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REGULAR ARTICLE

Smart Factory Navigation: Sensor-Driven Access Point Selection for Automated Guided Vehicles

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In smart factory settings, ensuring the optimal navigation of Automated Guided Vehicles (AGVs) is essential for streamlining material handling operations and enhancing overall efficiency. This paper introduces a novel Sensor-Based Access Point Selection Strategy (SBAPSS) designed specifically to enhance the navigation capabilities of AGVs within smart manufacturing environments. The SBAPSS harnesses a comprehensive array of sensor data, including inputs from laser scanners, vision systems, ultrasonic sensors, and proximity sensors, to dynamically evaluate and select optimal access points for AGV navigation routes. Utilizing real-time sensor information, the SBAPSS algorithm employs sophisticated decision-making mechanisms to identify the most favorable access points based on multiple criteria. These criteria encompass factors such as obstacle detection, proximity to designated loading/unloading stations, traffic congestion, and path optimization. By integrating sensor-driven intelligence into the access point selection process, AGVs can adaptively adjust their navigation paths to circumvent obstacles, avoid collisions, and optimize travel routes in real-time. The effectiveness and reliability of the SBAPSS are demonstrated through extensive simulation studies and experimental validations conducted in representative smart factory environments. Results indicate significant improvements in AGV navigation efficiency, throughput, and safety, thereby validating the efficacy of the proposed strategy. Moreover, the SBAPSS's ability to seamlessly integrate with existing AGV control systems underscores its practical feasibility and scalability for deployment in industrial settings. This innovative sensor-driven approach represents a substantial advancement in AGV navigation methodologies, offering a robust solution tailored to the demands of modern smart manufacturing facilities. By empowering AGVs with intelligent decision-making capabilities, the SBAPSS contributes to the realization of agile, adaptive, and autonomous material handling systems in the industry 4.0 era.

Keywords: Sensor-based navigation, Access point selection, Industry 4.0, Sensor fusion Real-time decision making and Path optimization.

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1. INTRODUCTION

Automated Guided Vehicles (AGVs) represent indispensable assets in modern manufacturing facilities, revolutionizing material handling and logistics operations. However, their navigation within dynamic factory environments poses significant challenges, necessitating innovative solutions to optimize efficiency and adaptability. In this paper, we present a novel Sensor-Based Access Point Selection Strategy (SBAPSS) designed to address these challenges and enhance AGV navigation within smart factory contexts. The primary contributions of this paper are two-fold: 1. Data-Driven Learning Approach: The SBAPSS utilizes a data-driven, learning-based approach that centers on the movement behaviors of AGVs within factory environments. Typically, AGVs adhere to predefined routes, prompting the collection of Received Signal Strength Indication (RSSI) data along with AGV positions and directions. Leveraging this information, the SBAPSS analyzes time series data to identify optimal Access Points (APs) along AGV routes. This methodology marks a significant advancement as it is the inaugural instance of leveraging both AGV movement data and Received Signal Strength Indication (RSSI) measurements from Access Points (APs) to dynamically choose APs within factory premises. This departure from traditional rule-based predictions is particularly significant in environments where RSSI turbulence poses challenges to prediction accuracy. 2. Experimental Validation: The efficacy of the SBAPSS is validated through experimentation conducted in an operational factory, encompassing both indoor and outdoor spaces. Results demonstrate a remarkable 1.34 times longer Communication Link Time (CLT) compared to

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traditional RSSI-based approaches, underscoring the practical benefits of the proposed methodology.

2. LITERATURE SURVEY

In dynamic manufacturing environments, stable communication for mobile devices like AGVs is crucial amidst frequent wireless fluctuations [1-2]. Various methods exist to address this, from fixed sensors to utilizing data from moving terminals[3-4]. Our proposed approach integrates sensing devices onto AGVs to determine AP switching based on wireless environment data along the route, reducing communication interference [5-6]. Despite limitations, RSSI is widely used for assessing wireless environments, showing efficacy in detecting early-stage link degradation in AGV scenarios [7-10. Prediction techniques for future RSSI trends have also been validated [11-15].

