Interactive Behaviors between an Aerial Robot and Ground Robots

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ABSTRACT

This paper is aimed at the 7th mission of International Aerial Robotics Competition. Firstly, Interactive behavior between aerial robot and mobile object (actually the ground robot); secondly, the navigation in an open surrounding. In this environment, there is no other navigation, static point, like GPS or wall; finally, compete with other aerial robot. According to the mission, a quad-rotor with stable attitude and good maneuverability will be a good choice as the aerial robot for the competition. Based on the commercial technology, vision navigation can be the quad-rotor's navigation. Single-eye vision distinguish and calculate, to program a best navigating commendation, and then guide the aerial robot move in the field, seek for the ground robot and dodge the barriers in the meantime, and finally guide the ground robot to the green line of the field, finishing the mission.

1. Introduction

Quad-rotor, a multi-propeller aircraft powered by four propeller, can be controlled by changing the rotate speed and attack angle of one propeller or more to change the features of torque and thrust. Thrust produced by four propeller can be easier realizing static hover than one propeller does, and quad-rotor's propellers can be smaller.

Recently, because of the small size, easy controllability, high load and easy design, quad-rotor is more and more popular in the field of UAV research.

The International Aerial Robotics Competition (IARC) has come to the 7th mission. That is, in a 400m square zone without GPS signal or any other extern navigation signal, aerial robot should dodge the barriers in the zone and guide the ground robot to the green line of the field in the meantime.

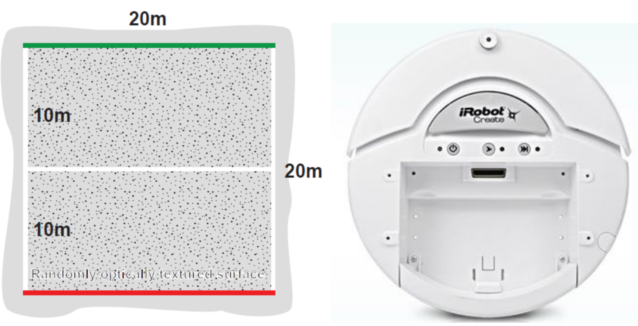

Figure 1. Competition field and ground robot

2. Conceptual solution to solve the problem

According to the mission, a quad-rotor with stable attitude and good maneuverability will be a good choice as the aerial robot for the competition. Based on the commercial technology, vision navigation can be the quad-rotor's navigation. Single-eye vision distinguish and calculate, to program a best navigating commendation, and then guide the aerial robot move in the field, seek for the ground robot and dodge the barriers in the meantime, and finally guide the ground robot to the green line of the field, finishing the mission.

