CAUC's Aerial Robot for IARC 2014

WANG Yao, YUE Fengfa, ZENG Zhengchao, JIN Yabo,

ZHANG Yunhao, ZHAO Long, SHI Yongzheng, JIANG Nan, HUO Lu

Civil Aviation University of China

ABSTRACT

To complete the 7th mission of the International Aerial Robotics Competition, a quadrotor aircraft consisting of flight control system and navigation system is designed. The flight control system is composed of a main chip and some sensors, and the traditional PID algorithm is used to control the attitude. The navigation system is composed of a small computer and some sensors. The vehicle is intended to be Civil Aviation University of China's entry for the 2014 International Aerial Robotics Competition.

I. INTRODUCTION

Quadrotor aerial robots have extensive application prospects because of its small size, stable flight, strong maneuverability and the ability of taking off, hovering, flying and landing in a restricted area. At present, the quadrotor aerial robots have been applied in many fields such as power line patrol, territory exploration, flood relief, forest fire prevention, and have been a hotspot in UAV research[1,2]. Indoor complex environment is an enormous challenge to the autonomous navigation of quadrotor aerial robots, which is mostly solved by global positioning equipments like VICON. The improvement of sensor technology, especially the development of MEMS devices, the improvement of microprocessors and power devices, the application of new material and the increasing of battery life, provide necessary hardware support for the development of quadrotor aerial robots[3]. To complete the 7th mission of the International Aerial Robotics competition, a quadrotor aerial robot is designed, and the technological details are introduced in this paper.

A. Statement of the Problem

Mission 7 will challenge teams to demonstrate three new behaviors that have never been attempted in any of the past six IARC missions. First, aerial robot should interact with moving autonomous ground robots. Second, the aerial robot should navigate in a sterile environment with no external navigation aids such as GPS or large stationary points of reference such as walls. Third, the aerial robot should compete with the other autonomous air vehicles.

The 7th mission of the International Aerial Robotics competition requires aerial robot which avoid the obstacles to make the number of ground robots attain the green line in Fig1.1 as much as possible. The whole process should be limited to 10 minutes. Vehicles must be unmanned and autonomous. They must compete based on their ability to sense the environment of the competition arena. The size of any aerial robot shall be limited to 1.25 meters in any dimension. There is no weight limit.

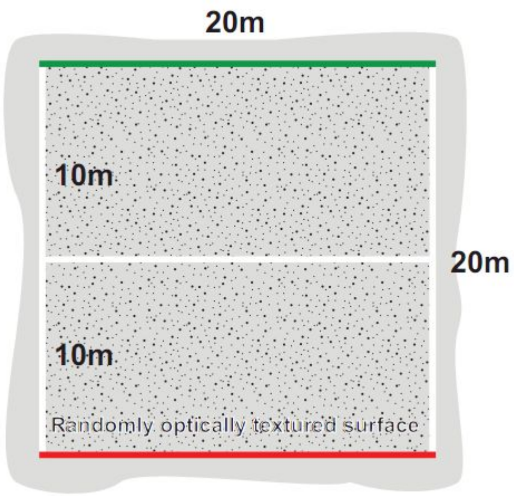


Fig1.1 Basic structure of the ground

B. Conceptual Solution

To accomplish this mission, an aircraft is made all by ourselves firstly. The PID algorithm is used to control the roll, pitch, yaw and height and the results shows the navigation requirement can be perfectly satisfied. The aircraft is equipped with one laser range finder, two cameras. The range finder is used to measure the distance between the aircraft and robot with tall cylinder extending vertically from their upper surface. The two bottom cameras are mainly used to search the target ground robots and navigate for the aerial robot.

C. Yearly Milestones

This is the second time for the CAUC team to participate in IARC. The aircraft is designed to complete the 7th mission and it will have the ability to navigate and explore the whole environment, detect the target ground robots and avoid the robot with tall cylinder. This year we have finished the design of the flight control system and navigation system, some of this mission have been finished, such as flying through the desired position, identifying and tracking the target ground robots, avoiding the robot with tall cylinder and so on, and in the next year we aim to finish the rest of this mission.