3. SENSOR-BASED ACCESS POINT SELECTION STRATEGY (SBAPSS)

The Sensor-Based Access Point Selection Strategy (SBAPSS) methodology improves Automated Guided Vehicle (AGV) navigation in smart factories by dynamically selecting the most appropriate Access Points (APs) along AGV routes. It begins with comprehensive data collection, integrating sensor data from onboard AGV systems and wireless communication devices.

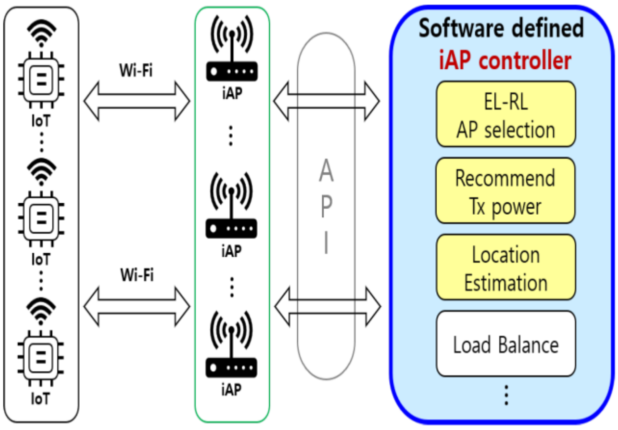

Fig. 1 – Energy Efficient AP selection using Intelligent access

ML algorithms analyze AGV movement and signal strength data to dynamically select APs, ensuring stable communication. Real-time implementation enables adaptation to changing conditions. SBAPSS enhances navigation efficiency in Industry 4.0.

3.1 Automated Guided Vehicle

Automated Guided Vehicles (AGVs) are autonomous mobile robots used for material transport in various industries. They feature onboard sensors, navigation systems, and control algorithms for precise navigation and obstacle avoidance, enhancing efficiency and safety in industrial environments.

Chassis: The base structure of the AGV that supports all other components. The three-dimensional model of the chassis is depicted in Figure 2.

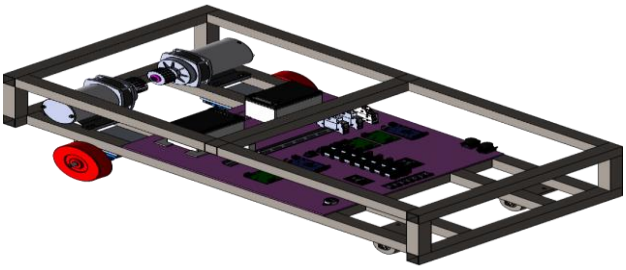

Fig. 2 – Chassis 3D model

Navigation System: Typically includes sensors, such as lasers, cameras, or magnetic tape detectors, to detect and follow paths. Figure 3 illustrates the AGV satellite navigation system.

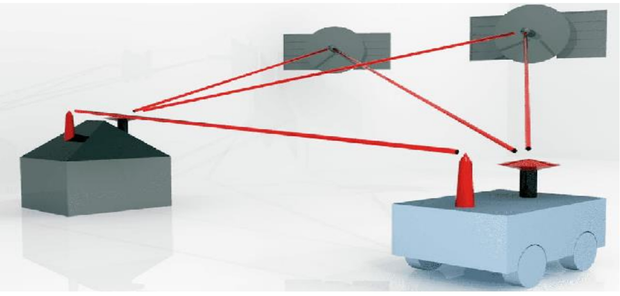

Fig. 3 – AGV Satellite navigation system

Control System: Centralized or distributed computer-based system that coordinates the AGV's movements, including route planning, obstacle avoidance, and task allocation. The control loop block diagram for the AGV is depicted in Figure 4.

