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Autonomous charging docking control method for unmanned vehicles based on vision and infrared

Yunya Zhou[12], Yang He[3*], Yu Yan[12], Fang Li[4], Neng Li[1], Chaofeng Zhang[12], Zijian Lu[2a], Zhiyong Yang[3b]

[1]State Grid Hunan Electric Power Company Limited Ultra High Voltage Substation Company, Changsha 410301, China

[2]Laboratory of substation intelligent operation and inspection State Grid Hunan Province Electric Power Co., Changsha 410301, China

[3]School of Mechanical Engineering, Hubei University of Technology, Wuhan 430068, China

[4]Guangdong Kekaida Intelligent Robot Co., Foshan 528300, China

[*]maxhe1020@163.com, [a]RobertLZJ027@163.com, [b]yzy017@126.com

Abstract—Unmanned vehicle charging is part of the autonomous workflow of unmanned vehicles. Most existing unmanned vehicles mostly rely on manual battery change or manual charging, which cannot realize autonomous charging. In order to achieve simpler and safer autonomous charging for unmanned vehicles, this paper proposes a new intelligent unmanned vehicle autonomous charging docking method based on infrared guidance and vision assistance. Firstly, the autonomous charging device and intelligent charging stand for unmanned vehicles are designed, and for the unmanned vehicle, charging is not easy to align and easy to detach when charging. The camber-type electric core and charging adsorption device are designed, respectively, and the autonomous charging docking device is designed. Secondly, in order to ensure the accuracy of the docking between the unmanned vehicle and the intelligent charging stand, the unmanned vehicle autonomous charging method is proposed. The combination method of infrared and vision adjusts the posture of the unmanned vehicle. Finally, a protection method of autonomous charging docking based on ultrasonic ranging of unmanned vehicles is proposed. The communication and ranging modules on the unmanned vehicle and intelligent charging stand are designed to prevent mistouching and obstacle avoidance to ensure the safety of the system. The experiment results show that the docking method of this unmanned vehicle autonomous charging system is accurate, efficient, and safe, which can satisfy the demand for unmanned vehicle autonomous charging.

1. Introduction

Unmanned vehicle charging is part of the autonomous workflow of unmanned vehicles, and the unmanned vehicle charging station contains functions such as unmanned vehicle communication, charging docking guidance, and charging. The unmanned vehicle determines whether it needs to be charged and starts charging back autonomously when the power is low. There are various ways to dock unmanned vehicles for autonomous charging [1], and most existing small robots rely on machine vision, laser, infrared and other methods to guide the robot charging plug to dock with the charging stand to complete autonomous charging. Most unmanned vehicle charging solutions apply the method of map building and navigation. When the unmanned vehicle is low on power, it returns to the corresponding charging area according to the built map and relies on manual battery change or manual charging, but it cannot achieve autonomous charging. To improve the efficiency of unmanned vehicle charging docking, it is of great importance to propose a safe docking algorithm for the autonomous charging of unmanned vehicles.

The back charging of mobile robots can be traced back to the emergence of mobile robots. Walter [2] used light to guide the robot to the charging area in 1948, and most robots still follow this idea for autonomous charging. However, the docking method is relatively simple and cannot guarantee the accuracy of charging docking. Silverman et al. [3] designed a charging stand, and the robot and the pile communicate. The robot is charged back autonomously through a battery voltage monitoring algorithm and docking control algorithm. However, the docking accuracy is not high by using only vision to guide docking through markers, which may lead to poor electrode contact during charging. Wu et al. [4] applied vision rough positioning on the inspection robot, precious positioning by variable theory domain fuzzy control method, and feedback on docking status based on the pressure sensor under the charging electrode. Although this method had a high docking success rate, the judgment of obstacles in the docking path was not performed. Su et al. [5] obtained the coordinates of the charging electrode through the communication between the robot and the charging electrode and then performed docking by laser ranging. This method is simple, but the docking accuracy is poor. Secuianu and Lupu [6] designed a complete robot charging control algorithm, and the robot discriminates the charging stake for docking charging by vision but using only the visual approach leads to a low docking success rate.

At present, there are still the following problems with the autonomous charging of unmanned vehicles.

1. The charging stand cannot judge the obstacle when charging docking.
2. It is not locked when the unmanned vehicle is charging, which may lead to unstable charging.
3. It does not do the anti-mistake treatment to the charging stand.

These problems not only lead to the lack of intelligence of unmanned vehicle products but also lead to the danger of autonomous charging. In response to the above problems, we propose a docking method with safe autonomous charging for unmanned vehicles. We design an autonomous charging device and charging stand for unmanned vehicles and verify the charging success rate as well as the safety of the charging system.

2. Autonomous charging devices in unmanned vehicles and intelligent charging stand

The charging stand, the unmanned vehicle autonomous charging assistance module, and the charging docking lane are shown in Fig. 1 The smart charging stand base is fixedly placed against the wall and is located right in the middle of the lane. Meanwhile, the two-lane lines have the same color and a certain contrast with the surrounding environment color to help unmanned vehicles dock visually. The unmanned vehicle enters the lane when the power is low, extracts the lane lines through the camera, and performs rough positioning visually. It continuously adjusts the body posture to keep the unmanned vehicle roughly in the center of the lane to drive in reverse. After the rough positioning is finished, the precious positioning is started with an infrared-based approach. The smart charging cradle emits infrared light to keep the infrared receiver at the rear of the car able to receive infrared light at all times. When the infrared cannot be received, the body deflection is judged by the lane line and the center captured by the camera, and the direction is adjusted to finally complete the docking.