3. System structure

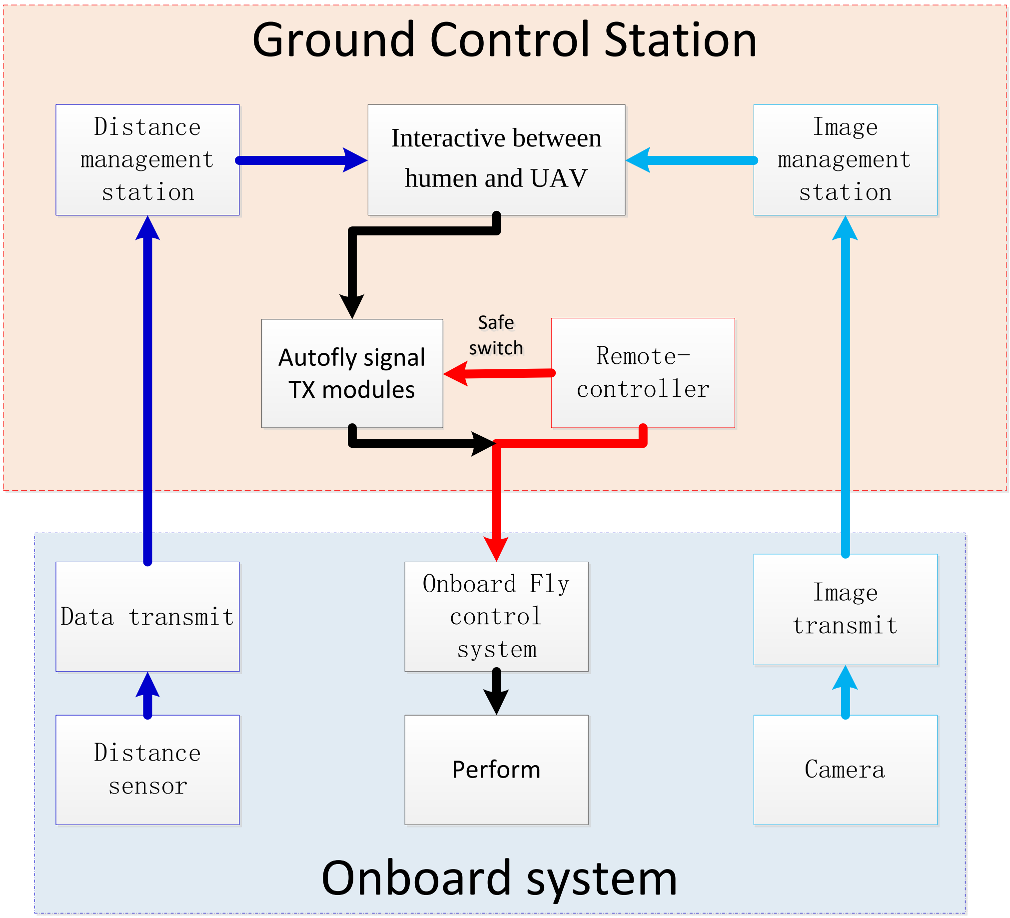

Figure 2. Aerial robot system structure

3.1 State control

3.1.1 Inner loop state control

WKM fly-controller is chosen as the Quad-rotor's Inner loop state control. WKM fly-controller, which is developed by DJI, an unmanned aerial vehicle develop company, use the robustness control algorithm, H_∞ control-technology.

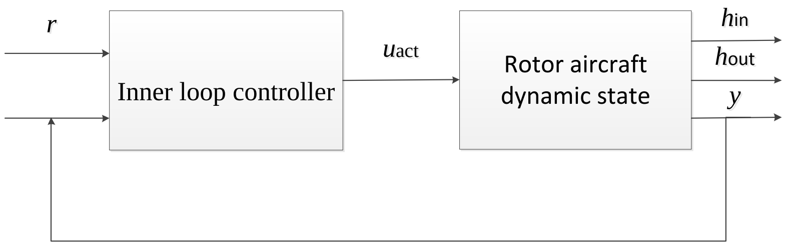

Figure 3. Inner loop control system design

Designing the inner loop control system, interference out of the dynamic state must be considered. So with the help of H_∞ technology, its affect can be minimize. There are 5 steps in the design process: 1. dynamic model linearization; 2. Describe the question; 3. Choose the index for design; 4. Design the H_∞ state control law; 5. Design reduced order observer.

3.1.2 Outer loop state control

Since WKM fly-controller is a commercial product, the flight data and the control program are unknown, this makes things knotty. In order to make it done, the only input channel will help, that is the remote-control unit input. Quad-rotor must fly automatically. Using a "virtual" remote-control unit to replace the "real" remote-control unit is a good idea. Design the fly-control law and compute navigation commends through the Windows OS.

In the outer loop state, the control law is as follows: with the height and distance information, after PID controller computing, the Analog Voltage IO device of the PC will output the exactly voltage. And then the voltage will be turn to the signal that the receiver can receive through the remote-control unit. So the control commends are sent to the WKM fly-controller. The control process is shown in the Figure 4.

