International Journal of
Automotive Manufacturing and Materials (*IJAMM*)

Article

A Control System Design for an Intelligent Unmanned Automotive

Yundi Yang [†], Xin Gao [†], Jinwen You, Dengbo Zhang, Zhuo Zhang, and Yuanmei Song [*]

School of Mechanical & Vehicle Engineering, Linyi University, Linyi 276000, China
* Correspondence: ymsong321@163.com
† These authors contributed equally to this work.
Received: 1 August 2024; Revised: 18 September 2024; Accepted: 28 November 2024; Published: 4 December 2024

Abstract: This study is dedicated to developing a control system for an intelligent unmanned delivery vehicle with rear wheel independent drive. This design includes kinematic analysis based on AT89C51 microcontroller, control software development, arc path interpolation technology and control system circuit design. Typically, a high-precision digital encoder was designed to be installed on the rotating shaft of the motor to produce two pulse signals with a phase difference of 90 degrees, which is essential for determining the motion state of the motor. And the detection of the motor's rotation direction was achieved through a cleverly designed forward circuit. This system will continuously monitor the driving trajectory concluding from the initially predetermined route and the actual trajectory. As a result, this miniature vehicle is engineered to autonomously navigate and meticulously control its movement trajectory with high precision and efficiency, effortlessly navigating both straight lines and intricate arcs, which propelled a significant enhancement in both the overall level of production automation and the efficiency of manufacturing processes.

Keywords: intelligent vehicle; control design; AT89C51 microcontroller

1. Introduction

The development of goods distribution systems in the industrial sector is currently growing rapidly, especially in terms of material handling technology. Material handling technology is one system or a combination of methods, facilities, labor, and material storage to meet certain objectives [1]. The automatic guided vehicle, also known as the unmanned distribution vehicle, represents a cutting-edge tool for material handling. It boasts the capability of autonomous loading at a predetermined location, independent navigation to another destination, and subsequent automated unloading. Powered by a battery, it exemplifies the pinnacle of autonomous industrial vehicle operation. In the realm of logistics, handling stands as a pivotal functional aspect, accounting for a substantial share of overall logistics costs. Hence, the advancement of transport vehicles is of paramount importance, with unmanned delivery vehicles stealing the spotlight due to their vast array of applicable scenarios and swift pace of development. These vehicles, armed with non-contact guidance mechanisms, serve a pivotal role in delivering materials via intricate routes, navigating precisely to their destinations under the meticulous control of computers [2].

With the rise of artificial intelligence, intelligent manufacturing has gradually become popular and applied on a large scale. Among them, automatic guided vehicles (AGVs), as a vital medium for intelligent manufacturing, has been used in many fields, such as factory workshops, logistics warehouses, and processing, and have good development prospects [3–5]. The journey towards the development of autonomous guided vehicles embarked in the mid-1950s, with Barret pioneering the design of an early prototype of a driverless truck, a precursor to the modern-day unmanned delivery vehicle [6]. By the 1970s, these vehicles had firmly entrenched themselves within production systems, finding widespread application across diverse industries such as automotive manufacturing, machinery, electronics, steel, chemicals, pharmaceuticals, printing, warehousing, transportation, and commerce. In recent times, the rapid progression of automation technology has fueled the gradual development and widespread adoption of domestic automated three-dimensional warehouses and flexible assembly lines. Within this landscape, the unmanned distribution trolley, bridging the gap between automated warehouses and production workshops, plays an indispensable role, facilitating seamless transitions between various transportation nodes and stations [7]. In contrast to traditional raceways or conveyor belts, the transmission routes of unaccompanied vehicles exhibit greater simplicity and flexibility, requiring less space while offering superior mobility and adaptability. Automated guided vehicles (AGV) are widely used in this context as a part of a reliable and flexible internal transport system. The automation of logistics vehicles can also bring other benefits, due to reductions in costs and operating times [8–10].

The landscape of intelligent unmanned delivery vehicles is currently experiencing relentless progress and deepening exploration on a global scale, with China at the forefront of this revolution. Over the past few years, Chinese e-commerce and logistics giants have significantly intensified their investments, research endeavors, and promotion of cutting-edge, intelligent unmanned delivery vehicle technologies, propelling the industry towards new heights. A prime exemplar of this thriving trend is Alibaba's seminal launch of the Cainiao Small Donkey unmanned vehicle in 2019, an innovative and meticulously crafted solution that is perfectly suited to revolutionize the logistics industry. This autonomous vehicle primarily excels in terminal distribution operations and intelligent parcel pick-up services, revolutionizing the landscape of last-mile delivery [11]. Furthermore, notable corporations like Jingdong and SF Express are vigorously advancing and advocating the technology of intelligent unmanned delivery vehicles, joining the ranks of pioneers in this field. JD. com has pioneered the development of an innovative unmanned delivery vehicle, leveraging advanced LiDAR technology for Simultaneous Localization and Mapping (SLAM). This cutting-edge vehicle boasts a sophisticated automatic obstacle avoidance system, ensuring seamless navigation, coupled with a facial recognition pickup function, elevating the convenience and security of delivery services to new heights [12]. Suning has unveiled the "Wolong One", a groundbreaking unmanned delivery vehicle that integrates both GPS and LiDAR technology, enabling it to seamlessly interact with elevators, revolutionizing the logistics industry with its advanced capabilities [13]. In the medical arena, the White Rhino L4 unmanned delivery vehicle prominently demonstrated its capabilities by efficiently carrying out the distribution of vital medicines and supplies to Wuhan Fangcang Hospital, showcasing its invaluable contribution to healthcare logistics during critical times [14]. Globally, international logistics behemoths such as FedEx and UPS are likewise actively delving into and testing the capabilities of these intelligent autonomous distribution vehicles. Concurrently, startups like Starship Technologies and Nuro are engaging in research and development, as well as exploring the commercialization potential of this innovative technology. In summary, the technology surrounding intelligent unmanned delivery vehicles remains in a continuous state of evolution, with enterprises relentlessly enhancing their exploration and practical application of technological advancements, both in R&D and commercial realms.