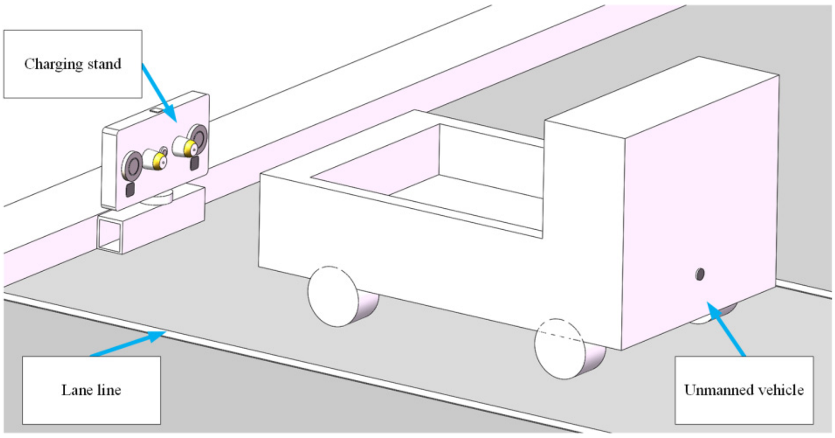


Fig. 1 Autonomous charging docking system

2.1. Charging stand design

The charging stand includes charging, charging locking, docking guidance, and other functions, and the design of the charging stand is concerned with the accuracy and safety of charging docking. The charging stake includes a charging panel bracket and a charging panel mounted above said charging panel bracket, wherein said charging panel is provided with a first charging module including two electric cells and a pressure sensing device set on top of the electric cells for sensing an unmanned vehicle and charging; a first adsorption module for adsorbing an unmanned vehicle while charging; a first distance measuring module for detecting the distance between an unmanned vehicle in the charging docking lane. The first charging guidance module is used to guide the unmanned vehicle for charging positioning docking; the first communication module is used to communicate with the unmanned vehicle; the first control module is electrically connected to the first charging module, the first adsorption module, the first ranging module, the first charging guidance module, and the first communication module, respectively.

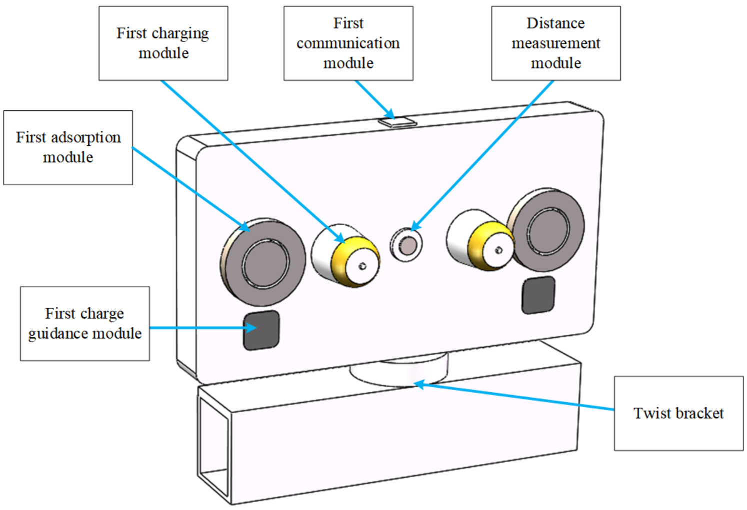


Fig. 2 Intelligent charging station

2.2. On-board charging device design

The unmanned vehicle charging device has the functions of charging, charging locking and charging docking, etc. In order to ensure the accuracy of the docking between the unmanned vehicle and the smart charging stand, the sensor, charging device, and charging locking device need to correspond to each other. The autonomous charging auxiliary module of the unmanned vehicle includes a vision module, which is set in the middle of the front of the unmanned vehicle for detecting obstacles or charging docking lane lines; a second charging module, a second adsorption module, a second ranging module, a second charging guidance module, and a second communication module, all of which are set in the rear of the unmanned vehicle and are respectively connected to the first charging module, the first adsorption module, the first ranging module, the first charging guidance module, and the first communication module. The second control module is electrically connected to the second charging module, the second adsorption module, the second ranging module, the second charging guidance module, and the second communication module, respectively.

