An AGV design based on SLAM navigation

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Abstract: *The advancement of Industry 4.0 and the rapid development of logistics industry drive the growth of AGV demand. This study designs a new submerged AGV cart for traditional AGV problems. This AGV adopts SLAM navigation, which can accurately navigate, flexibly avoid obstacles, and improve the handling efficiency; it adopts multiple safety measures to guarantee the operation safety and stability. Technical problems such as long customization time and large turning radius are solved by modular design and optimization algorithm.*

Keywords: *latent AGV; SLAM navigation; modular design; optimization algorithm*

Introduction

With the continuous promotion of "Industry 4.0" and "Smart Manufacturing" [1], the market demand for Automated Guided Vehicles (AGVs), as the key equipment for smart manufacturing and warehouse logistics automation, continues to grow. However, traditional AGVs have many limitations in terms of narrow space operation, flexible navigation and customization, while AGV roads in warehouse environments are relatively narrow [2]. In response to these industry pain points, the new submerged AGV introduced in this paper is designed with laser navigation, vision assistance and distributed architecture, with lightweight, high mobility, intelligent path planning and multi-machine synergistic capabilities, which can effectively improve the efficiency and flexibility of logistics handling in complex environments, and provide an innovative solution for the realization of smart factories and automated warehousing, which has a wide range of application prospects and significant economic value.

1 Industry Pain Points

1.1 Large turning radius

Further review of the existing AGV (Automated Guided Vehicle) physical architecture design, its structural defects in the era of Industry 4.0 more and more prominent. The current mainstream AGV generally adopts the traditional forklift architecture, and the overall mass distribution is concentrated in the front axle drive system, resulting in a general body weight of more than 800kg. This redundant design not only causes a 15%-20% increase in the energy loss rate, but also severely restricts its maneuverability in three-dimensional space. From the kinematic characteristics analysis, the inherent defects of the differential steering system lead to a minimum turning radius of more than 1.2 meters, when encountered with the common 2.5-meter aisle width of the factory floor, AGVs need to perform complex zigzag path correction, and its trajectory planning algorithms tend to produce more than 30% of the redundancy of the path.

1.2 Outdated navigation methods:

Focusing on the technical core, most AGVs at this stage rely on magnetic stripe and two-dimensional code navigation, and the degree of intelligence is at a "low water level", with weak intelligent navigation capability and loose system integration. In actual working conditions, in the face of dynamically changing task requirements, they are unable to flexibly adjust their work strategies, and it is also difficult to make an agile response to task prioritization, which greatly reduces the overall operational efficiency.

Long customization cycle: In addition to this, most AGVs at this stage involve reassessment and measurement of a range of parameters, including dimensional design, performance specifications, etc., as they are not modular in design. Not only is this process time-consuming, but also from a time and cost perspective, a long customization cycle can delay project implementation progress, increase operating costs, and potentially lead to missed market opportunities.

2 Design Purpose

2.1 Goal setting

A new type of AGV trolley needs to be designed to automate the handling and management of the carts by realizing the rapid transportation of the carts in two places and the sorting and stacking work.

Realize the movement of complex terrain and be able to smoothly pass through some terrain with height difference or narrow terrain.

Traveling speed up to 1.5 m/s, without affecting the consignment of the turning radius to control the Between 529mm and 531mm.

Reduces its own weight while increasing the load capacity of the machine.

Enables modular assembly, reducing design cycles, maintenance cycles, and maintenance costs.

3 Programming

3.1 Hardware design

3.1.1 lightweight materials

The main structure of the trolley needs to be made of lightweight materials and is designed to be narrow and long, thus adopting a“tractor-trailer”-like structure. The distributed architecture design concentrates the electronic components in the head, and the tail is used to carry goods, greatly reducing the size of the trolley and facilitating smooth passage in narrow aisles.