The evolution of unmanned distribution carts is intricately enmeshed with the ascendancy of flexible processing systems, the emergence of agile assembly lines, the proliferation of sophisticated computer-integrated manufacturing systems, and the establishment of state-of-the-art automated three-dimensional warehouses, collectively fostering the technological progress in this domain. These technological advancements have synergistically catalyzed the evolution of unmanned distribution carts, nurturing a more efficient and streamlined logistics ecosystem that streamlines operations and enhances overall performance. Drawing upon Japanese research, flexible machining systems have been in operational use since 1981, indicating that the extensive deployment of unmanned delivery vehicles, colloquially referred to as 'small cars,' has a historical trajectory spanning approximately 15 to 20 years. This extraordinary advancement underscores the astonishing pace at which this technology has evolved and been embraced. Since General Motors pioneered the utilization of unmanned delivery minicars in 1981, the fleet of such vehicles has flourished, reaching a significant milestone of 3000 by 1987. Notably, Europe claims an impressive share of approximately 40% of these autonomous mini-vehicles catering to the automotive industry, while Japan contributes 15%, showcasing the widespread adoption of this technology across various industrial landscapes.

This research is dedicated to the development of an intelligent, autonomous delivery vehicle that possesses the capability to navigate seamlessly within a planar environment, adhering meticulously to a predefined route. This project employs the AT89C51 single-chip microcomputer as the central control unit for the small distribution vehicle, incorporating a four-wheel configuration design. This innovative design features two independent driving rear wheels and two front omnidirectional wheels serving as steering mechanisms. This unique four-wheel structure imparts exceptional stability and maneuverability to the autonomous guided vehicle, enhancing its overall performance. Guided by the meticulous precision of a single-chip microcomputer, the distribution vehicle proficiently performs a wide spectrum of mobile maneuvers, including agile left and right turns, seamless forward and backward movements, and precise stopping, all with remarkable dexterity. This versatility underscores the vehicle's remarkable adaptability and flexibility in executing distribution tasks, empowering it to navigate efficiently and deliver goods with precision and effectiveness, regardless of the diverse environmental conditions it encounters. In contrast to previous iterations of intelligent unmanned vehicles, our project incorporates the AT89C51 microcontroller as the cornerstone of its central control unit, leveraging its exceptional processing prowess and adaptability to guarantee the flawless execution of intricate control directives. This strategic selection not only enhances the overall stability and reliability of the system but also underscores our commitment to ensuring the safety and efficiency of cargo transportation. Furthermore, our meticulously crafted control algorithm and programming architecture incorporates circular path interpolation technology, a testament to our innovative approach. This innovative small car is capable of autonomously navigating and precisely controlling its trajectory, seamlessly traversing both straight lines and intricate curves along a predefined route. As a result, this delivery vehicle excels in path tracking and operational tasks with unparalleled precision, aligning perfectly with the demands of modern logistics and automated production environments.

2. Design of the Control System

2.1. Comprehensive Design Scheme for the Control System

In the design of the control system for the intelligent unmanned distribution vehicle, the AT89C51 single-chip microcomputer is chosen as the pivotal control and computational element, assuming the central role in commanding and processing diverse information. It collaborates seamlessly with the digital encoder mounted on the motor, which emits pulse signals as the motor rotates. By processing these signals through a custom-built set of pulse mirrors and transmitting them to the circuit, the motor's operational direction can be precisely determined. This innovative circuit design enhances signal processing efficiency and fortifies the overall system reliability.

Subsequently, the positive and negative pulse signals are directed to two 8253 counters, where they undergo meticulous counting, yielding precise measurements of the motor's rotational speed and displacement. These metrics are indispensable for the meticulous control of the entire system. The data refined by the counters is then transmitted to the AT89C51 microcontroller, where it is further honed by sophisticated control programs, transforming it into specific control parameters.

These control parameters are subsequently transformed into analog signals by two DAC1208 converters, a pivotal step in the system's control segment. This conversion bridges the gap between digital and analog realms, enabling the direct motor actuation. The resulting analog signals are dispatched to the pulse width modulators of the two UC3637 DC motors, where the innovative pulse width modulation technique is employed to meticulously regulate the motor's speed and torque. Ultimately, these refined control signals undergo amplification via an H-Bridge switching amplifier, ensuring precise motor control.

Figure 1 showcases the comprehensive architecture of the entire control system.

