Designing Navigation and Obstacle Avoidance System Combining Smart Car And Quadrotor Aircraft

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Abstract. The navigation and obstacle avoidance system combining smart car and quadrotor aircraft takes MK60FX512VLQ15 microcontroller as the intelligent car control unit and STM32F767IGT as the image processing unit of flying platform. This system first collects image information through the infrared camera equipped in the quadrotor aircraft, and sends it to the processing unit for extraction and processing. Then this system transmits the information to the smart car master through the NRF2.4G wireless module and integrates it with the smart car's own gyroscope data. In this way, the system is able to tell the relative angle of the smart car with the target according to the result, obtain the operating environment and state of the car body through its own ultrasonic ranging, encoder and other modules, and adjust the car's speed and direction so as to avoid obstacles. The system is smooth in operation, flexible in adjusting speed and direction, and is fully capable of avoiding obstacles.

1. Preface
Recent years have seen the industrial trend of the interweaving of artificial intelligence (AI), automobile manufacturing and communication technology and intelligentization of the car navigation system. The design of the navigation and obstacle avoidance system combining the smart car and quadrotor aircraft also becomes an important goal and direction of the current research on industrial technology. Compared with independent navigation and obstacle avoidance system of traditional vehicles, a combination of smart car and quadrotor aircraft undoubtedly expands the scope and breadth of the vision. It also offers the new ideas of navigation and obstacle avoidance design combining the air and the ground.

At present, research on the mechanical structure of the quadrotor aircraft, its flight mode and intelligent navigation avoidance of smart cars has delivered abundant results. The system design in this paper is a combination of the essence of the smart car and quadrotor aircraft, which will surely bring new breakthroughs in the future application of navigation and obstacle avoidance.

2. Overall Design of the System
The two major parts of the system are the smart car and the four-rotor aircraft: (1) The aircraft partly adopts the Dji aircraft carrying the STM32F767IGT image processing module as the aircraft platform. (2) The smart car partly adopts the new CI car model, and uses the 32-bit microcontroller MK60FX512VLQ15 as the core control unit. Coupled with the speed encoder, infrared ultrasonic
ranging, gyroscope, motor, gyro and other hardware, the design part of the vehicle is completed. The overall design of the system is shown in Figure 1.[1,3,4]

Figure 1 Overall system

The infrared camera Mt9v032 installed on the quadrotor aircraft collects the road information, and sends the data to STM32F767 image processing unit. Then the information is transferred to the smart car via the NRF2.4G wireless communication module. After receiving the data, the smart car performs system control flow including gyroscope angle acquisition and calculation, infrared ultrasonic obstacle avoidance calculation, and motor drive output. In this way, the system is able to autonomously plan the path by identifying the target position and becomes capable of navigation and obstacle avoidance.

3. Design and Optimization of Hardware

3.1 NRF24L01 Wireless Transceiver Module

NRF24L01 wireless sensor module is an important bridge for system wireless data transmission and reception. It is also a link between air and ground data communication, and a major feature distinguishing itself from traditional bicycle navigation and obstacle avoidance systems. NRF24L01 wireless sensor module is required in both aircraft platforms and smart car modules.

The main principle of the NRF24L01 wireless sensor module in receiving and transmitting data in this system is: When the flying platform converts the image information collected from the air and transmits it to the car through NRF24L01, it is required to first configure the NRF24L01 on the aircraft platform to the transmission mode; then write the receiving node address TX_ADDR and the valid data TX_PLD into the NRF24L01 buffer zone from the SPI port according to the sequence (TX_PLD must be continuously written when the CSN is low, while TX_ADDR can be written once during the transmission). The NRF24L01 wireless module installed on the car is set to the acceptance mode, and transmits information received from the NRF24L01 module in the air to the main control unit MK60FX512VLQ15 of the car for subsequent data processing. Figure 2 shows the circuit diagram of the NRF24L01 wireless transmission module.

