

Multi-Vehicle Unmanned Following Operation Driving System Based on OpenMV

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Abstract. In response to the low level of agricultural production automation and labor shortage, to improve the efficiency of agricultural machinery utilization and the reliability of automatic navigation, this paper designs an intelligent agricultural machinery system based on OpenMV for multi-vehicle unmanned following operations. Firstly, the kinematics of the agricultural machinery vehicle is analyzed, the path recognition and location line extraction are carried out using the OpenMV vision module, and the agricultural machinery steering control system is designed using the cascade PID closed-loop control technology, which achieves accurate steering control and path tracking on straight lines and curves. Subsequently, using embedded microcontrollers to manage the workflow, utilizing OpenMV visual modules to receive, store, and process positioning information, and sending control instructions to execution units such as the TB6612FNG motor drive module. Moreover, in response to the communication issues involving multiple HC-05 Bluetooth modules in the system's multi-vehicle communication, corresponding protocol specifications have been developed, and combined with the use of the HC-SR04 ultrasonic module to maintain dual vehicle distance and obstacle detection, achieving multi-vehicle collaborative following operations. The experimental results show that the system achieves a path recognition navigation accuracy of 93.4% and a communication success rate of 97.5% in simulating the process of farm harvesting and transportation, effectively proving the multi-vehicle collaboration of the system in the paper.

Keywords: Following multiple vehicles, OpenMV, Intelligent agricultural machinery, PID control.

1. Introduction

In recent years, automatic navigation technology has been widely applied in the field of agricultural machinery intelligent equipment. The intelligence of agricultural machinery has led China's agriculture to gradually move towards modern precision agriculture. This new type of agriculture, which is more efficient and high-quality, provides strong support for China's grain production increase and stable and rapid development of the national economy [1].

At present, intelligent agricultural machinery generally utilizes GPS satellite positioning technology and multi-sensor fusion technology for multi-vehicle following operations. References [2,3] all use RTK-DGPS technology to obtain the deviation between the actual position of the locomotive and the predetermined route, achieving automatic linear tracking of agricultural machinery; Reference [4,5] added an inertial navigation system to the GPS to achieve integrated positioning and navigation, achieving high-precision path tracking with a lateral error of less than 5cm and an angle deviation of less than 5°, improving the coordination of multiple vehicle movements; Reference [6] focuses on practical and complex field operation scenarios, equipping agricultural machinery with various obstacle detection sensors such as laser scanners to fuse and perceive the open working environment around, achieving linear path tracking function in orchard environments.

At present, intelligent agricultural machinery multi-vehicle following operations mainly rely on GPS, IMU, and obstacle detection sensors for positioning and attitude measurement, achieving linear following driving in specific scenarios. However, the satellite signals of the positioning system may be subject to electromagnetic interference [7-9], resulting in the system being unable to function properly. And obstacle detection sensors cannot mimic the most important features in the environment that humans perceive comprehensively and accurately [10-12]. For this purpose, an

intelligent agricultural machinery system based on OpenMV for multi-vehicle unmanned following operation was designed in the

article. The system adopts path recognition and following based on the machine vision module OpenMV. The OpenMV visual module can perceive the surrounding environment in real-time and comprehensively and has the advantages of low cost, rich information, and not relying on external antenna support. It combines ultrasonic sensors to maintain obstacle detection and safety car distance, uses Bluetooth for multi-vehicle communication, and designs the steering control of a multi-vehicle tracking system based on PID control technology. After simulation scenario testing, the system can achieve path recognition tracking and collaborative operation in common field environments.

2. System Structure

The structure of the multi-vehicle unmanned operation following a driving system based on OpenMV is divided into the master vehicle and slave vehicle. Both the master car and the slave car are composed of a path identification module, microcontroller, communication module, ultrasonic ranging module, and motor drive, as shown in Figure 1.