II. Description of Vehicle

A. Aerial Platform

The platform is based on an XAircraft 450Pro quadrotor UAV. Only the basic structure and the propulsion system are adopted. The basic structure of the platform is shown in Fig 2.1.

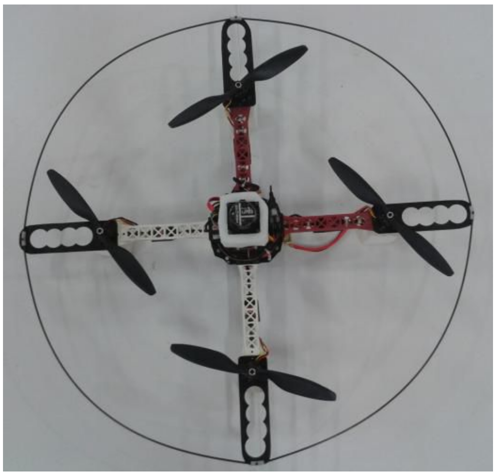


Fig2.1 Basic structure of the platform

There are three major systems: the propulsion system, the flight control system and the navigation system, as shown in Fig 2.2.

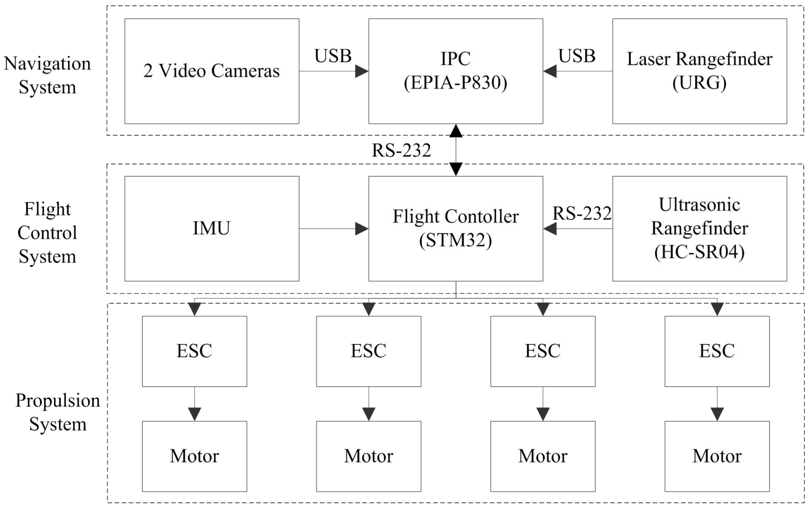


Fig2.2 System hardware structure

B. Propulsion and Lift System

The propulsion system provides power for the platform. It consists of four Xaircraft 2215 brushless DC motors (Fig 2.3) and matching propellers. Four ESCs (Electronic Speed Controller) are used to control the speed of the motors. The ESCs transform the PWM signal to alternating voltage signal, which controls the speed of the DC motors.

All the electrical power supply is from a rechargeable lithium battery of 4000mAh, which meets the requirement of the task.

Fig2.3 Xaircraft 2215 brushless DC motor

C. Flight Control System

Considering the coupling of the system, a double loop PID[4] control method is adopted. The structure of the controller is shown in Fig 2.4. The inner loop controls the attitude, i.e. the rotation angle (θ,ϕ,ψ). The outer loop controls the displacement, i.e. the location (x,y,z).

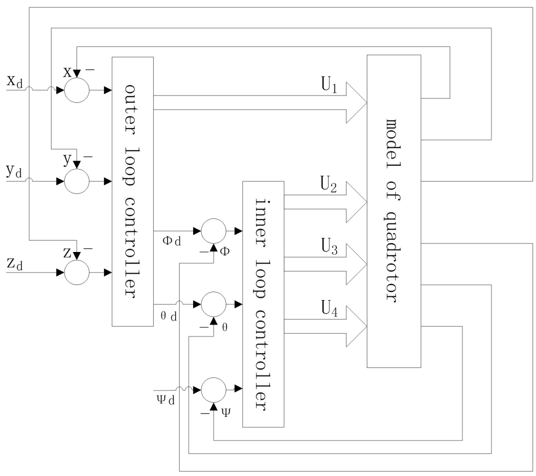


Fig2.4 Structure of the double loop PID control system

As shown in Fig 2.4, the input of outer loop controller is the error between the desired location and real location, while the outputs are the desired roll angle and pitch angle, as well as the control value U_1 . The input of the inner loop is the error between the desired attitude and real attitude, while the outputs are the control values for roll channel, pitch channel and yaw channel named U_2, U_3 and U_4.