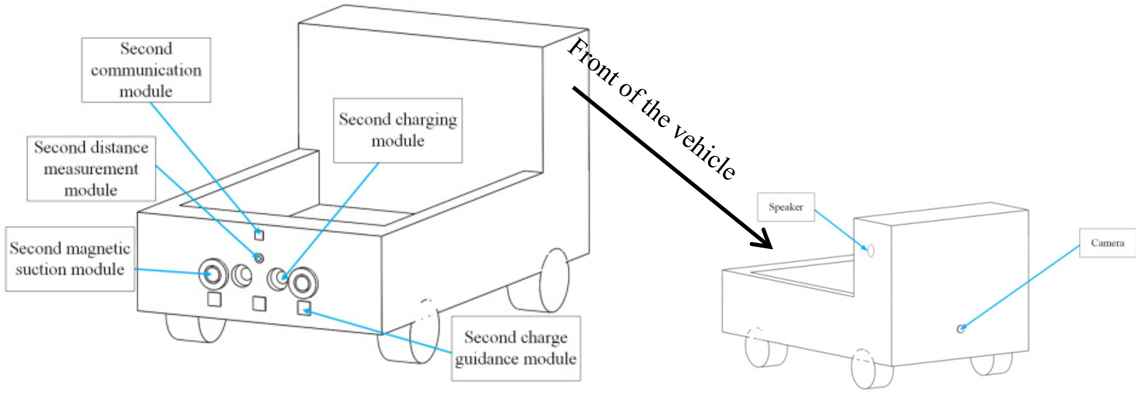


Fig. 3 Unmanned vehicle charging system

3. A control method of adsorption type unmanned vehicle automatic charging device by fusing vision and infrared

Autonomous charging docking is required when the unmanned vehicle is low on power or on charging standby. Among them, autonomous charging docking is divided into three parts: charging preparation, rough positioning, and precious positioning. Since the unmanned vehicle cannot steer in place, when the unmanned vehicle is located in the charging preparation area, it first performs the body orientation and enters the charging lane. After entering the charging lane, rough positioning is started. The distance between the top and bottom of the lane line in the image captured by the head camera and the axis in the image is used to judge the deflection of the body. Then, the adjustment is made. When the infrared signal cannot be received by the middle infrared receiver of the second charge guidance module, precious positioning starts. The precious positioning carries out the adjustment of body attitude by infrared guidance and visual assistance. Since the left and right infrared are aligned with the adsorption module, the adsorption charging can be successfully carried out after the infrared module is aligned. The detailed steps are as follows.

1) The unmanned vehicle enters the preparatory charging area, and the unmanned vehicle sends a preparatory charging signal to the first communication module of the charging stand through the second communication module.
2) After receiving the signal, the first communication module detects obstacles through the first ranging module to the charging docking lane. At the same time, the unmanned vehicle conducts obstacle detection in front of the vehicle through the vision module.
3) When there are no obstacles in the charging docking lane and in front of the vehicle, the unmanned vehicle uses the vision module to photograph the lane line reality of the charging docking lane, drives into the charging docking lane and enters the rough positioning area, and starts charging docking rough positioning reversing.
4) When the unmanned vehicle reaches the preset threshold of the rough positioning area and the precious positioning area, the unmanned vehicle is guided into the precious positioning area by the vision module and the second charging guidance module and reverses so that the second charging

module fits with the first charging module; at the same time, the second adsorption module and the first adsorption module carry out adsorption so that the unmanned vehicle and the charging stand are locked tightly.

5) When the unmanned vehicle and the charging stand are connected to meet the preset anti-touch conditions, the charging stand is energized.
6) After charging is completed, the first adsorption module and the second adsorption module generate a repulsive force so that the unmanned vehicle is detached from the charging stand.

Moreover, in order to ensure charging safety, the control method is designed for the problem that most of the current unmanned vehicle charging stand charging point cells are exposed to cause danger.