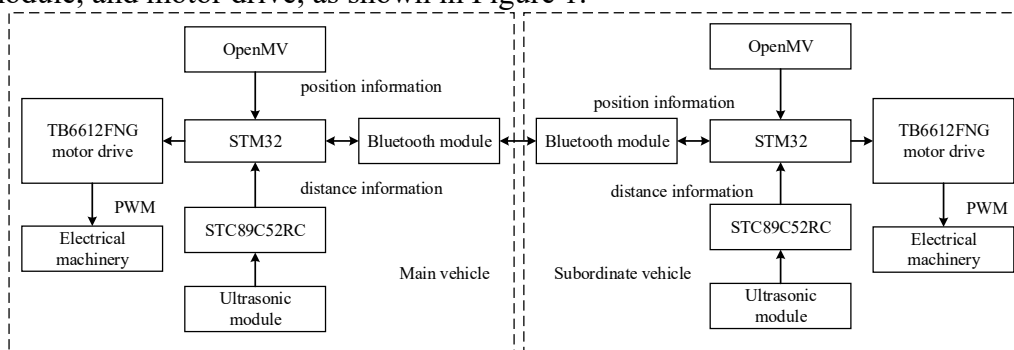


Figure 1. System overall structure diagram

The path recognition module adopts a high-performance and machine vision capable sensor module, OpenMV plus, with a 480MHz Cortex-M7 core processor STM32H746 and a 5-megapixel high-resolution OV5640 camera module, to meet the recognition design requirements. The microcontroller adopts ST Company's STM32F103ZET6, with a Cortex-M3 core and a frequency of 72MHz. It is rich in on-chip resources and has excellent data processing ability and fast interrupt response-ability, which can effectively complete various tasks of the system and calmly respond to multiple work scenarios of the system [13].

The HC-05 Bluetooth module is used for communication between the two vehicles. Due to the need to control the distance from the front vehicle as required, the secondary vehicle uses HC-SR04 ultrasonic sensor to detect obstacles ahead, and outputs distance information through STC89C52RC processing to return to the main control to follow the main vehicle. Vehicle tracking uses OpenMV to divide the captured image field of view into four parts: upper, lower, left, and right. In these four parts, different colors are selected based on different color thresholds, and the positions and sizes of color blocks are returned. The different signs identified, such as straight lines, intersections, turns, and parking signs, are then processed into direction-al information for PID control [14].

3. System Motion Model and Control Method

3.1 Vehicle modeling of multi-vehicle following system

For the convenience of modeling, a two-wheel differential drive robot model consisting of a vehicle body, two independent driving wheels, and a follower wheel is established, ignoring the slip that occurs during the movement of agricultural machinery. The follower wheel can only play a supporting role in the movement to maintain the balance of agricultural machinery and has little influence on the establishment of kinematics equations, which can be ignored. Figure 2 shows a

simplified model of agricultural machinery motion, with XOY as the navigation coordinate system; O is the origin of the navigation coordinate system; (x, y) represents any point on the trajectory, θ represents the attitude angle of the model relative to horizontal rotation during motion.

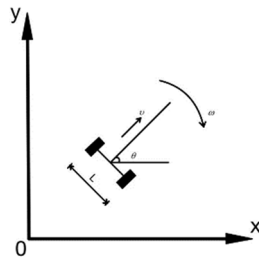


Figure 2. A simplified model for the motion of two-wheeled agricultural machinery

The model satisfies the non-holonomic constraint condition [15] without slipping, and the relationship between robot position (x, y) and attitude angle θ is expressed as follows:

$$\frac{\dot{x}}{\dot{y}} = \tan \theta \tag{1}$$

In the Cartesian coordinate system, the pose of a robot can be represented as $p(x, y, \theta)$, with a linear velocity of v and an angular velocity of ω , The motion equation of the robot is expressed as:

$$\begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta} \end{bmatrix} = \begin{bmatrix} \cos \theta & 0 \\ \sin \theta & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} v \\ \omega \end{bmatrix} \tag{2}$$

The pose of agricultural machinery is influenced by linear velocity v and angular velocity ω . According to the physical relationship between the distance traveled by agricultural machinery when turning and the speed of the left and right wheels, the relationship between the speed and angular velocity of agricultural machinery and the left and right driving speed can be obtained as follows [16].

$$\begin{bmatrix} v \\ \omega \end{bmatrix} = \begin{bmatrix} \frac{1}{2} & \frac{1}{2} \\ \frac{1}{d} & -\frac{1}{d} \end{bmatrix} \begin{bmatrix} v_l \\ v_r \end{bmatrix} \tag{3}$$

In the formula, d is the fixed axial distance between two wheels, v_l is the left wheel linear velocity, and v_r is the right wheel linear velocity. According to formula (3), the left wheel linear speed v_l and the right wheel linear speed v_r influence line speed v and angular speed ω . Therefore, through the microcontroller, a pulse that matches the expected linear and angular velocities of the steering is sent to drive the two-wheel motors of the vehicle, forming a speed difference for steering adjustment and control.