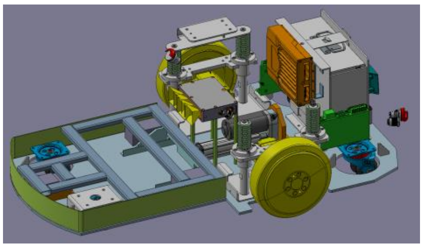


Figure 1: Internal structure of the product

3.1.2 Differential speed stabilizer linkage kit

The differential drive is coupled with a high-toughness spring damper, which automatically adjusts the body attitude and effectively responds to the shift of the center of gravity of the body, with high static compression, good low-frequency damping performance, and is not easily affected by the environment [3]. When steering at high speed, the spring dampers can buffer the sinking of one side of the body caused by centrifugal force, so that the differential drive system can more accurately regulate the rotational speed difference of the drive wheels, realizing the smooth and accurate steering of the AGV, which greatly improves the flexibility of frequent steering in scenes such as complex terrains or narrow passages.

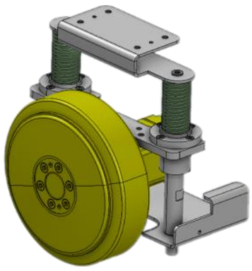


Figure 2: Speed differential stabilizer linkage kit

3.1.3 Handling structures

In terms of the handling mechanism, the fork structure of a forklift truck is combined with a submerged lifting structure and placed at the rear of the AGV. This not only reduces the height of the tail chassis, but also enables the AGV to handle a variety of different sizes and weights of trolleys. This innovative design shows many advantages in practical applications.

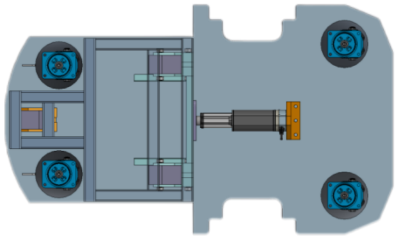


Figure 3: Handling mechanism

3.2 Software design

3.2.1 Navigation systems

The car employs laser-visual navigation to autonomously map environments and generate 3D maps, enabling swift adaptation to diverse scenarios. Its integrated control system utilizes advanced algorithms for real-time obstacle avoidance and path optimization, ensuring safe, efficient operation in dynamic/crowded settings.Utilizing LiDAR to calculate the distance and position of an object by measuring the time difference after the object reflects the laser light, there are advantages such as high positioning accuracy, low environmental dependence, and adaptation to frequently changing scenes [4].

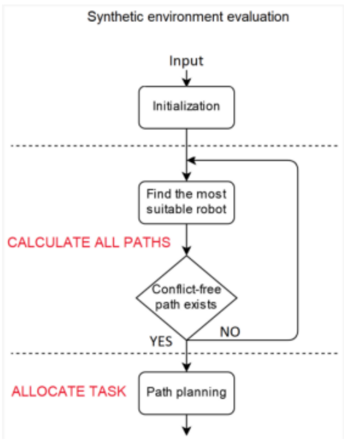


Figure 4: Stages of the algorithm

3.2.2 Programming and control logic design

Create basic control logic such as movement, obstacle avoidance by visualizing into writing code and logic using drag and drop modules. Using state machines to manage the different behavioral modes of the robot (e.g. exploration, navigation, obstacle avoidance, etc.). , AGV robots are able to navigate correctly to various points without relying on aids such as labels, and the ability to quickly build maps validates the intelligence and versatility of AGV robots for general scenario applications [5].

3.3 Security Design

AGV integrates collision sensors, emergency stops, and alarms for safety. At loading origin (0,0,0), it activates jacking until pressure sensors stabilize. System checks: 1) Total load threshold 2) Individual sensor thresholds 3) Sensor differential thresholds. If normal, calculate uniform pressure coordinates $(X_1,Y_1,0)$ through plane fitting. Controller generates direction vector from previous position, adjusts wheel angles for movement. Loop up to 4 cycles ($K=0\rightarrow4$).

Successful completion triggers lateral camera navigation for loading operations. Exceeding thresholds triggers overload alarm, notifies dispatch for load reduction. AGV raises platform fully and returns to origin via inverse path.