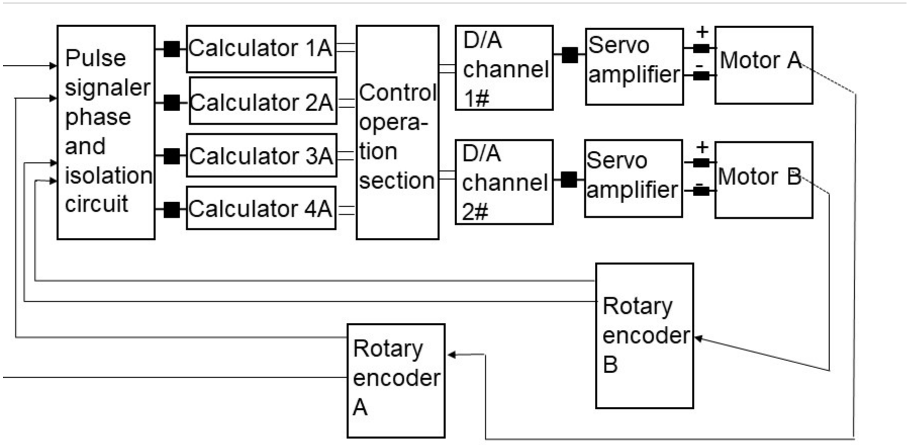

Figure 1. The block diagram of the control system..

2.2. Refine the Direction Identification

In this system, the servo motor adeptly operates across four distinct quadrants, tailored to the specific control requirements, showcasing its unique design and application. To fulfill this multifaceted functionality, the system necessitates robust dynamic response and precise control mechanisms. Among the servo motor's pivotal functions lies state monitoring, which demands meticulous detection of motor speed and unequivocal discernment of the motor's rotational direction (Survey Model). To accomplish this, we integrate a high-precision digital encoder onto the motor's rotating shaft. This encoder generates two pulses, 90 degrees out of phase, pivotal for accurately determining the motor's movement during operation.

The forward circuit is meticulously designed to discern the motor's rotational direction. Leveraging two pulse signals with a phase difference, this circuit adeptly determines the motor's rotation through intricate logic processing. This approach significantly bolsters the system's responsiveness and reliability, while concurrently enhancing the accuracy of directional judgment. Figure 2 provides a detailed illustration of this orientation process, encompassing the circuit's design intricacies and working principle. This visualization is pivotal in comprehending the mechanics behind motor orientation detection.

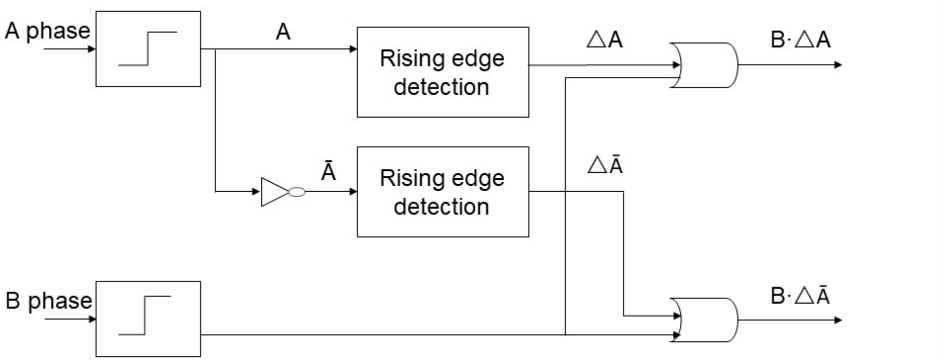

Figure 2. Orientation principle..

The precise analysis of the phase relationship between the A-phase and B-phase pulses enables the detection of the servomotor's rotation direction. Specifically, during reverse rotation, our system observes that the B-phase pulse leads the A-phase pulse by 90 degrees. This distinct phase difference is harnessed within our circuit design to generate reverse counting pulses, which are subsequently transmitted to the cp ten terminal. Conversely, during positive rotation, the scenario reverses: the A-phase pulse precedes the B-phase pulse by 90 degrees. This pivotal shift is meticulously captured by the circuit, triggering the generation of forward counting pulses at the cp end. These nuanced phase variations and the subsequent pulse generation mechanisms are pivotal components of the motor control system, as clearly illustrated in Figure 3b,c.

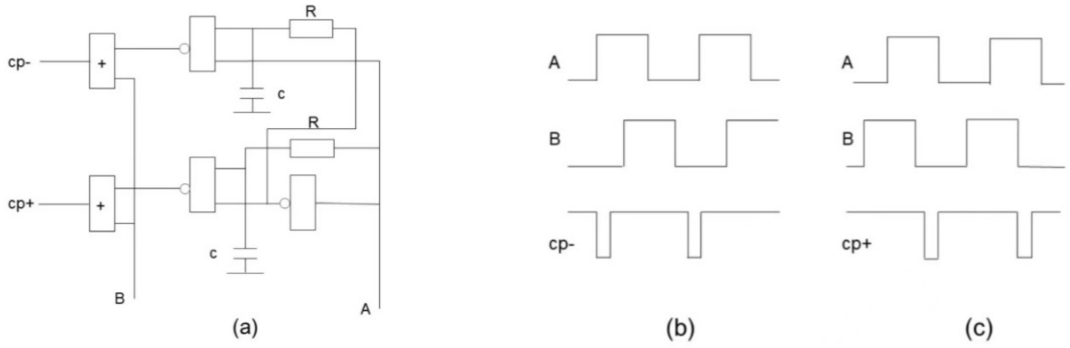

Figure 3. Illustration of the Motor Rotation Direction Discrimination Circuit: (**a**) presents a detailed circuit diagram, (**b**) represents reversal and (**c**)represents forward rotation..

To refine the signal processing, the generated pulses are routed to a meticulously crafted pulse counting circuit. Within this circuit, every pulse is rigorously counted, furnishing invaluable data that underpins the subsequent motor speed and direction control strategies. Upon completion of the counting process, the acquired data is read by the computer, where it undergoes advanced processing to guarantee the precision and reliability of the motor's movements. The circuit's design holds paramount importance, as it not only safeguards the accuracy of signal processing but also bolsters the system's responsiveness and overall efficiency. Figure 3a presents a detailed circuit diagram, offering a visual representation that fosters a profound comprehension of this intricate process.