3.2 Path recognition and location line extraction

The system designed in the article uses an OpenMV visual module for environmental perception and path recognition tracking. At present, research often uses GPS positioning technology, which makes it impossible to perceive and process complex environments in real-time [17]. Most intelligent agricultural machinery is tracked and driven in a straight line in specific environments. The visual module can perceive the working environment in real-time, so based on the common field centripetal detour working environment, two elements, namely the curved path and the branching road, were selected for experimental tracking.

After the camera captures the image, it undergoes binary preprocessing. To distinguish the track route from other interfering elements, linear fitting is also performed on the binary image. The track route will be extracted as a diagonal line [18] for positioning and navigation (blue line in Figures 3 and 4). The midpoint of the lower boundary line of the OpenMV field of view image shown in Figure 4 is the origin, with the horizontal direction being the x-axis, and the line perpendicular to the lower boundary line and passing through the origin being the y-axis. The intersection coordinates x_0 and

slope k of the diagonal and x -axis represent the actual position information and actual rotation angle information of the current agricultural machinery, respectively.

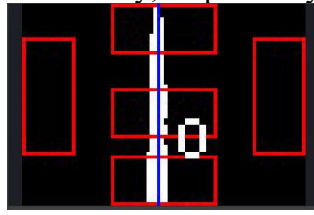


Figure 3. Linear path recognition

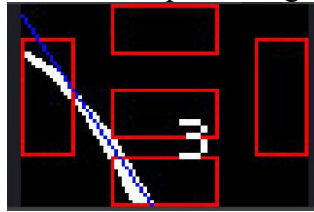


Figure 4. Curve Path Identification

The mathematical relationship between the actual rotation angle deviation α of agricultural machinery and the linear slope k of the track line fitted by OpenMV can be expressed by the following formula:

$$\alpha = \arctan k \quad (4)$$

It is expected that the current vehicle will follow the trajectory closely, without position deviation and angle deviation, so when the actual rotation angle deviation α is 90° and the position deviation coordinate x_0 is zero, the trajectory line fitted by OpenMV will be in the middle of the OpenMV field of view image. This indicates that the centerline of the vehicle coincides with the tracked path, which ensures that the vehicle accurately tracks the path in real-time. Therefore, the feedback deviation e_k of PID control can be expressed by angle deviation α and position deviation coordinate x_0 :

$$e_k = b * (90^\circ - \alpha) + (1 - b) * x_0 \quad (5)$$

In the equation, α Both x_0 and x_0 represent the current actual angle orientation information of the vehicle; b is the proportion coefficient, representing the proportion of the fusion of two deviations. The feedback information e_k is the difference between the expected angle deviation information of the agricultural machinery and the actual observation position of the vehicle angle using OpenMV.

The feedback information is transmitted to the MCU through OpenMV serial communication, facilitating vehicle steering control and successfully achieving the tracking of the car along the marked path. The specific recognition results of OpenMV are shown in Figure 3. If the straight path recognition is successful, the number 0 will be returned, and if the curve path recognition is successful, the number 3 will be returned.

When there are three forked intersections in the marked path, it is necessary to identify the forked intersections. Using the Color Block Detection Function `find` in `OpenMV_Blobs()` is used to determine whether there are marked routes in the pre-designated recognition area. Taking a three-way intersection as an example, its characteristic is that there are still other sub-paths beyond the left or right side of the normal straight path. Therefore, the recognition area is defined on the left and right sides of the OpenMV frame buffer. When a normal straight path appears and the designated area also detects the path, it can be determined that the current position is a fork intersection [19], so that the car can choose to turn or continue moving according to the command. The specific recognition results of OpenMV are shown in Figure 5, where the number 1 is returned if the bifurcation recognition is successful.