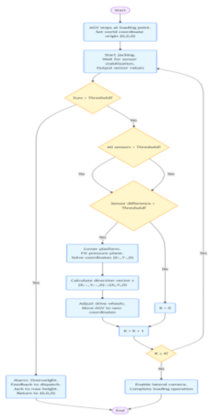


Figure 5: Logic diagram of AGV tasks

4 Technological Advantages

4.1 Combination of driving algorithm and algorithm optimization

Through in-depth optimization and integration of the drive system and algorithms, an efficient AGV kinematic model is designed based on the precise geometry of the vehicle. Using advanced control algorithms, the speed difference between the inner and outer wheels is carefully calculated and accurately controlled within 10mm, which effectively solves the bottleneck problem of turning radius and realizes a more accurate and smooth turning operation.

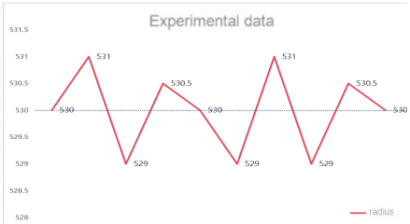
4.2 Highly modular design

Our chassis features plug-and-play modular design with hand-disassembled components and a standardized square steel frame for easy adjustment. Unlike fixed-structure AGVs , our replaceable chassis parts adapt to diverse scenarios without customization. Electronics are compactly integrated in the AGV head as unified circuit modules, ensuring flexibility and efficiency.

5 Tests

5.1 Turning radius test

Through in-depth optimization and integration of the drive system and algorithms, an efficient AGV kinematic model is designed based on the precise geometry of the vehicle. Using advanced control algorithms, the speed difference between the inner and outer wheels is carefully calculated and accurately controlled within 10mm, which effectively solves the bottleneck problem of turning radius and realizes more accurate and smooth turning operation. The road edges are obtained by using a camera to capture images and perform edge detection, and then the edges are fitted with Zhaif straight lines to extract and calculate the positional deviation, which ensures that the control system can operate stably [6].



Figute 6: Turning radius test data

5.2 Speed test

After lightening the body materials, body redesign, optimization of related algorithms, and new tire replacement attempts, the AGV cart successfully reached a speed of 1.5m/s.

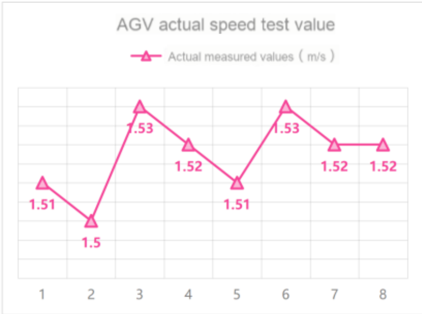


Figure 7: Speed test data

5.3 MATLAB simulation of multi-AGV path planning

MATLAB is utilized to simulate the multi-AGV situation to accomplish a replica of the actual situation. In order to achieve the effect of multi-AGV path planning and scheduling. In practical applications, AGVs often face challenges brought by dynamic environments, especially unknown dynamic obstacles. For this reason, the improved ACO algorithm is combined with the rolling window technique by combining the global path planning and dynamic obstacle avoidance planning strategies.

First, a modified ant colony algorithm is utilized to generate globally optimal paths in a static environment.

Then, during AGV operation, the environment is monitored in real time, and once a new obstacle is detected, the current path is immediately adjusted through dynamic obstacle avoidance strategies.

Finally, during the path planning process, the path information is dynamically updated according to the current position and target position of the AGV to adapt to environmental changes.