We have selected a high-precision digital encoder featuring a specification of 500P/R, ensuring that the motor can emit up to 500 pulses per revolution, vital for the meticulous control of the entire system. To refine the output signal's compatibility with practical applications, we have incorporated a 62: 1 reduction gear between the motor and the wheel. Consequently, each full rotation of the wheel, either forward or backward, triggers an enhanced signal of up to 31,000 pulses from the encoder, thanks to the amplification effect of the reduction gear. This innovative design significantly elevates the system's resolution, empowering us to exert unparalleled precision in controlling every nuance of the wheel's movement.

Furthermore, the encoder employs a differential transmission method for the pulse signal, conferring upon it superior anti-interference capabilities. This ensures that the signal remains stable and accurate amidst diverse environmental conditions. Our system incorporates a dedicated directional circuit, meticulously designed to receive and process these differential pulse signals. For comprehensive statistical analysis, the refined signal is subsequently conveyed to Computer No. 8253. This pivotal step in the control system is imperative, as it ensures the precise interpretation and processing of the signal, thereby guaranteeing the flawless operation of the entire control framework.

2.3. Expansion of Counting Capabilities

To precisely measure the kinematic parameters of the drive wheel, including speed and displacement, we employ a digital encoder. The encoder's pulse signal, post-circuit processing, can distinguish between the motor's clockwise and counterclockwise rotations. To accurately derive vital parameters like velocity and displacement from these pulses, they undergo meticulous counting and analysis. Our system integrates two 8253 counter chips, each housing three 16-bit counting units, totaling four independent counting units designated as 1#, 2#, 3#, and 4#. These units are dedicated to counting the pinwheel pulses generated by the two motors, separately for clockwise and counterclockwise rotations, ensuring precision and efficiency.

The 8253 is a robust and adaptable programmable timer/counter, meticulously crafted to operate in parallel with the CPU, thereby alleviating the burden on CPU time. Boasting three independent 16-bit count channels, it effortlessly performs counts spanning from 2 to 2^{10} digits. Each counter boasts six distinct operational modes and handles frequencies as high as 2MHz with ease. Furthermore, the chip's input and output ports seamlessly interface with TTL levels, significantly augmenting its application versatility and flexibility.

For an in-depth understanding of the intricate construction and functional arrangement of the 8253 counter, please consult its comprehensive internal block diagram (Figure 4) and pin configuration diagram (Figure 5).

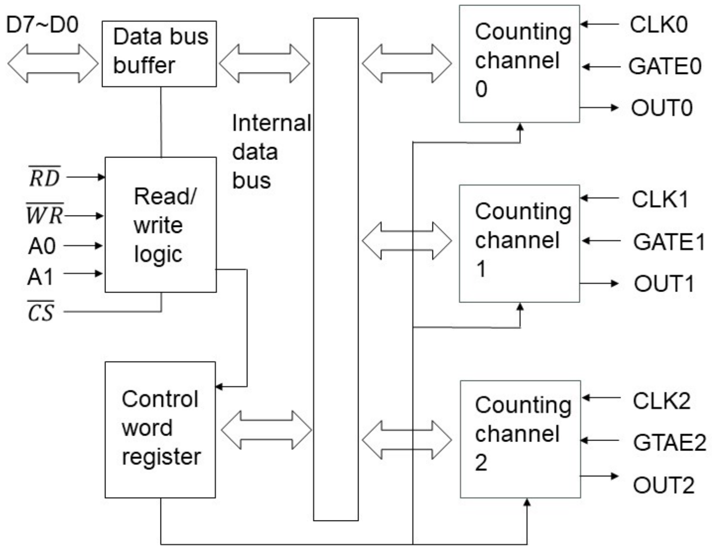

Figure 4. Internal Architecture Framework of the 8253..

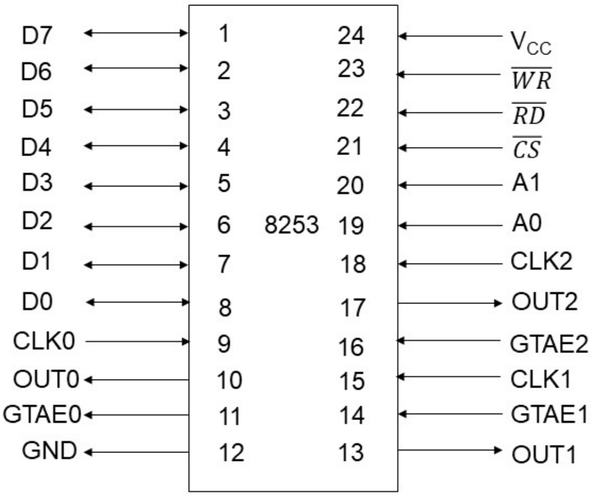

Figure 5. Pinout Diagram of the 8253..

U6 address: 8000H counter 08001H counter 18002H counter 28003H Control word

U7 address: 6000H counter 06001H counter 16002H counter 26003H Control word

U6 Connect cables to the read/write control logic: $\overline{CS} = Y_4$, $Q_0 = A_0$, $Q_1 = A_1$;

U7 Connect cables to the read/write control logic: $\overline{CS} = Y_3$, $Q_0 = A_0$, $Q_1 = A_1$.