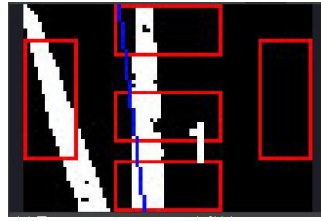


Figure 5. Schematic diagram of identifying branching intersections

3.3 Steering control of multi-vehicle following system

3.3.1 PID control algorithm

The discrete PID control is used in the article. The discrete PID consists of three parts: Proportional (P), Integral (I), and Derivative (D), as shown in Figure 6.

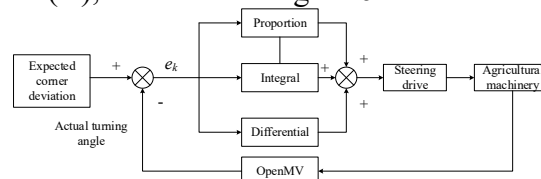


Figure 6. PID algorithm block diagram

The mathematical relationship between the output parameter y_k and the input parameter e_k of proportional integral differential control for discrete systems is expressed as follows:

$$y_k = k_p * e_k + k_i * \sum_{j=0}^k e_j + k_d * (e_k - e_{k-1}) \quad (6)$$

In the equation, k_p is the proportional coefficient, k_i is the integral coefficient, k_d is the differential coefficient, and e_k is the regulator deviation value calculated from the feedback information of the system through the mathematical relationship shown in equation (5).

Among them, adjusting the k_p coefficient can enhance the sensitivity of the system to identify the correct path and speed up the response of the system. Adjusting the k_i coefficient can improve the accuracy of the system's path identification. Adjusting the k_d coefficient can reduce the body oscillation during the movement process of agricultural machinery systems and improve the stability of agricultural machinery. At the same time, it can also accelerate the path recognition speed of the system, thereby improving the dynamic performance of the system [20].

In the article, the PWM output of the left and right wheel motors is adjusted according to the size of y_k to achieve differential steering and automatic trajectory tracking. At the same time, the HC-SR04 ultrasonic ranging module is added to the vehicle to control the distance from the previous vehicle, and the priority is higher than PID control.

3.3.2 Control parameter tuning for path tracking

Agricultural machinery operates in different motion scenarios on the farm, and using the same PID parameters can cause it to shake on straight roads and turn insufficiently or discontinuously when turning. Therefore, the article proposes the use of different PID control methods for straight and curved paths, where the curved path adopts dual closed-loop cascade PID control.

Linear path PID control. For the determination of PID parameters, the binary method is used in the article to gradually reduce and determine the parameter range. Adjust the k_d parameter so that the car can move forward with small amplitude and equal amplitude oscillation on the straight track. Adjust the k_i parameter until the car is adjusted to travel along the center of the straight line without interference. Adjusting the k_d parameter, as differential control will suppress proportional control, first increase the k_p value by less than 10%, then use the binary method to narrow the range of k_d while fine-tuning the k_p value until the car can drive steadily along the straight path.

Cascade PID steering control for the curved path. Considering that the master and slave vehicles drive at differential speeds on curves, motion control is more precise than on straight roads. The difference between the position angle of the vehicle when turning and the trajectory angle observed

by OpenMV is used as the entrance parameter of the cascade PID angle outer loop, and its output is used as the set value of the speed inner loop PID. The speed inner loop output controls the motor speed, thus having a better control effect on the controlled variables in the outer loop. The internal and external loop tuning of the cascade PID also uses the binary method for parameter determination.

4. System Hardware Design

4.1 Power supply and motor drive design

Figure 7 is the driving and power supply stabilization circuit diagrams of the DC motor used in the simulation of agricultural machinery in the text. The motor drive adopts a DC motor driver component TB6612FNG produced by Toshiba Corporation. It has a high current MOSFET-H bridge structure, dual channel circuit output, and can drive two motors simultaneously. It has characteristics such as high integration, strong driving ability, and flexible control methods. The power regulator circuit adopts a highly integrated and efficient synchronous buck DC-DC converter MT2492, which reduces the external battery input voltage to 5V. The voltage input range of MT2492 is 4.5V-16V, and the maximum input current can reach 3A, providing excellent transient response without the need for additional external compensation components. This device includes an internal low resistance high-voltage power MOSFET with a working frequency of up to 600K, ensuring a compact and efficient design with excellent AC and DC performance [21].