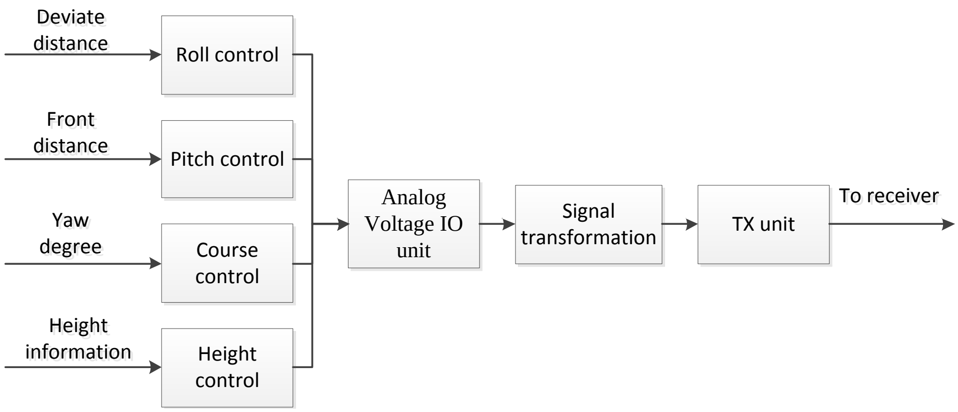

Figure 4. Outer loop control system design

Since the position information is from different sensors, position control will be divided to two part, vertical control and horizontal control. Vertical position information is from SRF02 sensor, and horizontal position information is from camera sensor.

(1) Vertical position control

Vertical control uses the PID controller, positioned by the SRF02 sensor. Different from state control, vertical control's control structure is not the double closed loop. It's because that the height information from SRF02 is in a low frequency, vertical control has to be control in the low frequency circuit. Hence, vertical control will be designed as the follow function:

$$u(t) = K_p \cdot \Delta h + K_d \cdot v + K_i \cdot h_i$$

In this function, Δh is the height d-value while v is the elevation velocity and h_i is the accumulate error.

In this structure, the speed may be not accurate enough, but it can still help to damp so to stabilize the height. The integral comes from the height D-value. The integral must be limited in a proper range, which will help to lower the steady state error, and improve the accuracy of vertical control.

(2) Horizontal control

The horizontal navigation information is provided by the ground control station. When received from the single-eye camera, this information will be calculated to navigation commends, which is related to the task of the quad-rotor closely. The navigation commends will lead the quad-rotor to fly along the boundary lines, or help the quad-rotor to guide the ground robots.

The navigation information that the horizontal control get is mainly defined as DTG (distance to go), lateral offset, translation speed damped from the first two variables and yaw angle. Substantially, the horizontal control of the quad-rotor is made by regulating the output voltage of the aileron or the elevator. According to the position offset and the translation speed, the PID controller will figure out commends to roll or pitch. The state control loop finally reply these commends, so the quad-rotor will act out. The roll voltage or pitch voltage commends are given as the follow function:

$$V_{out}(t) = K_p \cdot \Delta l - K_d \cdot v + K_i \cdot l_i$$

In the function, $V_{out}(t)$ is the state voltage commend, while Δl is the position offset, v is the translation speed and l_i is the accumulate error.

In the horizontal control, forward and backward of the movement of the quad-rotor is an independent process from the left and right. Since the control process is not done at a step. It is in a step by step format. It can be say that the controls of these two directions carry out at the same time.

3.2 Navigation control

The major component of the visual navigation system is the Hero3 sport camera with an 848×480 resolution and an acquisition frequency of 240 frames per second.

Circling Flight

The visual navigation system uses the measuring method based on monocular vision. When the quad-rotor doing planar motion, with camera height and angle being fixed, the system can transform the coordinate of the center point from the world coordinate system (WCS) to the calibration coordinate system (CCS). Then the system can get the distance between the quad-rotor and the center of the calibration plate by inverse transformation. We use ultrasonic on the quad-rotor to fix the aircraft's height and use cradle to fix camera angle. By lots of experiments, the distance measurement error is less than 10 centimeter when its altitude changes in a range of 20 centimeter.

The algorithm judges each type of lines according to its gray value. By using edge detection and linear fitting, the system can get contours of lines and store its coordinates. In order to ensure the accuracy of distance measurement, we select the contour which is closer to the square arena as measuring basis. And then the algorithm transforms the coordinates of the image center and its projective point on the contour to the world coordinates system for the corresponding distance. Relying on the distance and the yaw of the quad-rotor, we can get the lateral distance in three cases. The initial distance is set to 1 meter.