In the meticulously designed system, the duo of chips, U6 and U7, occupy a pivotal position. Notably, the U6 chip houses counters 0 and 1, which are intricately configured to meticulously track the revolutions of the revolver motor, distinguishing between clockwise and counter-clockwise rotations. Analogously, the U7 chip's counters 0 and 1 diligently oversee the rotations of the right wheel motor. Operating in Mode 3, these counters efficiently execute their counting duties, ensuring precise monitoring and management of motor movements.

The core functionality of these four counters within the system's interrupt service routine lies in precisely documenting the positive and negative directional pulse durations of the two servomotors. By strategically calculating the differential between the present pulse count and the previously recorded count, we gain insight into the temporal variation in pulse numbers. Specifically, the counterclockwise and clockwise rotation metrics pertaining to the right-wheel motors are sequestered within temporary variables designated as temp 1 and temp 2, respectively. In parallel, the analogous data for the left-wheel motors are safeguarded in temp 3 and temp 4. Within the main program's ambit, these variables undergo intricate calculations and analyses, culminating in the accurate derivation of the mobile robot's dynamic state parameters.

2.4. Kinematic Analysis

2.4.1. Kinematic Equations

Given the driving speed of the wheel, the objective is to determine the translational velocity of the mechanism's body, as well as the rotational speed associated with the angle of rotation. The speed analysis of the driven four-wheel mechanism is performed individually, focusing on the two rear wheels, where 'Q' represents the instantaneous center and 'P' denotes the center of the rear wheel.

$$v_p = \frac{v_1 + v_2}{2} \tag{1}$$

$$\dot{x} = v_p \cos\theta = \frac{v_1 + v_2}{2}\cos\theta \tag{2}$$

$$\dot{y} = v_p \sin\theta = \frac{v_1 + v_2}{2}\sin\theta \tag{3}$$

$$R = \frac{v_1 B}{v_2 - v_1} \tag{4}$$

$$\dot{\theta} = \frac{v_1}{R} = \frac{v_2 - v_1}{B} \tag{5}$$

In which, *B* is for the distance between its two driving wheels and *R* is turning radius, referring to the distance from the center of each driving wheel to the center of the turning circle, as shown in Figure 6.

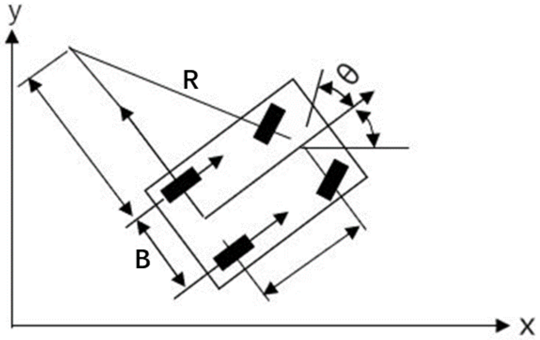

Figure 6. Illustrative Representation of Autonomous Guidance for an Unmanned Dolly..

According to the above analysis, the Matrix Form was organized as follows:

$$\begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta} \end{bmatrix} = \begin{bmatrix} \frac{\cos\theta}{2} & \frac{\cos\theta}{2} \\ \frac{\sin\theta}{2} & \frac{\sin\theta}{2} \\ -\frac{1}{B} & \frac{1}{B} \end{bmatrix} \begin{bmatrix} v_1 \\ v_2 \end{bmatrix} = J \begin{bmatrix} v_1 \\ v_2 \end{bmatrix} \tag{6}$$

J represents the Jacobian matrix.

2.4.2. Turning Radius

When the car executes a turning maneuver, it maintains a consistent rotational velocity. Given that the small car's mass is evenly distributed. By considering the friction coefficient between the car and the driving surface, we can accurately calculate the rotational speed of both wheels based on these parameters. This comprehensive analysis provides a deeper understanding of the dynamics involved in the car's turning performance [1]. The turning radius could be calculated as:

$$R > \frac{v^2}{ug} = \frac{(10000/60)^2}{4 \times 9.8} = 708.6\ \text{mm} \tag{7}$$

Among which, take $\mu = 4$ according to literature review [2]

Therefore, the minimum turning radius of the car is $R = 710$ mm.

According to the literature [1], the speed of the left and right wheels is

$$2\pi r v_2 = \frac{(2R+B)v}{2R} \tag{8}$$

$$v_2 = \frac{(2R+B)v}{4\pi r R} = \frac{(2 \times 710 + 260) \times (10000/60)}{4 \times 3.14 \times 70 \times 710} \approx 0.4486\text{mm/s} \tag{9}$$

$$2\pi r v_1 = \frac{(2R-B)v}{2R}$$

$$v_1 = \frac{(2R-B)v}{4\pi r R} = \frac{(2 \times 710 - 260) \times (10000/60)}{4 \times 3.14 \times 70 \times 710} \approx 0.3097\text{mm/s}$$

2.5. Design and Implementation of Control Software

The state quantities, including the position coordinates (*x*, *y*) and the orientation angle (φ3), can be precisely derived from the given Equations (1) and (5), which respectively represent the linear and angular velocities of the robot. This computation enables accurate tracking and control of the robot's movement.