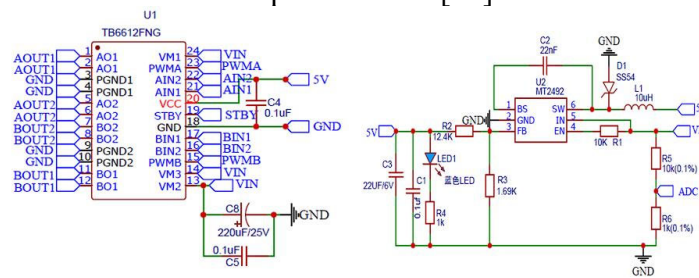


Figure 7. TB6612 motor drive circuit and 5V power supply regulator module circuit

4.2 Mechanical structure design of the entire vehicle

Figures 8 and 9 are physical images of the main and auxiliary vehicles. The mechanical structure of the vehicle is a rear-wheel drive tricycle, consisting of two motor-driven wheels and one driven wheel. Both the master and slave vehicles are composed of OpenMV visual modules, Bluetooth modules, and microcontrollers. In addition, the following operation is carried out by using ultrasonic modules to maintain a specified distance from the vehicle.

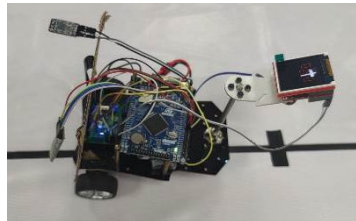


Figure 8. The physical image of the main vehicle

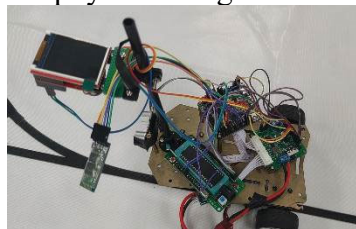


Figure 9. The physical image of the subordinate car

5. Agricultural machinery operation process

5.1 Overall operation process

The multi-vehicle following operation of agricultural machinery not only needs to consider planning the path of a single agricultural machinery but also considers the task allocation and operation process of the agricultural machinery group. The core task flow of the multi-vehicle following system designed in this article is divided into the main vehicle system and the slave vehicle system. The MCU of the main vehicle system generates a fixed time timer interrupt to achieve the output calculation of the PID controller and analyze the data received from OpenMV. The specific communication task flow between OpenMV and MCU is shown in section 5.3. Then the microcontroller performs corresponding operations based on the parsed command data. If OpenMV recognizes that the trajectory of the farm is a straight line, then controls the motor to drive normally in a straight line; If a three-way intersection is identified and the command requires finding the inner lane, the main control MCU controls the motor to turn at a differential speed. OpenMV recognizes a parking sign and will stop the motor when stopping. The entire control process achieves PID closed-loop, and commands are also sent to the slave vehicle through the Bluetooth module when the main vehicle starts and runs. The specific communication task process of Bluetooth is shown in section 5.2. The main vehicle program flowchart is shown in Figure 10.

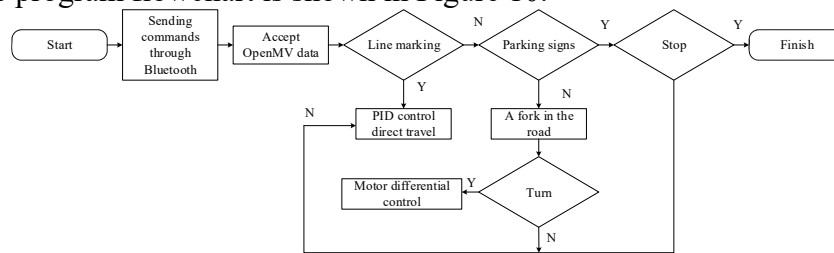


Figure 10. Main vehicle operation flowchart

In addition to the basic tracking function of the main vehicle, the slave system also needs to accept commands from the main vehicle to start through the Bluetooth module. The slave vehicle also needs to have the HC-SR04 ultrasonic ranging module to maintain a certain distance from the main vehicle. When the distance is less than the set value, the motor will immediately stop rotating. The slave vehicle program flowchart is shown in Figure 11.