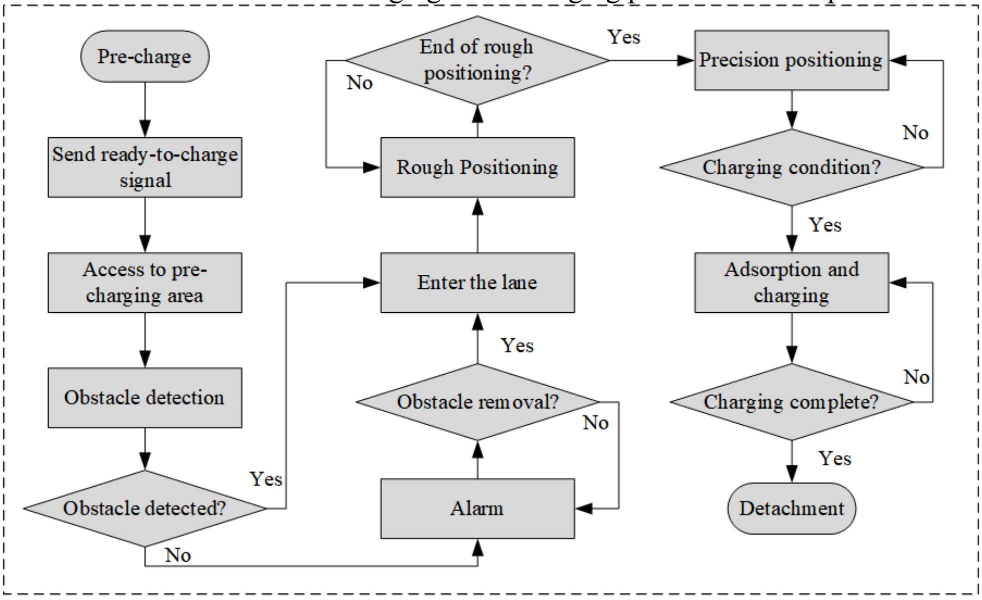


Fig. 4 Autonomous charging control method

3.1. Automatic charging docking method for unmanned vehicles

3.1.1. Charge preparation

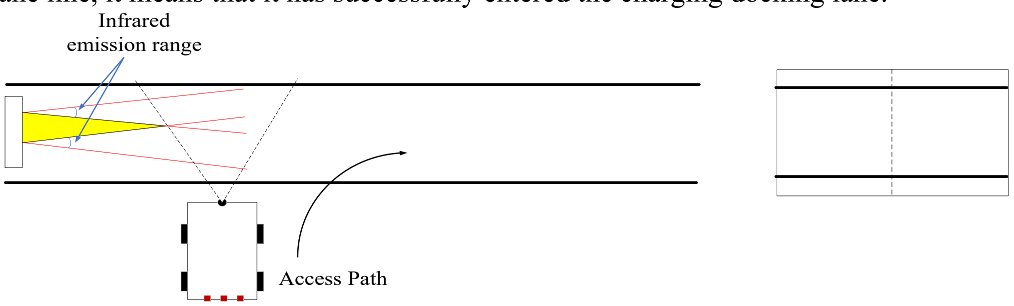
When the unmanned vehicle is low on power, it returns to the side of the charging docking lane. The unmanned vehicle enters the preparatory charging area and prepares to dock for charging. The unmanned vehicle sends a preparatory charging signal to the charging stand via the second communication module. When the charging stand receives the ready charging signal, the first control module sends a command to control the charging stand to turn on the first ranging module and the first charging module. The first distance measurement module starts to measure the length of the road surface of the charging docking lane. If the measured distance is less than the preset road surface length, there is an obstacle on the road surface of the charging docking lane; meanwhile, the unmanned vehicle detects the obstacle in front of the vehicle through the vision camera. If there is an obstacle, the unmanned vehicle keeps stopping and emits a warning tone through the alarm module to alert the staff that there is an obstacle on the charging docking lane that affects the docking obstacles. If the obstacle is removed or not detected by the unmanned vehicle and the charging stand, charging docking continues. In addition, during docking, the unmanned vehicle and the charging stand always keep the obstacle detected, which greatly improves safety during charging docking.

3.1.2. Access to charging docking lanes

Based on the vision camera shooting the lane lines of the charging docking lane to guide the unmanned vehicle into the charging docking lane, when the left and right lane lines appear on both sides of the central axis of the vision camera shooting screen, the charging docking rough positioning reversal is prepared. At this time, the ultrasonic range sensor at the rear of the vehicle is turned on to transmit ultrasonic waves to the charging panel for ranging. At the same time, the ultrasonic range radar on the charging panel sends ultrasonic waves to the unmanned vehicle for ranging. Based on whether the distance measurement values obtained by the unmanned vehicle and the charging panel are equal and the rate of change of the distance measurement values, we judge whether there are obstacles in the charging docking lane. If no obstacle exists, the charging docking rough positioning and charging docking precious positioning are started, and obstacle detection is always maintained during the positioning process.

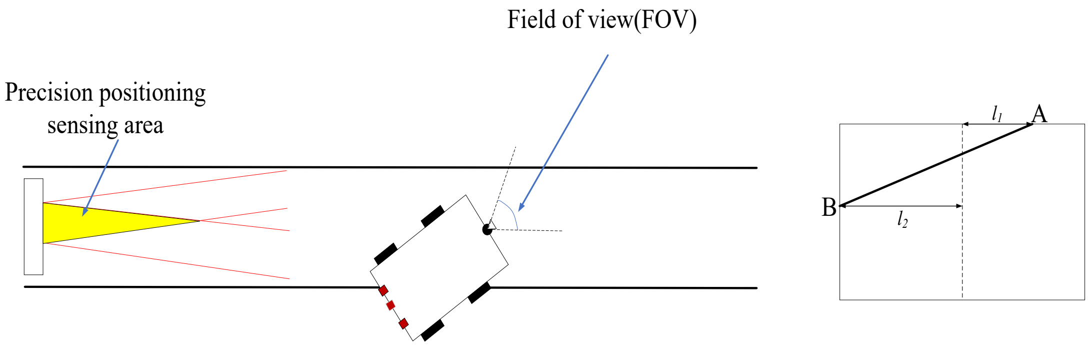
Specifically, the specific adjustment process of the unmanned vehicle entering the charge docking lane is as follows:

When there are no obstacles on the charge docking lane, the unmanned vehicle detects the two lane lines of the charge docking lane by the vision camera. The unmanned vehicle is located in the preparation charging area (shown in Fig. 5(a)). When the vision camera detects the left and right lane lines (shown in Fig. 5(b)), the unmanned vehicle prepares to turn right into the charging docking lane (Fig. 6(a)). As the unmanned vehicle in the process of turning into the lane near the unmanned vehicle end of the lane line will be lost in the vision camera's field of view, the vehicle's turn adjustment to the upper lane line of the screen, that is (Fig. 6 (b)) in the AB. This process always measures the two ends of lanes A and B in the shooting screen. l_1 in the Figure is the distance from point A to the central axis of the camera, and l_2 is the distance from point B to the central axis of the camera. If point A is on the right side of the central axis of the screen, the vehicle is entering the lane. Then, the turning angle is increased until AB is on the same side and the driving direction of the unmanned vehicle is fine-tuned, keeping l_1 and l_2 unchanged in driving. When the camera of the unmanned vehicle can capture the second lane line, it means that it has successfully entered the charging docking lane.