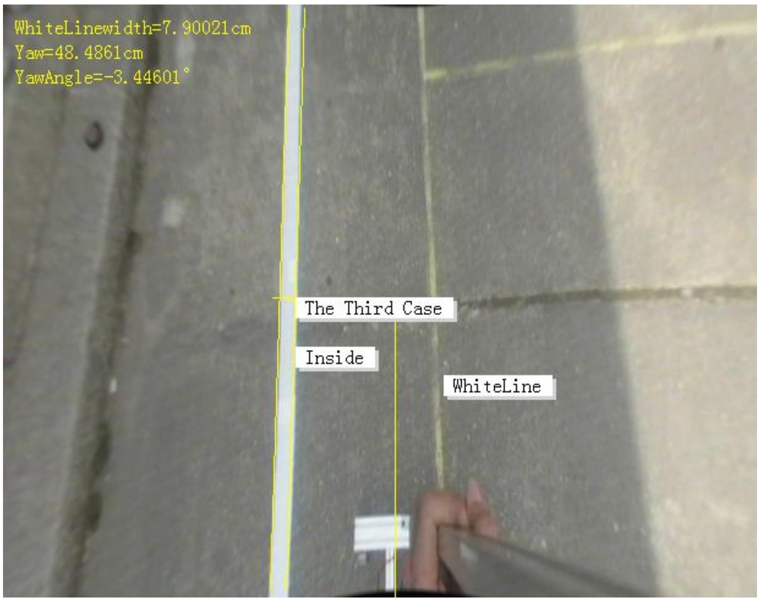

Figure 5. Edge Extraction

The algorithm leads the quad-rotor to do clockwise motion. It can judge whether the quad-rotor is inside the square arena by computing relative position between the image center and the projection point on the boundary. Constantly calibrate accuracy of judgment on condition that the quad-rotor is inside the competition arena so that it can make the correct judgment when doing anticlockwise motion. At each corner, the square arena can be divided into four different regions according to yaw angle and gray value of the intersecting lines. When the yaw angle is greater than 65 °, the algorithm modifies the yaw angle by clockwise rotation. When the lateral distance is greater than 1 meter or there are no horizontal lines in sight, the vertical line will be selected as the leading line to modify the yaw angle and the lateral distance. When the lateral distance is less than 1 meter, the quad-rotor will stop flying forward and the algorithm selects the horizontal line as the leading line to modify itself.

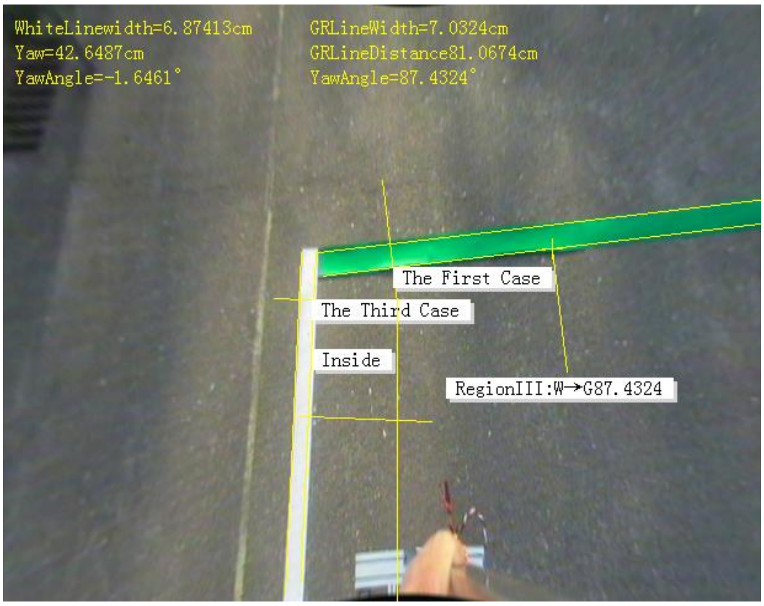

Figure 6. Region Dividing

When the quad-rotor encounters a region like "├"----a type of two intersecting white lines, the algorithm guides the aircraft keep on flying forward by open operation. In contrast, the system calculates the lateral distance and yaw angle of the horizontal line if it encounters a region like "┬". The aircraft will make a turn by the same way above when the lateral distance is almost 1 meter.