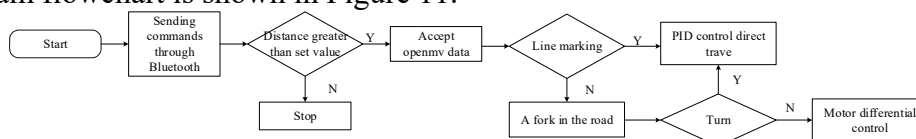


Figure 11. Subordinate vehicle operation flowchart

5.2 Bluetooth communication task flow and protocol specifications

During the system operation, the main vehicle will send corresponding instructions to the slave vehicle based on the specific work scenario, instructing them to cooperate with it to complete the corresponding tasks. The slave vehicle will return to the corresponding working status to the main vehicle, making it convenient for the main vehicle to command and control it.

We have formulated corresponding protocol specifications for the information sent by Bluetooth and stipulated that the first digit of the information sent by Bluetooth is the sender's number, the second digit is the receiver's number, the third digit is the delimiter "#", and the fourth and subsequent digits are used as data bits, which can be control commands sent by the main vehicle to the slave vehicle or operation status information returned by the slave vehicle to the main vehicle [22]. The main vehicle program flowchart and slave vehicle program flowchart of Bluetooth communication are shown in Figure 12 and Figure 13.

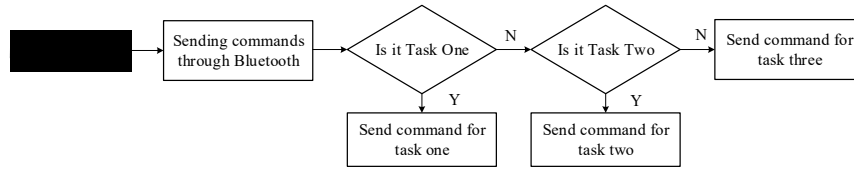


Figure 12. Main vehicle Bluetooth communication flowchart

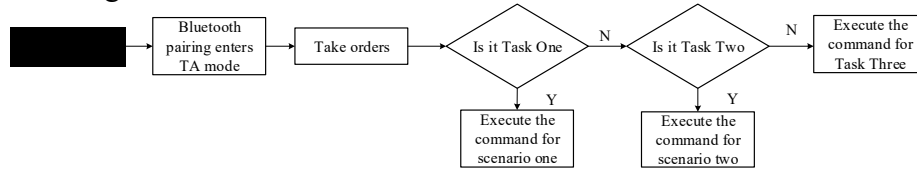


Figure 13. Subordinate vehicle Bluetooth communication flowchart

5.3 OpenMV communication task process

The communication between OpenMV and MCU is mainly carried out through serial communication, mainly through the serial port interrupt of the microcontroller. The data received by the serial port interrupt is stored in the data buffer, and the received data is analyzed in the main function. Firstly, ensure that the frame header and frame footer are complete and reliable. After checking whether the data format and length are reasonable and correct, the communication process is shown in Figure 14.

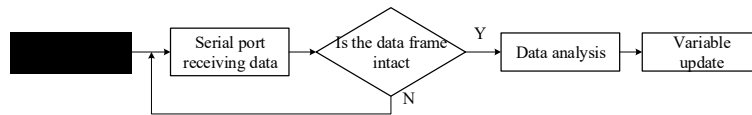


Figure 14. OpenMV and MCU serial communication flowchart

6. Experiment

6.1 Testing tasks

The detour method is a commonly used process route planning method for agricultural machinery operations. Agricultural machinery will perform centripetal detours from the outer circle to the inner circle in the field. Therefore, three testing tasks were designed based on the detour method to test the recognition success rate and multi-vehicle cooperation ability of OpenMV. The experimental test uses a map shown in Figure 15 to simulate the farm environment of multiple agricultural machineries working together. The map is divided into inner and outer circles, with point A being the parking point.