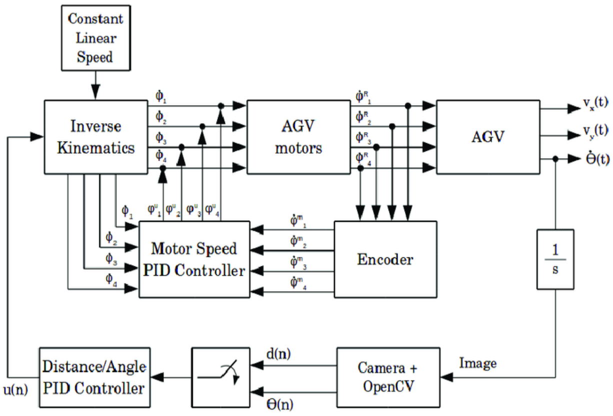

Fig. 4 – Control loop block diagram for AGV

Power Source: Battery or other power supply to provide energy for propulsion and onboard systems. The power transmission unit is illustrated in Figure 5.

Drive System: Motors, wheels, or tracks used for locomotion. The compact drive system for the AGV is depicted in Figure 6.

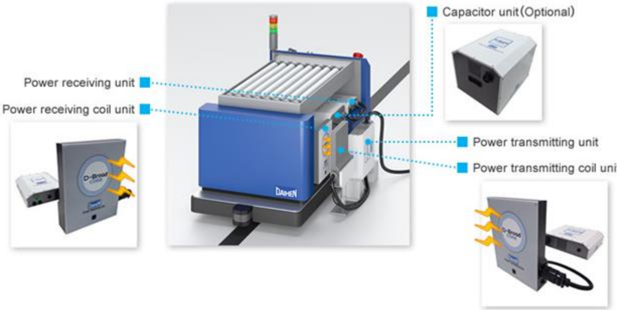

Fig 5 – Power transmission unit

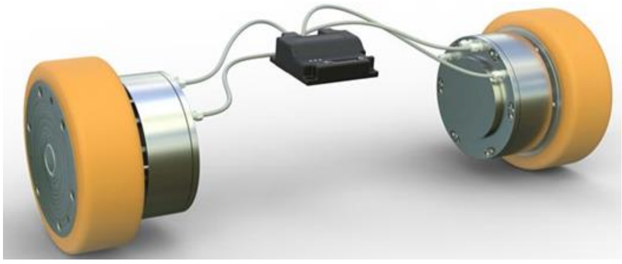

Fig. 6 – Compact drive system for AGV

Payload Handling System: Mechanisms such as forks, conveyors, or lift platforms to transport goods. Figure 7 displays the payload ground vehicle.

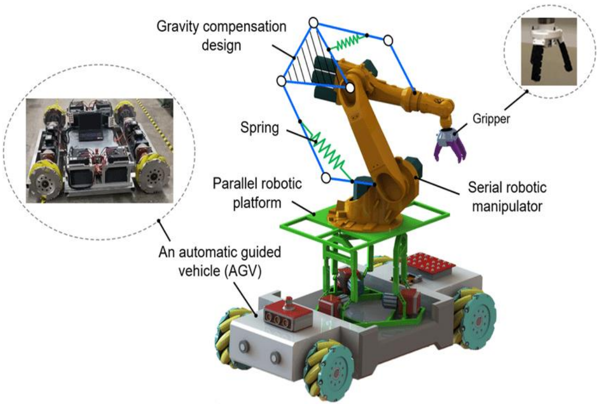

Fig. 7 – Payload ground vehicle

Safety Systems: Sensors, bumpers, and emergency stop buttons to ensure safe operation and prevent collisions with obstacles or humans. The AGVs safety system is illustrated in Figure 8.

Fig. 8 – AGVs safety system

Communication System: Allows the AGV to communicate with the central control system, other AGVs, and peripheral devices. Figure 9 presents the central control system for the AGV.

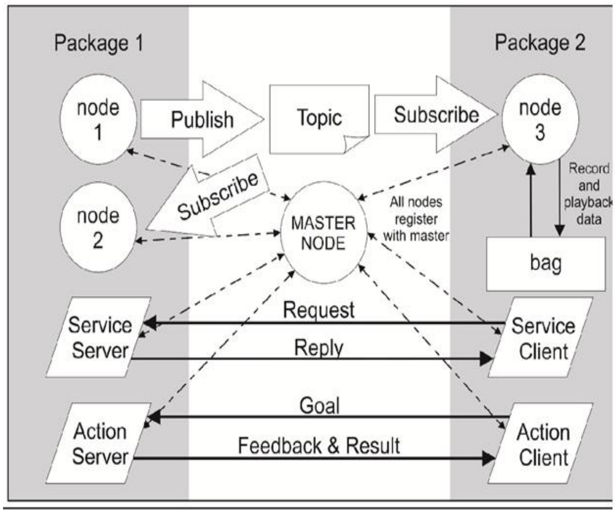

Fig. 9 – Central control system for AGV

User Interface: Displays and controls for monitoring and interacting with the AGV, including status indicators, buttons, and touchscreens.