（a）Preparing to enter the charging lane （b）Image in camera

Fig. 5 Unmanned vehicle ready for charging



（a）Entering the charging lane （b）Image in camera

Fig. 6 Unmanned vehicles begin the charging process

3.1.3. Charge docking rough positioning

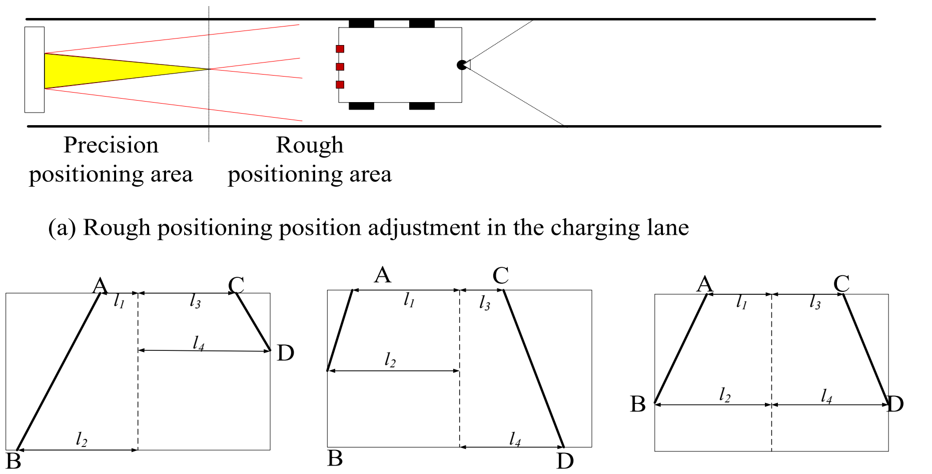
Since the body of the unmanned vehicle is generally larger, each body attitude adjustment requires a certain turning radius. Thus, a rough positioning is performed to align the second charging module with the first charging module. During the reversing process of rough positioning, the vision camera to the left and right lane lines of the charging docking lane takes a picture. According to the size of the distance between the top and bottom of the left and right lane lines in the picture and the central axis of the picture, we determine whether the unmanned vehicle is driving on the center line of the charging docking lane and adjust the unmanned vehicle so that it drives on the center line of the charging docking lane. When the third infrared receiver in the second charging guidance module in the middle of the rear of the unmanned vehicle fails to receive the infrared signal, it indicates that the rough positioning of the charging docking of the unmanned vehicle is over, and the precious positioning of the charging docking is started. Specifically, the specific adjustment process of the unmanned vehicle for charge docking rough positioning is as follows.

Before the unmanned vehicle prepares to enter the charge docking lane in the preparation charging area, it sends a preparation charging signal to the charging stand through the second communication module. The charging stand opens the first charging guidance module after receiving the signal. The first charge guidance module emits a preset angle infrared beam, i.e., an infrared signal. When all three infrared receivers at the rear of the car can receive the infrared signal, it indicates that the unmanned car is docking rough positioning for charging. At this time, the unmanned car starts to reverse (Fig. 7 (a)). At the same time, the two lane lines are detected and starts to measure the distance l_1, l_2, l_3, and l_4 between the four points A, B, C, and D, respectively and the central axis of the shooting screen (Fig. 7 (b, c, and d)). At this time, the following situation exists:

1) If $l_4 > l_2$, the unmanned vehicle to the right fine-tunes the reverse, l_4 decreases, l_2 increases, l_1 decreases, and l_3 increases. As the vehicle goes back to the right, it will also travel a distance to the right rear. Hence, when the size of l_4 is close to the size of l_2, it starts back in the opposite direction, l_4 slowly decreases, l_2 slowly increases, l_1 increases, and l_3 decreases. Until l_1 is equal to l_3, it stops back to the right. It continues to reverse backward and keeps adjusting, keeping $l_1=l_3$, $l_2=l_4$, basically keeping in the middle of the lane line straight backward (Fig. 7 (b)).
2) If $l_4 < l_2$, then no one car to the right fine-tunes the reverse, l_4 increases, l_2 decreases, l_1 increases, and l_3 decreases. As the vehicle back to the right, it will also travel a distance to the left rear. Therefore, when the size of l_4 is close to the size of l_2, it starts to back in the opposite direction, and l_4 slowly increases, l_2 slowly decreases, l_1 decreases, and l_3 increases when back to the right. Until l_1 is equal to l_3, it stops back to positive (Fig. 7(c)).

According to the above method, the unmanned vehicle is adjusted until the vision camera takes a picture of Fig. 7 (d), which in turn causes the unmanned vehicle to reverse in a straight line along the central axis.

In the rough positioning stage of the unmanned vehicle, there is a certain distance between the first charge guidance module of the charging stand and the unmanned vehicle. The first charge guidance module emits infrared beams at a preset angle so that the two sets of infrared emitters of the first charge guidance module emitting infrared beams will form a triangular signal-free zone inside (Fig. 7 (a)). When the third infrared receiver in the second charge guidance module of the unmanned vehicle cannot receive the infrared signal, the rough positioning of the charge docking ends.



(a) Rough positioning position adjustment in the charging lane

(b) Camera image when shifted to the left (c) Camera image when shifted to the right (d) Camera image when no shift

Fig. 7 Unmanned vehicle charging rough positioning

3.1.4. Charge docking precision positioning

When the first charging module is inaccurately docked with the second charging module, it is easy to cause bad extrusion between the charging modules and damage the charging modules. Moreover, it is prone to poor contact, generating electric sparks and damaging the charging parts. Precision positioning ensures the accuracy of docking, avoids the effectiveness of charging docking, and ensures the safety of charging. During the charging docking precious positioning reversing process, the unmanned vehicle determines whether the unmanned vehicle is offset according to whether the first and second infrared receiving in the second charging guidance module can receive infrared signals. If offset occurs, the position of the unmanned vehicle is adjusted according to the method used in charging docking rough positioning so that it reverses in a straight line on the centerline again. The closer the unmanned vehicle is to the charging stand, the smaller the infrared signal range is, and the more accurate the charging docking precious positioning is. In addition, the first charging module of the charging stand and the second charging module of the unmanned vehicle are both set up in correspondence. Under the action of the first adsorption module and the second adsorption module, the unmanned vehicle can be accurately adsorbed and charged with the charging stand. The specific adjustment process of the unmanned vehicle for charging docking precious positioning is as follows:

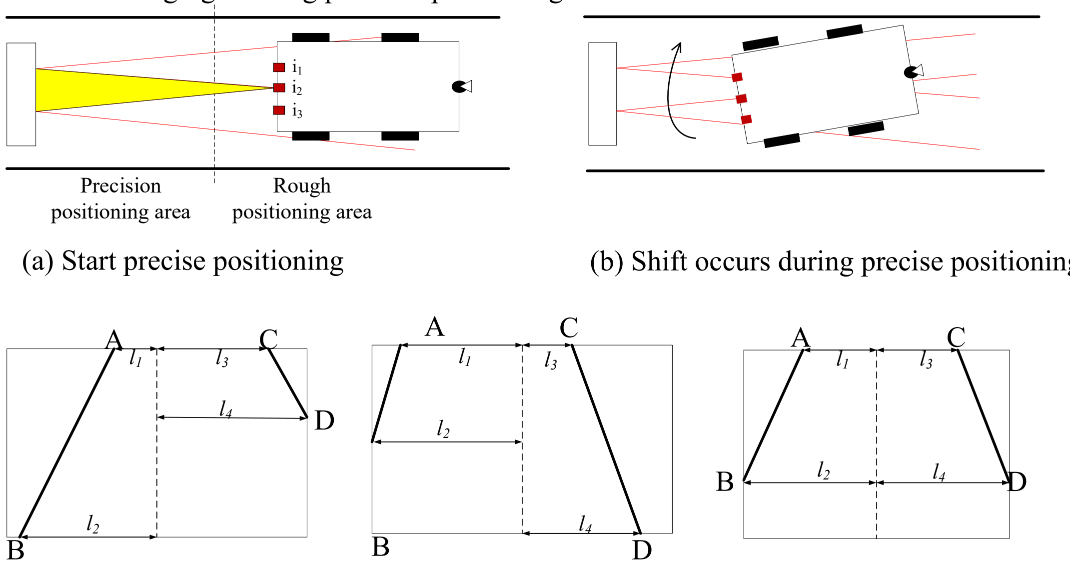
When the unmanned vehicle charging docking rough positioning reversing reaches the dividing line of the rough positioning area and precious positioning area, the first and second infrared receivers at the rear of the vehicle are still in the signal receiving area. They can receive infrared signals (Fig. 8(a)) while the third infrared receiver reaches the signal area critical point. If the unmanned vehicle continues to reverse, it cannot receive infrared signals. When there is no signal from the third IR receiver, the rough positioning of charge docking ends, and charge docking enters the precious positioning stage of charge docking.

After entering the precious positioning area, the infrared guidance of the first charge docking guidance module is dominant, and the visual guidance of the vision module is supplementary. The unmanned vehicle still maintains a straight line to reverse during the charging docking precious positioning phase. In the process of reversing, there may be a situation where the unmanned vehicle is offset, and the unmanned vehicle is not in the centerline of the docking lane (Fig. 8(b)). Therefore, when the unmanned vehicle is in the process of reversing, the left infrared receiver at the rear of the vehicle is in the critical signal reception area, which generates a sudden change in the signal amount. The unmanned vehicle docking can be judged to have deviation. At this time, through the visual camera as an aid, according to the four points of A, B, C, and D and the distance l_1, l_2, l_3, and l_4 of the axis in the shooting screen, respectively, the size of the relationship to determine the deviation of the unmanned vehicle. The specific situation is as follows:

1) If $l_4>l_2$, the unmanned vehicle is backed up to the right finely, l_4 decreases, l_2 increases, l_1 decreases, and l_3 increases. As the vehicle goes back to the right, it will also travel a distance to the right rear, so when the size of l_4 is close to the size of l_2, it starts back in the opposite direction, back to the right when l_4 slowly decreases, l_2 slowly increases, l_1 increases, l_3 decreases. Until l_1 is equal to l_3, it stops back to positive. (Fig. 8(c))
2) If $l_4<l_2$, the unmanned vehicle is fine-tuned to the right to reverse, l_4 increases, l_2 decreases, l_1 increases, and l_3 decreases. As the vehicle back to the right, it will also travel a distance to the left rear, so when the size of l_4 is close to the size of l_2, it begins to back in the opposite direction, back to the right l_4 slowly increases, l_2 slowly decreases, l_1 decreases, l_3 increases. Until l_1 is equal to l_3, it stops back to positive. (Fig. 8(d))

The unmanned vehicle reverses backward and keeps adjusting the unmanned vehicle by the above way to keep the first and second infrared receivers at the rear of the unmanned vehicle always able to receive infrared signals. The closer the first charging guidance module of the charging stand is, the smaller the angle of the infrared signal area is, and the finer the adjustment made by the unmanned vehicle will be. And the first and second infrared receiver at the rear of the unmanned vehicle is installed correspondingly with the two groups of infrared emitters of the first charging guidance module on the charging panel. This means that the first and second infrared receivers at the rear of the unmanned vehicle in the state of vehicle alignment charging can receive all the infrared signals from the two groups of infrared emitters of the first charging guidance module. Thus, the infrared guidance of the unmanned vehicle aligned with the charging stand after the camera shooting screen is realized in Fig. 8 (e).

When the unmanned vehicle is close enough to the charging stand, the bottom plane of the charging slot at the rear of the unmanned vehicle squeezes the metal block of the pressure sensing device on the charging panel. The pressure is transmitted to the pressure sensor at the bottom of the core slot through the spring connected to the metal block. The pressure sensor senses the pressure, at which time the charging docking precious positioning ends.