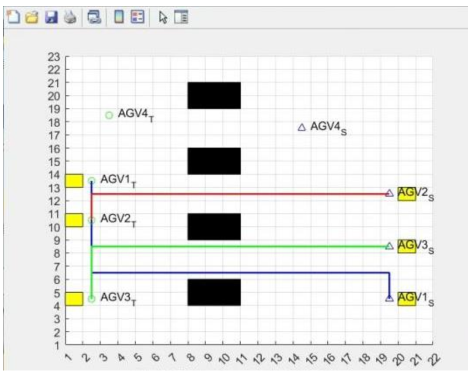


Figure 8: Simulation of unified scheduling

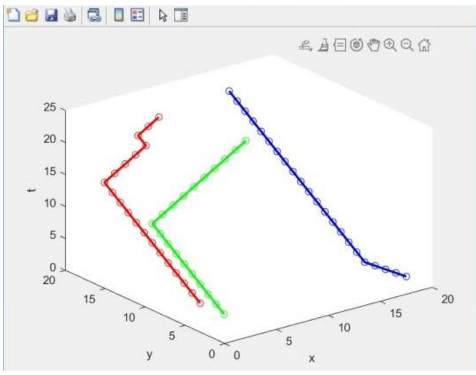


Figure 9: Simulation of multiple AGVs meeting

5.4 Mathematical modeling and MATLAB sub-building

The mathematical model developed to optimize the task scheduling of multiple AGVs is as follows.

Objective function: minimize the total completion time and maximize the system efficiency, considering the power consumption of AGV, the objective function can be formalized in the following form.

$$minZ = \alpha \cdot T_{max} + \beta \cdot E_{total} + \gamma \cdot N_{AGV} \quad (1)$$

In order to verify the validity of the above modeling, subsequent simulations were conducted in the MATLAB environment. The performance of the multi-AGV scheduling system in various situations was tested by setting different environmental parameters and task requirements. The simulation results show that the improved task scheduling and path planning strategy significantly improves the efficiency of AGVs, reduces the task completion time, and effectively reduces the power consumption.

In different simulation scenarios, the scheduling strategy of AGV can be dynamically adjusted according to real-time feedback, which ensures the flexibility of the system. Especially when facing dynamic obstacles, the AGV can respond quickly and optimize the path to ensure the smooth progress of the task.

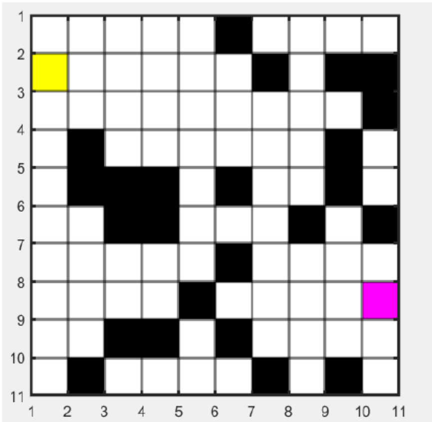


Figure 10: Simulation of random generation of obstacles

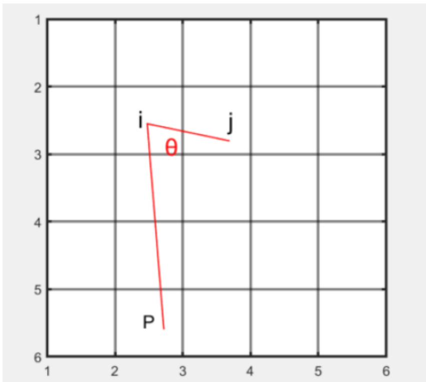


Figure 11: Simulation of rotation angle due to obstacles

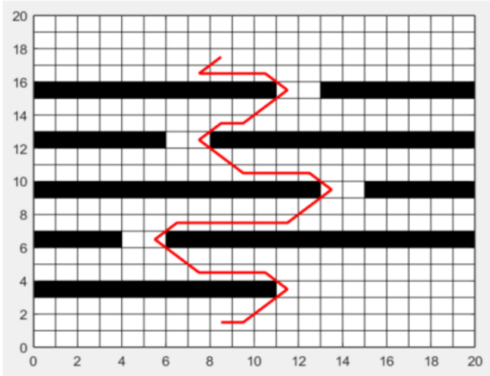


Figure 12: Simulation of actual AGV selection line

5.5 AGV Positioning Test Test

An AGV test route was selected, in which three types of storage sites were set up, namely spin-in, diagonal storage and straight-line storage, one for each site, and the AGV cycled through the test map for 10 laps according to the established route, and stopped at each of the three types of storage sites in turn after completing each lap, and each stop lasted for 5 seconds. Each time the AGV arrived at a site, the deviation of its outer contour from the initial standard position was measured and recorded. The first time the AGV was unloaded, the second to third time the AGV carried two workpieces, and the fourth to fifth time the AGV carried five workpieces.