As a classical control method, PID has many benefits such as simple structure, satisfactory control performance etc, and fits the double loop control. The expression of positional PID is:

$$u(k)=k_p e(k)+k_i\sum_{j=0}^{k}e_j T+k_d\frac{e(k)-e(k-1)}{T}$$

D. Navigation System

The key issues of this mission are the localization and navigation for the UAV.

The hardware of the navigation system is based on a VIA EPIA-P830 IPC, which is pico-ITX embedded compact native X86 main board, and a URG laser range finder and two cameras. The IPC is used to process the data from laser and cameras and then transform the results to the flight control system; at the same time, it also monitors the attitude of the aircraft. The navigation system communicates with the flight control system though serial port, by sending the commands in string format.

The laser range finder is used for self-localization, obstacle avoidance and path planning of the aircraft. As the map is mostly given, a grid map is drawn as an indication of indoor environment and then laser is used to acquire environment data. The process result of the laser is shown in Fig2.5.

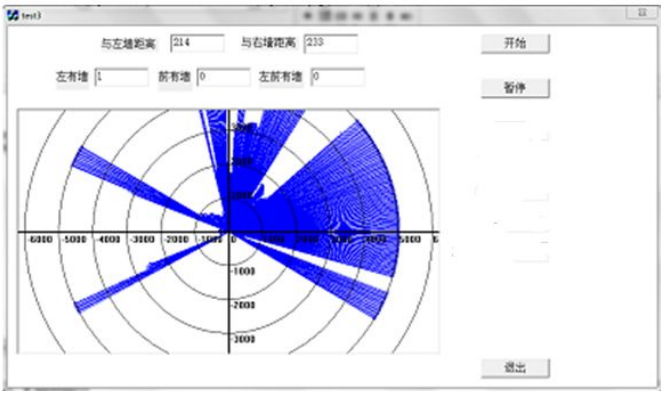


Fig2.5 The process result of laser

In order to track the object, the edge and color features of objects [5-6] have been integrated and combined with the algorithm of phash [7] object detection based on perceptual algorithm on the foundation of Camshif. The tracking algorithm process is illustrated in Fig2.6.

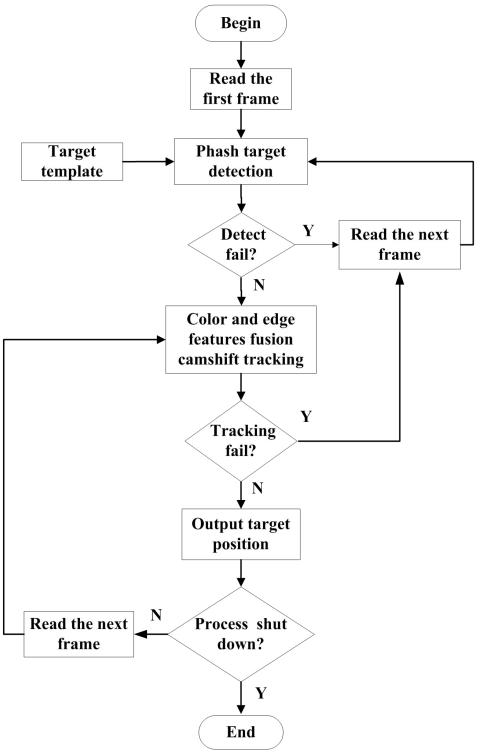


Fig2.6 Ground target tracking algorithm

In the first frame, Phash target detection algorithm is utilized to scan the entire window, calculate the Hash code of each scan window, comparing them with the Hash code of the target template to get hamming distances. The window, whose hamming distances is the minimum distance and less than 5, is the target window, used as the initialization window of Camshift tracker which based on edge and color features fusion for target tracking. It will restart Phash detector to regain the tracking target if tracking is fail.