Figure 2 NRF24L01 wireless transceiver module
3.2 Design of the Quadrotor Aircraft Flying Platform

The modules on the quadrotor aircraft flying platform include units of camera for data acquisition, processing and wireless transmission. The image acquisition and processing module of the aircraft platform is crucial to the stability and efficiency of the entire navigation and obstacle avoidance system. The STM32f7+ infrared wide-angle camera and Mt9v032 camera are adopted after comprehensive comparison. [2,4]

The STM32F767 core board used on the flying platform has rich onboard resources and can be used independently and in electronic automation designs in various fields. With main frequency of 216MHZ, it is equipped with dcmi interface, which renders it more efficient in collection. The infrared filter added into the infrared wide-angle camera can reduce the interference of natural light, thereby reducing false positives; at the same time, it improves the resolution so that the flying platform can collect and transmit the highest quality image and data for analysis. The design of the main control board of the flying platform image processing in this system is shown in Figure 3.

![Figure 3 Design of the main control board of the flying platform image processing](image)

3.3 Design of Smart Car Platform

The two tasks of the smart vehicle module are route-based driving and obstacle avoidance. The platform is composed of a main control board and a motor drive board. In order to reduce interference from the motor drive circuit, the control part is separated from the motor drive in this design. The main control board is responsible for signal acquisition, processing and motor control. The smart car is equipped with power supply voltage regulator circuit, NRF24L01 wireless interface circuit, speed encoder circuit, motor drive circuit and so on.[3,4]

The sensor of the smart car module is a guarantee for obstacle avoidance. Smart car sensors are distributed according to the theoretical analysis of the model structure and mechanical structure of the car and the actual needs of the system. The sensors include speed sensor, car angle sensor, ranging sensor, etc. For speed encoder, the M-T3D2512 line encoder module is used to control and react to the motor speed during operation. The L3G4200D three-axis digital gyro sensor is used to measure the angular velocity of the smart car and estimate the motion of the car in order to develop a good path planning. The gyro circuit is shown in Figure 4.
4. Software Design
Efficient and sophisticated software is the basis for system’s smooth operation. The aircraft platform of navigation and obstacle avoidance system of smart vehicle and four-rotor aircraft uses the camera to
collect road image information. Image acquisition and correction processing becomes the core of the software design. Matlab software is mainly adopted for image correction. The entire programming of the navigation and obstacle avoidance function is carried out under the IAR Embedded Workbench IDE. The software design is mainly divided into the following aspects.[5]

4.1 Recognition and Optimization of the Position of Target and Vehicle

4.1.1 Acquisition and Correction of Original Images
The information extracted by the wide-angle camera Mt9v032 camera includes: the coordinates of the center point of the target, the head and the tail. Problems of edge noise, edge lines, unclear light and distant images, and image distortion occur during collection. The wide-angle camera used also leads to the serious barrel distortion of the images. As the car moves toward the edge along lens radius direction, the distortion becomes even more serious, which makes the information seen from the camera unreal. In order to solve that problem, the system uses Matlab software for image correction. The original image captured by the camera is a two-dimensional data matrix, with each element of the matrix corresponding to one pixel. Since the barrel transformation requires operation on each pixel, which is huge calculation work, the design uses Matlab to generate a barrel distortion correction table. Therefore, the main control chip can find a point by looking up the table, thus saving a lot of time and making the processed images more real. Image before and after processing are shown in Figure 7.

![Figure 7 The original image captured by the camera (left) and the processed image (right)](image)

4.1.2 Target Recognition
In the aspect of target recognition, the system uses the STM32F767 core processor to find the center point and length of the white area (or the target area) of each line, and then decide whether it is the same with the white area of the previous line. If yes, accumulate the length and average the center point; otherwise create a new target area. Continue the progressive scan to the end. In order to scan faster, the design changes progressive scan to skip scan. It only needs to scan half of the original images, thus halving the scan time. In addition, some isolation and noise points are filtered out. The target recognition procedure is shown in Figure 8.[6,7]

4.1.3 Road Planning
Whether the car can reach the target position in the shortest time after recognizing the targets depends largely upon its speed and path. Therefore, it is of utmost importance to drive according to the most reasonable and efficient path. The following is for path optimization:

1. Increase the length and width of the field of view
   According to experiment, when the aircraft is high above and acquires wider image field, the distortion of images collected by the camera is small and the cars drives towards the target through a good path.