$$v_q = \frac{v_1 + v_2}{2} \tag{10}$$

$$\dot{\theta} = \frac{v_2 - v_1}{B} \tag{11}$$

$$\phi = \phi_0 + \frac{1}{2b}\int_0^t r(\omega_r - \omega_t)dt \tag{12}$$

$$x = x_0 + \frac{\cos\phi}{2}\int_0^t (\omega_r + \omega_t)dt \tag{13}$$

$$y = y_0 + \frac{\sin\phi}{2}\int_0^t (\omega_r + \omega_t)dt \tag{14}$$

The method of numerical integration is employed for approximate detection, ensuring precision by adhering to specific conditions. When the motion speed chosen for partitioning is sufficiently low in relation to the mobile robot's velocity, or the control period is kept brief, the interval can be segmented into numerous, sufficiently minute sub-intervals. This approach guarantees that the detection accuracy fulfills the operational requirements, ensuring reliability and precision in the robot's movements. Concretely reflected in: $[0\ t][0_t,\ 1][t_1\ t_2],\ldots[t_{n-1}\ t_n],[t_i\ t_{i+1}]$

$$\phi_n = \phi_{n-1} + \frac{1}{2b}\int_{t_{n-1}}^{t_n} r(\omega_r - \omega_t)dt \tag{15}$$

$$x_n = x_{n-1} + \frac{\cos\phi_{n-1}}{2}\int_{t_{n-1}}^{t_n} r(\omega_r + \omega_t)dt \tag{16}$$

$$y_n = y_{n-1} + \frac{\sin\phi_{n-1}}{2}\int_{t_{n-1}}^{t_n} r(\omega_r + \omega_t)dt \tag{17}$$

The cornerstone of our system's critical state quantity measurement relies heavily on the precise pulse signals generated by the digital encoder. To accurately convert these pulse signals into the robot's travel distance and rotation angle, rigorous calibration is imperative. This necessitates determining the exact correlation between each type of pulse and the corresponding distance traversed by the driving wheel, ensuring accurate and reliable measurements. Given that the drive wheel radius measures 70 mm, the motor-to-wheel deceleration ratio is 62: 1, and the motor generates 500 pulses per complete revolution, we can meticulously calculate the distance traversed by the robot per pulse. Specifically, we divide 2π (representing the circumference of the wheel) multiplied by the wheel radius (70 mm) by the product of the motor's pulses per turn (500) and the deceleration ratio (62), yielding approximately 0.01418 mm per pulse. This calculation ensures precise translation of pulse signals into the robot's travel distance.

It is imperative to meticulously select a programming language that aligns with the specific demands of the system, ensuring optimal performance for the control system. An ideal choice would embody attributes such as concise code, high execution efficiency, and unparalleled real-time responsiveness. It is of paramount importance to meticulously select a programming language that is congruent with the unique requirements of the system, thereby guaranteeing optimal performance for the control system. An exemplary choice would embody attributes like conciseness in code, unparalleled execution efficiency, and exceptional real-time responsiveness, thereby ensuring the system's peak operational capabilities. Considering the automated unmanned distribution car navigation system as a prime example, cornerstone the lies in meticulously crafting a program that precisely adheres to the predefined path, guaranteeing seamless navigation and operation. Utilizing the voltage signals captured by the digital encoder, the system adeptly identifies deviations between the vehicle's current position and the designated path. The control system then dynamically adjusts the motor speed in response to these positional deviations, correcting course deviations and ensuring the vehicle adheres strictly to the predetermined route. This necessitates real-time speed modulation of the motor, coupled with instantaneous control based on the received positional deviation signals. Moreover, in the realm of automated navigation for unmanned distribution vehicles, the complementary role of hardware control is indispensable, ensuring seamless integration and optimal performance. The comprehensive unmanned distribution process for the small vehicle, equipped with automatic guidance control, is comprehensively illustrated in Figure 7.

Upon initiating the program execution process, the primary tasks encompass the configuration of functions and variables, alongside the initialization of every chip to ensure a clean slate. Subsequently, the system proceeds to load the predefined driving trajectory coordinates, meticulously applying interpolation processing to these trajectory data points, specifically employing circular arc interpolation as exemplified in Figure 8. Once this is accomplished, the program retrieves the latest recorded error data, leveraging it as a basis to commence the automatic guidance of the vehicle, ensuring seamless and precise navigation.

As the small car navigates its course, the system meticulously monitors its trajectory in real-time. To ascertain whether the vehicle has deviated from its intended path, the system initially assesses the first segment of the predefined route. In the absence of any deviation (NO), the system meticulously compares the actual trajectory detected with the pre-set trajectory, meticulously calculating the travel deviation to ensure precise navigation. Subsequently, this calculated deviation is seamlessly fed into the D/A converter, enabling the system to adjust the car's trajectory to ensure it remains aligned with the predetermined path. Once the first path segment has been successfully traversed (YES), the program seamlessly directs the car towards the subsequent path. As the journey progresses, the system continually assesses whether the car has reached the designated finish line. If not, the program persistently guides the car towards the next track segment; however, upon reaching the endpoint, the program gracefully concludes its execution. Meanwhile, the DDA arc interpolation program to describe Figure 8 is depicted in detail in the Supplementary Materials.

