluation

Performance is measured through:

P = {status, accuracy, completion time}

where:

status signifies task completion (successful/unsuccessful),

accuracy signifies successful path following, and

completion time measures total time taken.

8. AI-Controlled Optimization

Though the system works mainly on rule-based control, AI control is included at the supervisory level to improve efficiency:

$A\_new = f(U, P)$

where performance factors P are applied to optimize task performance.

9. Algorithm for Task Execution

Algorithm 1: Stock Movement Execution

Input: Task U

Output: Task completion

1. Initiate the system
2. Take task input through the web interface
3. Form action plan A
4. Commence movement with line tracking
5. Locate pick up point
6. Turn on lifting mechanism
7. Proceed with navigation
8. Locate delivery point
9. Release stock
10. Retrace path back to starting point
11. Report task completion

SYSTEM ARCHITECTURE

The architecture of the AutoStock Rover is developed in such a way as to make the interaction between web interfaces and robot easy by using IoT communications. It contains several interlinked modules used to automate stock movement.

The main system workflow starts with supplying it with electricity. Then, its control is carried out via the web interface, where users can allocate different tasks, like picking up goods or delivering them.

Data from the web interface is transferred to the ESP8266 controller, which serves as the brain of the system. It accepts the commands, runs the rule-based algorithm, and regulates operations of all hardware modules.

Interaction takes place with two main subsystems of the robot:

1.Navigation Subsystem

In this case, we have to do with IR sensors, which allow detecting the predefined line path. According to their signal:

- Robot follows the path
- Turns when a deviation occurs

Thus, an effective navigation inside a warehouse is possible.

2.Motion Control Subsystem

Motion is regulated through the L298N motor driver, which accepts the signals from the ESP8266 module and controls the DC motors.

- It enables movement in any required direction:
- Forward, backward

3. Lifting Mechanism

The architecture incorporates an electromagnet-enabled lifting device which is managed by the microcontroller.

- Switches on for pickup point to enable lifting of objects
- Switches off for delivery point to drop objects

This ensures automated picking and placement without any manual involvement.

4. Feedback System

Once the action is completed, the rover provides feedback to

the web interface.

- Status of Task Completion
- Status of Execution

This facilitates instant observation and management.

5. Flow of Data

The data flow in the system is as follows:

Power Supply → Web Interface → ESP8266 Microcontroller → (IR Sensors + Motor Driver) → Movement → Lifting via Electromagnet → Feedback of Status → Web Interface

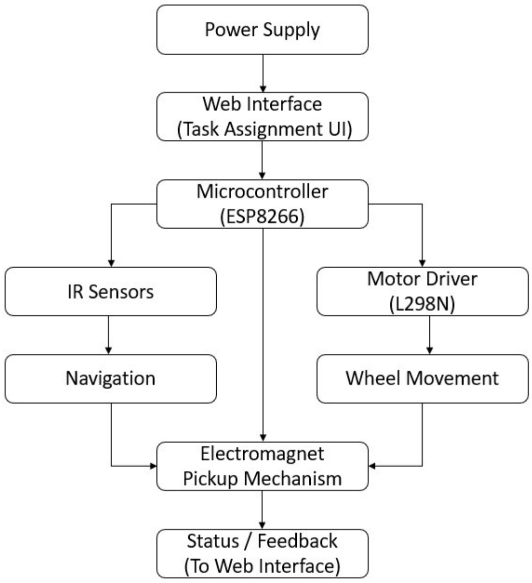

Fig. 1. System Architecture

IV. RESULTS AND DISCUSSION

The AutoStock Rover was developed and implemented to conduct automated stock movements within an enclosed space resembling the environment of a warehouse. The device was capable of performing reliably by executing navigation, picking, and dropping tasks according to the parameters entered by the user. The rover was able to follow the specified route accurately through infrared sensors that enabled smooth and constant motion in straight paths and proper direction changes during turns. The rules for navigation made sure that the path is tracked properly without considerable deviations.

While conducting tests, the rover was able to pick up and drop objects as required through electromagnets. As it approached the designated position for picking up the object, the electromagnet functioned properly in picking up the item. It then released the object when the vehicle approached the designated delivery spot.

The communication process between the web interface and the rover was found to be efficient and reliable. Commands were received from the former in time to execute tasks. At the same time, status updates were relayed to the latter as well.

This particular system showed stable performance throughout the experiment, owing to its rule-based management. It proved possible for the robot to perform several task cycles in accordance with high efficiency levels without making numerous mistakes, but this system cannot be used in an unpredictable and dynamic environment because it is confined to only pre-set routes. It lacks effective obstacle management, which further decreases its usability.

Nevertheless, the introduced system represents a very efficient, affordable, and useful method of automating operations in a warehouse setting. AI-based management can contribute positively to task planning and performance, while at the same time not affecting negatively the stability of the rule-based system. As a result, it can become a prototype for future smart warehouse systems.

Fig. 2. Auto-Stock Rover.

CONCLUSION

It is possible to consider that the proposed AutoStock Rover system is an efficient method of achieving autonomous movement of stocks in warehouses based on rule-based control, IoT interaction, and AI-based monitoring. In its turn, the system can perform the basic functions required, namely, navigation, pickup, and delivery of goods. The application of IR sensors allows for accurate navigation through line following. The ESP8266 chip performs efficient communication and control through web interface.

The presence of rule-based decision makes the system predictable and suitable for the structured environment. Moreover, the electromagnet-based lift makes the system more advanced and capable of handling the material transportation processes efficiently. Finally, AI-based supervision is one of the methods that increase efficiency of the system without adding complexity.

Thus, the results show that the proposed system can save the human work and improve efficiency of warehouse management. At the same time, its functionality is rather restricted because of predefined routes, but the system is a good basis for further innovations.

In summary, the proposed system can be viewed as a step toward the development of a smart warehouse in accordance with the idea of the fourth industrial revolution, namely, Industry 4.0.

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