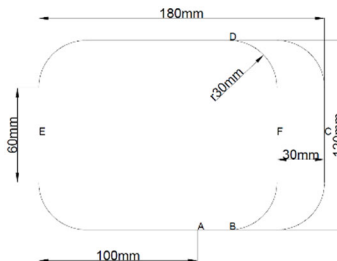


Figure 15. Schematic diagram of the on-site following driving test site

The main vehicle represents the harvester, and the secondary vehicle represents the grain transport vehicle. The following three testing tasks are set as follows.

Task 1: Conduct tests on the recognition of road elements and communication between two vehicles by the system in both stationary and moving states.

Task 2: Considering the different parking positions of the grain transport truck and the harvester after the completion of the operation, the grain transport truck will start at the same time when it lags behind the harvester for a certain distance before the next operation begins. After the specific test begins, start the two vehicles at different positions on the homework map, so that the subordinate

vehicle can catch up with the main vehicle within two laps, and maintain a distance of 20cm to follow the vehicle until it stops.

Task 3: After the grain truck is filled with grain, it needs to enter the unloading point. During the test, the grain truck needs to overtake the harvester in the second circle to simulate its entry into the unloading point; After the unloading of grain is completed, the grain truck needs to return to the operating point to continue cooperating with the harvester for grain harvesting operations. During testing, the harvester is used to simulate the completion of grain unloading by running the inner circle of the harvester and overtaking the grain truck. After the specific test begins, place the main vehicle at the starting position and the secondary vehicle at a distance of 20cm behind the main vehicle. The two vehicles depart at the same time and drive three laps respectively. The first lap follows the main vehicle normally, and both vehicles operate normally in the outer circle; In the second lap, the grain truck represented by the cart is filled with grain and passes through the inner circle to the unloading point, running at low speed and waiting for the harvester to pass; In the third lap, the harvester represented by the main vehicle undergoes reverse overtaking through the inner circle and returns to the normal operation mode of the grain truck following the harvester. After the reverse overtaking, the two cars will continue to drive on the first lap until the end of the third lap.

6.2 Test Results and Analysis

6.2.1 Task 1

Repeat the experiment 20 times with the test vehicle model at rest and 20 times with the vehicle model in motion under the same conditions, and record the number of successful recognitions of road elements, as shown in Tables 1 and 2.

Table 1. Test results of road element recognition at rest.

| Road Elements | Number of successful recognition attempts |
|--------------------------|---|
| Line | 20 |
| Bifurcation Intersection | 20 |
| Parking Sign | 20 |

Table 2. Test results of road element recognition during movement.

| Road Elements | Number of successful recognition attempts |
|--------------------------|---|
| Line | 19 |
| Bifurcation Intersection | 18 |
| Parking Sign | 19 |

The test is carried out according to the test method of the Bluetooth communication test, and the results of the 20-time Bluetooth test are shown in Table 3.

Table 3. Bluetooth Communication Test Results.

| Sender | Receiver | Number of successful communications |
|---------------------|---------------------|-------------------------------------|
| Subordinate Vehicle | Main Vehicle | 20 |
| Main Vehicle | Subordinate Vehicle | 19 |

From the data in Table 1 and Table 2 above, it can be seen that the success rate of OpenMV in identifying road elements in a stationary state is as high as 100%. But in motion, OpenMV's ability to recognize road elements will decrease, with an average success rate of 93.3%. In Bluetooth communication testing tasks, the average success rate of system communication success is 97.5%. In summary, it can be seen that the use of the OpenMV visual module and Bluetooth module in the article enables the multi-vehicle following collaborative system to have excellent recognition ability and good communication quality.

6.2.2 Task 2

Complete Task 2 20 times at three different speeds and record the tracking operation of the two vehicles. The test results are shown in Tables 4, 5, and 6.