Fig. 10 – User interface-Home page, Robot Control, vehicle station tracking and settings

Software: Programs and algorithms for route optimization, task scheduling, and system monitoring.

This is a general overview, and the specific components may vary depending on the application and manufacturer.

4. SOLUTION TECHNOLOGY

Ant Colony Optimization (ACO) is a metaheuristic algorithm inspired by ants' foraging behavior, devised by Marco Dorigo. It helps determine optimal routes for AGVs within facilities by mimicking ants' pathfinding strategies. The AGV route planning scheme generated using ACO outputs is validated through simulation, comparing performance against conventional methods. Figure 11 illustrates the shortest path identified by ACO.

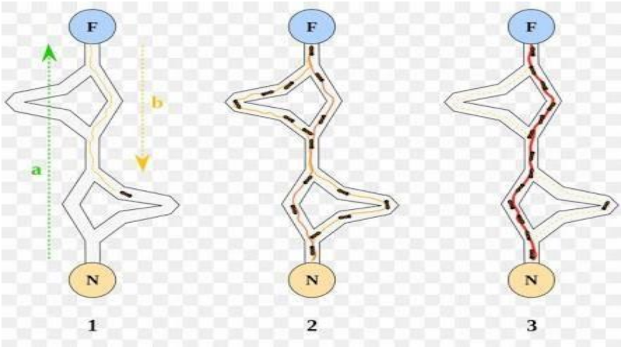

Fig. 11 – Shortest path through ACO

Procedural steps ACO:

```
AntColonyOptimization
Initialize required parameters and set initial pheromone levels.
while termination condition is not met:
  Generate a population of ants.
   Calculate fitness values for each ant based on their solutions.
   Determine the best solution using selection methods.
   Update pheromone trails based on the solutions found.
End--------------------------------------------------------------------
-while
```

let's consider a simplified task scheduling problem with 4 layouts (machines, workstations, etc.) and 10 job sets. Each job set consists of multiple tasks that need to be scheduled on these layouts.

5. EXPERIMENTAL RESULTS

Sensors on the AGV monitor deviation from the guideline by comparing readings from two specific sensors, $W1$ and $W4$. Deviation is computed as the difference between their readings, as defined by Eqn. 1.

$$\text{Deviation} = W4 - W1 \tag{1}$$

Deviation categorization into eight levels allows efficient handling, adjusting left and right motor velocities accordingly. Positive deviation indicates a leftward deviation, while negative indicates rightward. Velocity Differentiation is applied based on deviation direction: added for right deviation and subtracted for left. Resultant Velocity Difference adjusts vehicle speed using specific formulas, ensuring AGV stays on course and maintains distance from the guideline:

$$V_r = V + \text{Velocity Difference} \tag{2}$$

$$V_l = V - \text{Velocity Difference} \tag{3}$$

The formulas face two critical considerations complicating their application. Firstly, motor driver speed is limited to 127 units (ranging from 0 to 127). Any value beyond this range can lead to operational issues or even system collapse. To mitigate this. When Velocity Difference is negative, direction shifts from forward to backward, with the absolute value of Velocity Difference. Additionally, if velocity surpasses 127 mm/s, it's capped at 127 mm/s, with excess velocity balanced by reduction from the opposite side.