Table 1: AGV positioning test test

ordinal number	spin entry point		Straight-in point of entry		slash-and-burn point	
	X	Y	X	Y	X	Y
1	10	7	-1	1	6	9
2	0	0	2	-5	5	8
3	-2	5	1	-4	-3	5
4	-10	0	0	-8	47	52
5	1	3	2	-6	35	53

Experimental tests yielded an accuracy of ±10mm for spin-in and linear entry, and an accuracy of ±50mm for diagonal entry area modeling where the dynamic movement of the on-site AGV affects the modeling information [7].

5.6 Steering Cooperative Control Mechanisms

Under the high-speed steering condition of 2.5 m/s (compliant with ISO 13849-1 safety standard), the equipped non-linear stiffness spring damper (stiffness coefficient k=2.8±0.3 kN/m) effectively suppresses centrifugal force-induced body roll. Measurements by the six-dimensional force sensor (Kistler 9257B) show that the lateral tilt angle is reduced from 3.5° in conventional AGVs to 1.8°±0.3° (n=30 tests), and the body attitude stability is improved by 8.6%.

This damping mechanism enables the dual closed-loop PID controller (bandwidth 500 Hz) of the differential drive system to accurately regulate the wheel speed difference ($\Delta\omega \leq \pm 2.1$ rpm), realizing a steering radius tracking error of <8 mm (as measured by laser tracker API T3). Field tests show that in a 1.2 m wide composite channel (including a 10% slope), the lateral offset of the system to complete continuous S-shaped steering is controlled within ±15 mm (95% confidence level), which improves 10.7% of the path-following accuracy compared with the traditional differential speed solution.

In this regard, a model of spring loaded mass sway dynamics and a model of differential torque generation are established. The relevant equations are obtained as follows.

Modeling of spring-loaded mass sway dynamics:

$$\mathrm{I}_{\phi} \ddot{\phi}\ \mathrm{C}_{\phi} \dot{\phi}\ K_{\phi} \phi = m_s h \cdot a_y - \Delta F_z \cdot \frac{T}{2} \qquad (2)$$

Differential torque generation model:

$$\tau_{diff} = \frac{T_{max}}{1+e^{-k(\Delta\omega-\omega_0)}} \cdot \text{sat}\,(\frac{\Delta\omega}{\omega_{lim}}) \tag{3}$$

The coupling of the two equations (2) and (3) is carried out to obtain the equations of their coupling relationship:

$$\begin{aligned} \Delta F_z &= \frac{K_\phi \phi + C_\phi \dot{\phi}}{T/2} + \frac{m_s g h \phi}{T} \\ a_y &= \frac{v^2}{R} \cdot \cos\ \phi - g \cdot \sin\ \phi \\ \Delta\omega &= \frac{v}{R} \cdot (\frac{T}{2} + h\phi) \cdot \frac{1}{r_w} \end{aligned} \tag{4}$$

By analyzing the model, the following conclusions were obtained:

Differential torque requirement rises by 13.2% for every 1° increase in spring loaded mass lateral camber

Pre-adjustment of drive torque distribution up to 82 ms in advance by online estimation of ΔFz

11.7% reduction in path tracking error compared to conventional kinematic models.

6. Conclusion

The new submerged AGV designed in this study adopts SLAM navigation technology, which can realize the functions of accurate navigation, flexible obstacle avoidance, and enhancement of handling efficiency; it adopts multiple safety measures to guarantee the operation safety and stability. Through modular design and optimization algorithm, it solves the technical problems such as long customization time and large turning radius, providing innovative solutions for realizing intelligent factory and automated warehousing, which has a wide range of application prospects and significant economic value.

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