(a) Start precise positioning

(b) Shift occurs during precise positioning

(c) Camera image when shifted to the left

(d) Camera image when shifted to the right

(e) Camera image when no shift

Fig. 8 Unmanned vehicle charging precise positioning

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3.1.5. Unmanned vehicle charging

The second charging guide module at the rear of the vehicle is aligned with the first charging guide module on the charging panel. The second adsorption module at the rear of the unmanned vehicle is also aligned with the first adsorption module on the charging panel. The second adsorption module of the unmanned vehicle is adsorbed with the first adsorption module of the charging panel. At this time, the bottom plane of the charging slot at the rear of the unmanned vehicle squeezes the metal block on the charging panel. The pressure is transmitted to the pressure sensor at the bottom of the core slot through the spring connected to the metal block, and the pressure sensor senses the pressure. Since the charging ring in the charging slot needs to be fitted with the core ring on the charging panel for charging when the unmanned vehicle is charged, the charging ring starts to energize and charge the unmanned vehicle when the pressure sensors at the top of the left and right core bodies are subjected to the same pressure and remain unchanged for a period of time.

There exists a twisting mechanism under the charging panel. When there is a small angle error in the docking charging panel of the unmanned vehicle, after the core on the charging panel enters the charging slot, the reversing of the unmanned vehicle will drive the charging panel to twist to ensure normal charging, which improves the charging success rate and eliminates the error as much as possible. Due to the existence of the twisting mechanism, after the unmanned vehicle is fully charged and driven away, the twisting mechanism will drive the charging panel to make an automatic return to the initial position to ensure the next normal charging.

3.1.6. Disengagement after charging

After charging is completed, the electromagnet in the first adsorption module of the charging stand is energized. It interacts with the circular permanent magnet at the rear of the unmanned vehicle, generating a force opposite to that of the circular permanent magnet. This causes the unmanned vehicle to disengage from the adsorption and wait for the first control module to issue the corresponding command or complete the corresponding task.

Specifically, when the charging of the unmanned vehicle is completed, the charging completion signal is sent to the charging panel via the Bluetooth device, and the electromagnet of the first adsorption module starts to be energized after the charging stand receives the charging completion signal. The energized electromagnet is opposite to the magnetic poles of the circular permanent magnet in the second adsorption module of the unmanned vehicle, generating a mutual repulsive force and making the unmanned vehicle successfully detach from the charging stand. This method can adsorb the vehicle to the charging stand, ensure charging stability and safety, and prevent the vehicle from accidentally sliding and generating charging sparks to cause danger. And the unmanned vehicle does not consume additional electrical energy outside of charging during the adsorption process. Only when the charging is completed and released, the electromagnet is energized and stops energizing after the release is completed, which effectively achieves energy saving and environmental protection. After the electromagnet on the charging panel is energized, the charging stand sends permission to drive away signal to the unmanned vehicle via Bluetooth module. The unmanned vehicle returns to the waiting area or performs handling tasks according to the next instruction.

3.2. Anti-touch design

As the charging voltage of unmanned vehicles is high and prone to electrocution hazards, the charging stand always determines whether a person mistakenly touches the charging device to prevent the risk of electrocution. The charging stand maintains two pressure sensors in the first charging module to detect pressure. The first communication module is always on, the first ranging module performs ranging, and the first charging guidance module is on. Said predetermined anti-touch conditions specifically as follows.

1) Whether the charging stand is in operating time is detected.
2) Whether the first communication module of the charging stand is connected to the second communication module of the unmanned vehicle is detected.

3) Whether the second charging guidance module can receive the signal sent by the first charging guidance module is detected.
4) Whether the distance data measured by the first distance measurement module is the preset distance when the unmanned vehicle is charging is detected.
5) Whether the distance measured by the first distance measurement module is the distance when the unmanned vehicle is charging is detected.
6) Whether the distance measured by the first distance measurement module and the second distance measurement module is the same is detected.
7) Whether the two pressure sensing devices in the first charging module have pressure and whether the pressure applied is the same are detected.

When all the above six conditions are satisfied, the first charging module of the charging stand is energized, which greatly ensures the safety of personnel and is of great significance in the autonomous charging of unmanned vehicles.