2. Relative angle processing
   The information collected and processed by aircraft platform sent to the car is only three coordinates arranged from small to large, and the number of detected targets. The car first judges which is the beacon light and the head according to the distance between the smallest beacon and the other two beacons; calculates the angle of the relative image of the tail and the front, and the angle of
the relative image of the tail and the beacon; then conduct subtraction and take from -180 to +180 degrees so as to calculate the angular difference between the car and the beacon.

![Target recognition flow chart](image)

**Figure 8 Target recognition flow chart**

4.2 **Main Control Algorithm**

The classic PID control algorithm is used in steering the smart car and controlling its speed. Coupled with theoretical calculation and actual parameter compensation method, the smart car can travel stably while avoiding obstacles. Since the steering gear and the motor have different working contents, they are explained separately.[8]

4.2.1 **Control algorithm of the steering gear**

The angle calculated using the image data collected by the camera in this system has a certain deviation. The system segments the vehicle model according to the position when calculating data. Due to the relatively large hysteresis of the steering gear, the PD is used for closed loop so that it is able to response faster. The system gives different KP values and KD values according to different deviations of turning.

4.2.2 **Control algorithm of the motor**

Different road conditions of driving gives different deviations of each angle based on the calculation of the image acquired by the camera. In actual design, the road conditions can be segmented according to their respective deviations so as to set a suitable speed.

When the deviation of the head from the beacon is very small, a faster speed can be given to the car for its acceleration on the straight road; when the deviation is getting larger, an appropriately reduced speed can be given so that the car can avoid obstacles and make turns. The motor control algorithm adopts PID algorithm for closed-loop. After the appropriate values of P, I, and D are given in the experiment, the closed loop of PID allows the car to accelerate and decelerate according to different road conditions, thus smoothly passing through different roads.
5. Implementation
During the implementation of the system, different beacon lights are placed on the road. Each time when a light is lit, its target position is sent to the car. When we verify the obstacle avoidance function, the lights not lit are temporarily taken as the obstruction. This method can also detect car’s ability of light adaptation and familiarization.

5.1 Implementation of navigation function
Three beacon lights are placed on the ground of the experimental site, among which the illuminated lights are used as the target lights. The car would drive toward the target through the path planned according to the data transmitted by the aircraft. At the same time, the smart car can also adjust the speed on straight road and around the corners according to the road information, as shown in Figure 9 and Figure 10.

Figure 9 Smart car recognizes target and plans the path

Figure 10 Smart car completes navigation

5.2 Implementation of obstacle avoidance function
After recognizing the first lit light target, we turn it off and change the position of the lit light by illuminating the leftmost one, while viewing the middle one as an obstacle. The system automatically avoids obstacles and heads towards the target light using target recognition and path planning, as shown in Figures 11 and 12.
6. Conclusion
For hardware, the navigation and obstacle avoidance system combining smart car and quadrotor aircraft takes MK60FX512VLQ15 microcontroller as the intelligent car control unit and STM32F767IGT as the image processing unit of flying platform. NRF24L01 wireless transmission module, infrared ultrasonic sensing module and steering gear control module, motor drive module and other key modules are also an integral part of the core circuit of the system. For software, the system uses Matlab software to process and correct the original image under the IAR Embedded Workbench IDE. Classic PID control algorithm, coupled with theoretical calculations and actual parameters compensation method, is used in steering the smart car and controlling its speed. After debugging and testing, the system runs smoothly and flexibly and fully realizes the navigation and obstacle avoidance function.

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