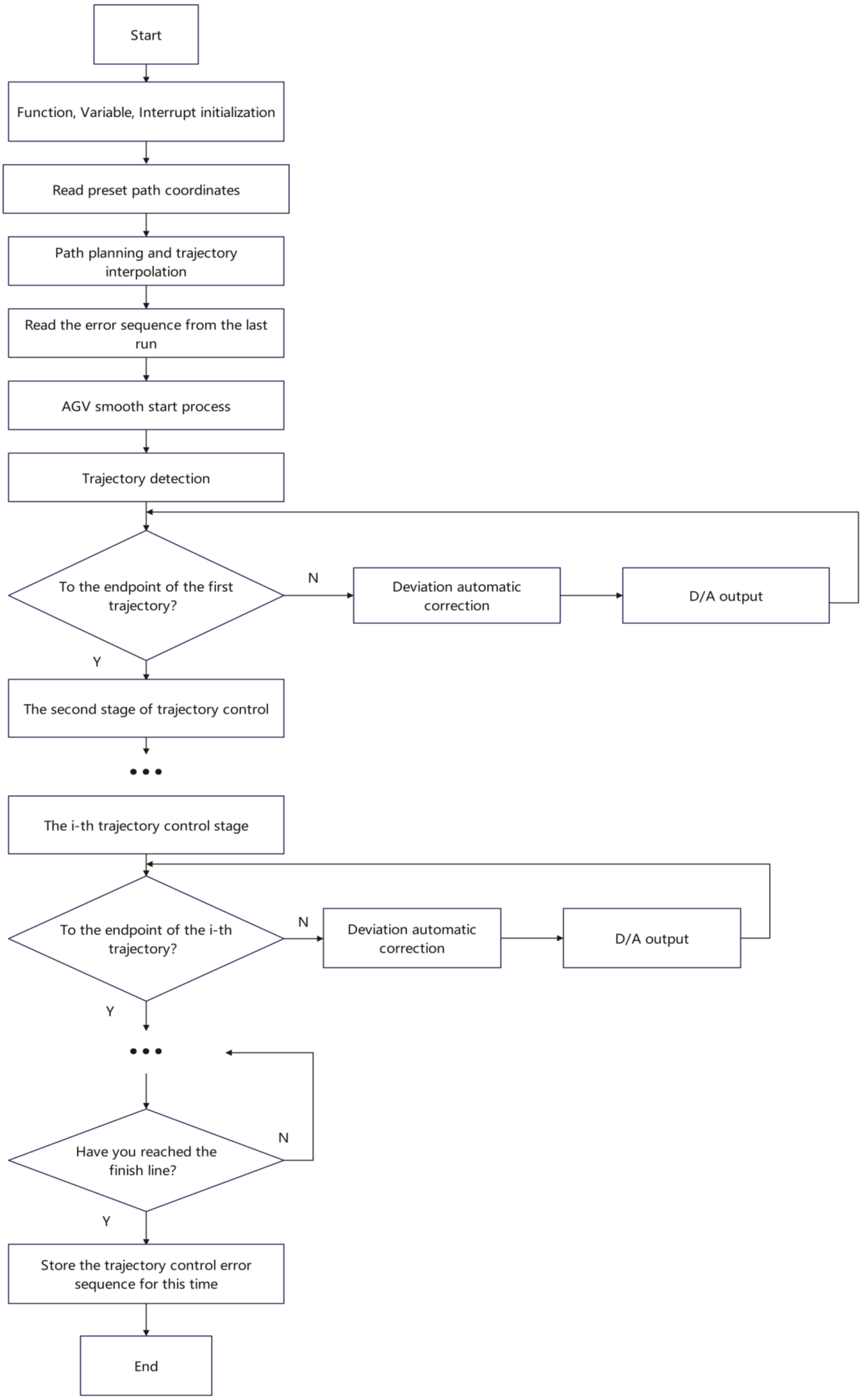

Figure 7. Programmed construction drawing of control system..

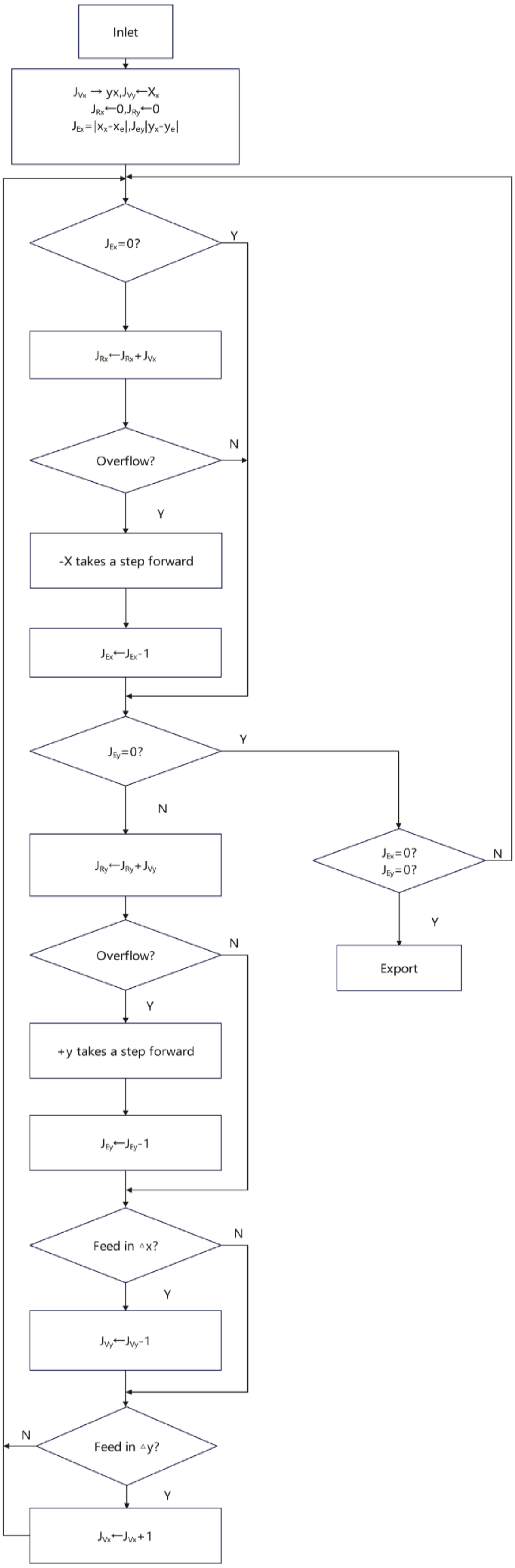

Figure 8. DDA arc interpolation degree of flow..