Figure 7. Detect Intersection Lines

Target Searching

Based on its features, such as white and round, the system searches robots by gray matching. It is easy to get the number of robots and their corresponding coordinate of the robot's center point. After discovering a robot, the algorithm keeps searching it nearby the corresponding center coordinate in the next frame to avoid any incorrect judgment due to the existence of multiple robots. Robots on the ground may be out of sight and another robots may appear in two consecutive frames. In addition, the trajectory noise frequency of ground robot is once every 5 seconds. So the algorithm collects two frames in every 5 seconds to judge the direction of robots. Considering that the quad-rotor and the ground robots are both in motion, the system controls the quad-rotor to hang in the air in order to reduce difficulty of judging robots motion direction during acquisition. After getting the data of robot motion, the visual navigation system can predict whether robots collision will happen and whether the robot will be out of the square arena after collision.

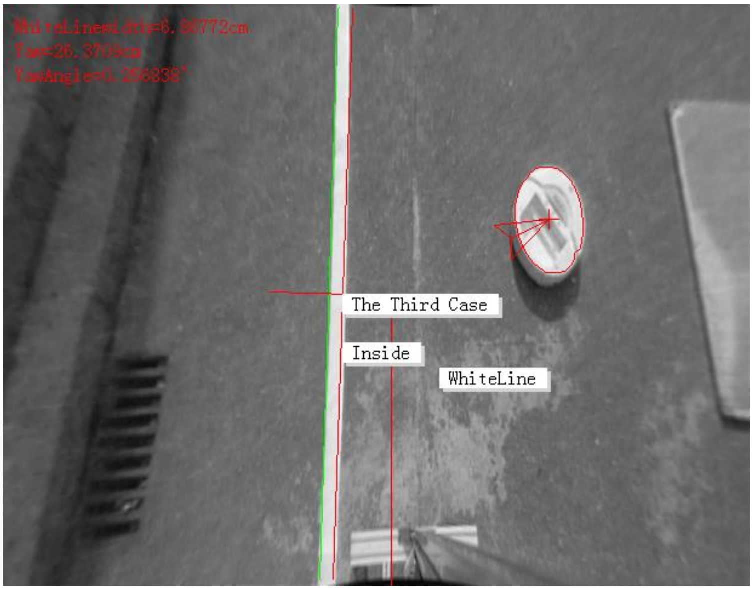

Figure 8. Target Searching

Motion tracking

Our system can estimate the yaw angle of the aircraft itself and the distance between boundary line and the ground robots by the same way above. For the speed of robots on the ground is about 0.33m/s, we can determine if it will run out of the arena in advance. The aircraft is allowed to land on the ground, so when it find that a robot on the ground is about to run out of the square arena through white or red lines, the vision system will drive the quad-rotor to land in the way of the robot and makes it turn away. Similarly, we can turn the robots near the green line out of the arena by the same way.

Autonomous Obstacle-avoiding

The system can identify columnar obstacle and locate obstacle robots by the use of three-dimensional match. By building an artificial-potential field, there will be “attraction” between aircraft and target robots and also “repulsion” between aircraft and obstacle robots. Given aircraft’s size, control error and motion errors, we set the situation as safe area where the aircraft keeps at least 1.2 meter away from all obstacle robots. The quad-rotor will treat the target robot as main target in preference to obstacle robots and flies toward it through the safe area.

Exception Handling

The aircraft will follow the leading line and keep cruising inside the safe area if there is no robot in sight. The algorithm detects the white line all the time while identifying green and red lines alternately. If there is no line in sight, the aircraft will follow one of the robots until find a new line.

In addition, when other obstacle and serious interference (like audiences and large reflections) comes up, error detection mechanism will filter these interferences and prevent the quad-rotor from out of control.

4. Conclusion

The design of this paper is to study and design the interactive behaviors between an aerial robot navigated by the single-eye control and ground robots. Based on the back ground of the

International Aerial Robotics Competition, quad-rotor feels the move of the ground robots, and the guides them to the destination direction.

This paper have finished the auto-fly and vision navigation of the quad-rotor, from design idea to structure of system, from state control to navigation control. The idea of "virtual remote controller" is wonderful and novelty. This makes it possible that auto-fly and navigation control can be done when in the case that data and procedure of the fly system are unknown. The system built can finish all mission that the competition request.

But with this method, all can be done is just outside the fly-controller, which has a good robustness. Extra sensors must be added to this system when studying the auto-fly or navigation or something else. This makes sensor reiteration and adds more weight to the quad-rotor. Moreover, the robustness will not makes any sense if only using the PID control in the outer loop.

5. References

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