Table 1 – Deviation Classification and Motor Velocity Adjustment

DL	DC	MVA
Level 1	Extreme Left	Maximum Left Turn
Level 2	Severe Left	Strong Left Turn
Level 3	Moderate Left	Moderate Left Turn
Level 4	Slight Left	Slight Left Turn
Level 5	Centered	Maintain Straight
Level 6	Slight Right	Slight Right Turn
Level 7	Moderate Right	Moderate Right Turn
Level 8	Severe Right	Strong Right Turn

These adjustments are essential to control vehicle speed and correct deviations without straining the motor drivers. They enable effective navigation along both straight and curved paths. Despite challenges like initial alignment issues and curved paths, the supervisory control system continuously monitors and adjusts the vehicle's trajectory to minimize deviations. Figure 3 visually illustrates potential deviations and necessary adjustments for accurate course maintenance, crucial for precise AGV navigation.

Table 2 – Examples of Velocity Adjustment for Different Deviation Classes

Deviation Class	Deviation Direction	Velocity Adjustment
Extreme Left	Left	Backward at Maximum Speed
Severe Left	Left	Backward at Strong Speed
Moderate Left	Left	Backward at Moderate Speed
Slight Left	Left	Backward at Slight Speed
Centered	None	Maintain Current Speed
Slight Right	Right	Forward at Slight Speed
Moderate Right	Right	Forward at Moderate Speed
Severe Right	Right	Forward at Strong Speed

6. CONCLUSION

In summary, the Sensor-Based Access Point Selection Strategy (SBAPSS) marks a significant breakthrough in AGV navigation within smart factories. By leveraging sensor data and machine learning, SBAPSS optimizes navigation paths, improving efficiency and adaptability. Its demonstrated efficacy and scalability make it a promising solution for enhancing AGV navigation in industrial settings. Looking ahead, refining algorithms, integrating emerging technologies, and adapting to evolving industry needs will further advance SBAPSS and AGV navigation, driving efficiency and innovation in smart manufacturing.

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Smart навігація: сенсорний вибір точки доступу для автоматизованих керованих транспортних засобів

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Забезпечення оптимальної навігації автоматизованих керованих транспортних засобів (AGV) має важливе значення для оптимізації операцій з обробки матеріалів і підвищення загальної ефективності. У роботі представлено нову стратегію вибору точок доступу на основі датчиків (SBAPSS), розроблену спеціально для покращення навігаційних можливостей AGV у інтелектуальних виробничих середовищах. SBAPSS використовує повний масив даних датчиків, включаючи вхідні дані від лазерних сканерів, систем зору, ультразвукових датчиків і датчиків наближення, для динамічної оцінки та вибору оптимальних точок доступу для навігаційних маршрутів AGV. Використовуючи інформацію датчиків у реальному часі, алгоритм SBAPSS використовує складні механізми прийняття рішень для визначення найбільш сприятливих точок доступу на основі багатьох критеріїв. Ці критерії охоплюють такі фактори, як виявлення перешкод, близькість до призначених станцій завантаження/розвантаження, затори та оптимізація шляху. Завдяки інтеграції сенсорного інтелекту в процес вибору точки доступу AGV можуть адаптивно коригувати свої навігаційні шляхи, щоб обходити перешкоди, уникати зіткнень і оптимізувати маршрути подорожей у режимі реального часу. Ефективність і надійність SBAPSS продемонстровано за допомогою масштабних досліджень моделювання та експериментальних перевірок, проведених у репрезентативних середовищах інтелектуальної фабрики. Результати вказують на значне покращення ефективності навігації AGV, пропускної спроможності та безпеки, тим самим підтверджуючи ефективність запропонованої стратегії. Крім того, здатність SBAPSS легко інтегруватися з існуючими системами керування AGV підкреслює його практичну здійсненність і масштабованість для розгортання в промислових умовах. Цей інноваційний підхід, керований датчиками, є суттєвим прогресом у методології навігації AGV. Запропоновано надійне рішення, адаптоване до вимог сучасних інтелектуальних виробничих потужностей. Наділяючи AGV можливостями інтелектуального прийняття рішень, SBAPSS сприяє створенню гнучких, адаптивних і автономних систем обробки матеріалів в епоху промисловості 4.0.

Ключові слова: Сенсорна навігація, Вибір точки доступу, Індустрія 4.0, Злиття сенсорів, Прийняття рішень у реальному часі та оптимізація шляху.