3. Conclusions

This research is centered on the intricate design of the control system for an intelligent, unmanned distribution vehicle with a highly efficient material handling solution, capable of autonomously loading and unloading goods at specified locations while navigating seamlessly to alternate destinations. The sophisticated system architecture typically encompasses a comprehensive sensor array, a robust control unit, and an advanced information processing unit. Typically, this small car has been meticulously designed to autonomously navigate and transport workpieces precisely to a pre-determined trajectory. The heart of its control is the AT89C51 single-chip microcomputer, which serves as the pivotal control unit for the distribution vehicle. Under its astute guidance, the vehicle executes a wide array of mobile operations and accurately fulfills intricate control commands with unwavering precision. Through the optimized design of this intelligent distribution car undertaken in this project, the remarkable transportation efficiency, energy conservation, robust reliability and versatility to adapt to diverse transportation requirements were achieved. Thereby, these exceptional attributes could have significantly elevated the overall level of production automation and efficiency.

Supplementary Materials: The supporting information can be downloaded at: https://www.sciltp.com/journals/ijamm/2024/4/639/s1.

Author Contributions: Y. Y. was responsible for designing the methodology and performing simulations; X. G. was responsible for managing the research project's progress; J. Y. was responsible for data computation, organization, and management; D. Z. conducted literature and data materials collection and drafted the initial manuscript; Z. Z. was responsible for the editing the manuscript; Y.S. was responsible for reviewing and revising the work, as well as making contacts for submission. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by the Shandong Provincial Natural Science Foundation of China (No. ZR2021QB137, ZR2021QA067 and ZR2022ME082), the National Natural Science Foundation of China (No. 12002142), the Youth Entrepreneurship Technology Support Program for Higher Education Institutions of Shandong Province (No. 2023KJ215), the Shandong Provincial Science and Technology Improvement Plan Project (No.2023TSGC0426) and the Scientific Research of Linyi University (Nos.Z620622003 and 2021PTXM001).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Srinivas, C.; Chittaranjan, D.V. Modelling and simulation of multi automated Guided vehicles in a factory layout. *Int. J. Sci. Res. Rev.* **2014**, *2*, 177–187.
2. Wang, R.M.; Zhang, C.T.; Chen, H.; Chen, H.Y.; Li, X.K.; Xu, W.H. Design and practice of intelligent Car based on vision Sensor. *Intern. Combust. Engine Accessories* **2024**, *4*, 84–86.
3. Correa, A.I.; Langevin, A.; Rousseau, L.M.Scheduling and routing of automated guided vehicles: A hybrid approach. *Comput. Oper. Res.* **2007**, *34*, 1688–1707.
4. Bordelon Hoff, E.; Sarker, B.R. An overview of path design and dispatching methods for automated guided vehicles. *Integr. Manuf. Syst.* **1998**, *9*, 296–307.
5. Chen, Z.Y.; Xu, B. AGV path planning based on improved artificial potential field method. In Proceedings of the 2021 IEEE International Conference on Power Electronics, Computer Applications. Shenyang, China, 22–24 January 2021; pp. 32–37.
6. Yang, R.L.; Wang, J.D.; Chen, R.R.System design of intelligent Obstacle Crossing detection Car based on MCU. *Microprocessor* **2024**, *45*, 58–60.
7. Li, Q.; Xu, W.; Gu, Y.A.; Wang, X.; Hu, P. Design of innovative experimental teaching System based on intelligent car for desert control. *Mech. Eng.* **2024**, 19–23.
8. Lothar, S.; Lindu, Z.Worldwide development and application of automated guided vehicle systems. *Int. J. Serv. Oper. Inf.* **2007**, *2*, 164–176.
9. Sigal, B.; Edna, S.; Yael, E. Evaluation of automatic guided vehicle systems, Robot. *Comput.-Integr. Manuf.* **2009**, *25*, 522–528.
10. Sabattini, L.; Digani, V.; Secchi, C.; Cotena, G.; Ronzoni, D.; Foppoli, M.; Oleari, F. Technological roadmap to boost the introduction of AGVs in industrial applications. In Proceedings of the 2013 IEEE 9th International Conference on Intelligent Computer Communication and Processing, Cluj-Napoca, Romania, 5–7 September 2013; pp. 203–208.
11. Han, Q. Q.; Geng, S. Y.; Fu, C. N.; Zhu, X. P. Design of Multi-function Intelligent Car Based on Single-chip Microcomputer Technology. *Mech. Eng. Autom.* **2024**, 160–162.

12. Wang, H. B. Research on Campus Unmanned Delivery System Based on Mobile Robots. Master's Thesis, Beijing Jiaotong University, Beijing, China, 2019.
13. Han, Y. F. Research on Distribution Path Planning of Unmanned Logistics Fleet Based on Deep Reinforcement Learning. Master's Thesis, Dalian University of Technology, Dalian, China, 2021.
14. Li, X.; Liu, Y.F.; Wang, H.J.The Impact of Sustainable Development of Cold Chain Logistics on China's COVID-19 Pandemic. *Sustainability.***2022**, *14*, 10358.