Table 4. Test Results at a Speed of 0.3m/s.

| Starting distance /cm | Normal communication times | The normal number of stops | Number of rear-end collisions | Number of derailments | Parking distance /cm |
|-----------------------|----------------------------|----------------------------|-------------------------------|-----------------------|----------------------|
| 20 | 20 | 20 | 0 | 0 | 19.6 |
| 80 | 20 | 20 | 0 | 0 | 19.5 |
| 160 | 19 | 20 | 0 | 0 | 19.6 |

Table 5. Test Results at a Speed of 0.6m/s.

| Starting distance /cm | Normal communication times | The normal number of stops | Number of rear-end collisions | Number of derailments | Parking distance /cm |
|-----------------------|----------------------------|----------------------------|-------------------------------|-----------------------|----------------------|
| 20 | 20 | 20 | 0 | 0 | 19.4 |
| 80 | 20 | 19 | 0 | 0 | 19.5 |
| 160 | 19 | 19 | 0 | 1 | 19.4 |

Table 6. Test Results at a Speed of 1m/s.

| Starting distance /cm | Normal communication times | The normal number of stops | Number of rear-end collisions | Number of derailments | Parking distance /cm |
|-----------------------|----------------------------|----------------------------|-------------------------------|-----------------------|----------------------|
| 20 | 20 | 19 | 0 | 1 | 19.0 |
| 80 | 20 | 18 | 0 | 2 | 19.0 |
| 160 | 18 | 18 | 0 | 2 | 19.1 |

From the data in Tables 4, 5 and 6 above, it can be seen that the average rear-end collision rate of the system is 0%, the average communication success rate is 97.8%, the average parking rate is 96.1%, and the derailment rate is 3.3%. The average rear-end collision rate is 0, which indicates that the use of ultrasonic modules as obstacle avoidance sensors greatly improves the safety of the system. From the data in the three tables, it can be concluded that the system performs well at low speeds, but as the operating speed gradually increases, the system's recognition ability, communication ability, and safety distance between multiple workshops all decrease.

6.2.3 Task 3

According to the requirements of task three, place the main vehicle at point A, follow the small car, and place it 20cm behind the main vehicle. Record the running status of each vehicle within three laps for 20 tests in Table 7.

Table 7. System operation status.

| Number of cycles the system runs | Number of correct runs of the main vehicle | Number of correct runs of the subordinate vehicle |
|----------------------------------|--|---|
| The First Circle | 20 | 20 |
| The Second Circle | 20 | 19 |
| The Third Circle | 18 | 18 |

From the data in Table 7 above, it can be seen that the success rate of the first round of the system is 100%, the success rate of the second round is 95%, and the success rate of the third round is 90%. The high success rate of these three laps indicates that based on machine vision modules, combined with the use of obstacle detection sensors, embedded microcontrollers, and PID control algorithms

are used to enhance the reliability of automatic navigation and multi-vehicle collaborative following methods, effectively verifying the accuracy of navigation and multi-vehicle collaboration in the multi-vehicle following collaborative system.

7. Conclusions

Automatic navigation and multi-vehicle collaborative following are key technologies for successfully achieving multi-vehicle unmanned following operations. With the widespread application of automation technology in the field of agricultural machinery, intelligent agricultural machinery based on GPS positioning technology and sensor technology has flourished. However, due to the instability of satellite positioning signals and the limitations of relying solely on obstacle detection sensors, the article proposes a multi-vehicle unmanned following operation driving system based on OpenMV, which utilizes machine vision modules, combined with obstacle detection sensors, and adopts embedded microcontrollers and PID control algorithms to enhance the reliability of automatic navigation and multi-vehicle collaborative tracking. The following conclusions were drawn through experiments:

(1) Through the design of the structure of the multi-vehicle unmanned operation following the driving system and the kinematics analysis of agricultural machinery, the model and motion equation of agricultural machinery motion control was established, and the system design was studied from the hardware circuit and software control.

(2) In the article, OpenMV visual module is used to extract positioning lines and track trajectories. For different operating scenarios, a dual closed-loop cascade PID control method for agricultural machinery steering is established, which enhances the accuracy and stability of agricultural machinery navigation and driving;

(3) According to the task requirements, the workflow of the main and subordinate vehicles was designed in the article, and low-latency Bluetooth modules were used for task allocation and information transmission, which improved the timeliness and collaboration of multi workshop communication.

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