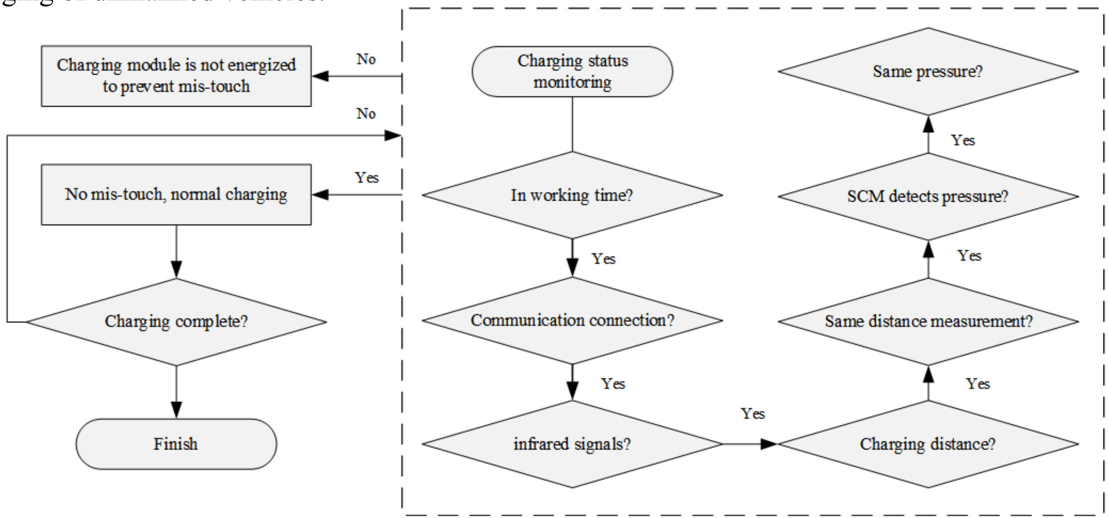

Fig. 9 Mistake-proof determination

3.3. *Obstacle avoidance during charging and docking*

The first ranging module on the charging panel is always on after the unmanned vehicle sends a ready charging signal to the charging stand until the unmanned vehicle completes docking and starts charging. When the unmanned vehicle performs the charging docking lane for rough positioning of charging docking and precious positioning of charging docking, the second ranging module at the rear of the vehicle is turned on to transmit ultrasonic waves to the charging panel for ranging. At the same time, the first ranging module of the charging panel is also sending ultrasonic waves to the unmanned vehicle for ranging. In Fig. 10, x_1 shows the distance between the charging panel and the obstacle measured by the first ranging module of the charging panel, and x_2 shows the distance from the unmanned vehicle to the obstacle measured by the second ranging module of the unmanned vehicle. The following situations exist:

1) When docking normally, the unmanned vehicle backs up at a uniform speed, and the change rates of x_1 and x_2 are comparable.
2) When there is a static obstacle in the docking path of the unmanned vehicle, x_2 decreases, and x_1 remains unchanged when the unmanned vehicle reverses so that the obstacle existing in the docking path can be judged.
3) If there is a dynamic obstacle, the change rate of x_1 and x_2 will fluctuate and change abruptly so that the existence of obstacles in the docking path can be judged. When an obstacle is sensed in the docking path, the unmanned vehicle immediately stops and sends out an alarm through the speaker on the side of the body to indicate the existence of an obstacle in the docking path and that

charging is blocked. This greatly enhances the intelligence and safety of autonomous charging and docking of unmanned vehicles.

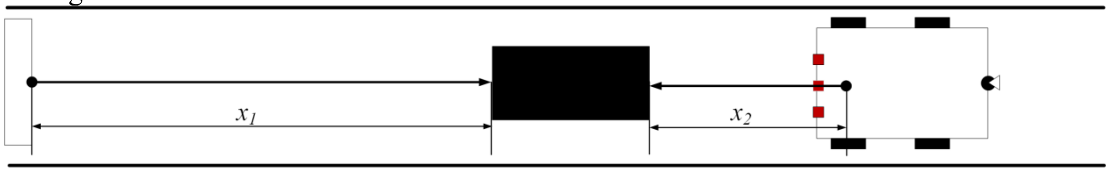

Fig. 10 Unmanned vehicle obstacle determination

4. Conclusion

To verify the effectiveness of this algorithm, the unmanned vehicle, smart charging stand, smart autonomous charging, and obstacle avoidance algorithm shown in Fig. 11 designed in this paper are installed and configured for autonomous charging experiments. To ensure the independence of each experiment, 50 consecutive times are selected for autonomous charging when the power of the unmanned vehicle is low after performing random tasks. Since the wheeled robot has certain requirements on the distance when adjusting the direction, it cannot be docked completely perpendicular to the charging seat each time. The twisting bracket of the charging seat can try to improve the charging docking success, record the average pressure difference of the first charging module, and verify the docking effect of the unmanned vehicle. The charging situation is recorded by the unmanned vehicle, and if the first docking is not successful, it continues to record the second docking situation. Secondly, obstacles are placed when the unmanned vehicle enters the lane and coarse and precise positioning. 20 experiments are conducted respectively to record whether the unmanned vehicle detects the obstacles and issues alarms to verify the safety of the algorithm in this paper. At the same time, in each experiment, the voltage of the first charging module is detected to verify the effectiveness of the anti-false touch algorithm in this paper. The results of the charging docking experiment are shown in Table 1. The results of charging obstacle avoidance are shown in Table 2.

Fig. 11 The unmanned vehicle used for the experiment

Table 1. Unmanned vehicle charging docking experiment results

Total	Success in the first time	Success in two times	Average docking time (s)	Average pressure difference (%)	Average success rate of anti-touch (%)
50	48	50	40	5	100

Table 2. Unmanned vehicle obstacle avoidance and anti-mistouch experiment results

Total	Obstacle avoidance attempts when entering lane	Obstacle avoidance during rough positioning	Obstacle avoidance during precise positioning	Obstacle avoidance (%)	Anti-touch (%)
60	20	20	20	100	100

The success rate of the unmanned vehicle charging docking experiment is high, with 96% success rate for the first charging docking and a 100% success rate for the two dockings. The average pressure difference received by the pressure sensors on the left and right sides of the first charging module is small, indicating that the charging-only algorithm in this paper has a certain accuracy in docking. In addition, the average docking time of the system is short, which is efficient and robust.

There are few studies on the safety of autonomous charging systems for unmanned vehicles. The anti-touch and obstacle avoidance algorithms proposed in this paper are experimentally verified to have a 100% success rate. This proves the effectiveness and safety of the autonomous charging system for unmanned vehicles proposed in this paper. It can provide strong support for the current research on autonomous charging for unmanned vehicles.

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