In this experiment, the cameras capture image size is 752 * 480(computing size is 376*240), acquisition environment is indoor open environment, tracking the target is ground iRobot Create programmable robot. As shown in Fig.2, experimental results demonstrate that this method can provide a long-term and real-time tracking of ground moving target, which processes both robustness and computational efficiency.

Frame 35 Frame 200 Frame 235 Frame 260

Fig2.7 The results of tracking algorithm

E. Flight Termination System

An IARC common kill switch is necessary for safety. It provides a simple and effective means of killing power to the motors through the use of a separate radio control receiver. When quadrotor loses control, the operator can take over the flying quadrotor through RC or just press the kill button.

III. Payload

A. Sensors

A laser range finder and two cameras are mainly used to offer the navigation information. The laser range finder used is the Hokuyo URG-04LX-UG01. It is capable of measuring distances up to 4m and has a maximum detection area of 240 degrees, with a resolution of 1mm and 0.31 degrees respectively.

B. Communications

The onboard IPC and the STM32 flight controller communicate via RS-232 interface. The IPC also has a wireless LAN through which it can communicate with a ground station computer, on which the status of the vehicle can be monitored.

IV. Operations

A. Flight Preparations

A pre-flight checklist has been developed in order to ensure the security of the pilot and potential bystanders.

1) Setup the Ground Control Station, make sure all devices work properly.
2) Check Wi-Fi transceiver connection.
3) Turn on the transmitter and make sure all buttons are set to the right position.
4) Program the UAV with the latest stable code.
5) Do a small test to check if the quadrotor is ready to fly.
6) Check the IPC and run the necessary software.

B. Man/Machine Interface(MMI)

This MMI system is composed of Remote Controller for manual mode and Control Station in Navigation System for autonomous system.

The WFT07 Remote Controller produced by the company of WFLY is used to let the aircraft fly manually and then change into the autonomous mode. When an emergency happens, it can also be used to stop the aircraft.

The Control Station has the ability of monitoring, communication setting and so on. The monitoring interface is capable of displaying the real-time state of the quadrotor including attitude, heading, altitude and location. The whole flight can be easily monitored from the pre-taking-off phase to the final landing.

V. Risk Reduction

A. Vehicle Status Monitoring

The ground station computer communicates with the IPC via wireless network, on which we can easily monitor the status of the vehicle. All mouse movements and keyboard signals are transferred from the local computer (ground station computer) directly to the remote computer (IPC) over the network (via LAN or Internet), relaying the graphical screen updates back in the other direction.

B. Safety to Bystanders

The protecting frame shown in fig 5.1 helps protect the vehicle as well as the bystanders, facilities and equipments around. It is made by carbon fiber, which is strong enough to protect the vehicle and people without adding too much weight to the platform.

fig5.1 protecting frame

C. Modeling and Simulation

(1) Modeling

The model of the vehicle is established to study its dynamics. The structure of the vehicle is shown in fig 5.2.

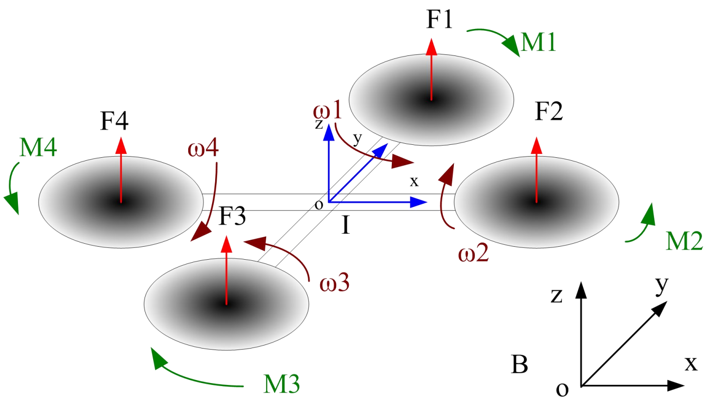


fig 5.2 structure of the vehicle

The quadrotor UAV is an under actuated system with 6 DOF and 4 inputs. The inputs are the speed of the 4 propellers. The propellers generate 4 thrust named F_1, F_2, F_3 and F_4, and 4 torques named M_1, M_2, M_3 and M_4. Based on the literatures[8-10], the linearized model of the system is given by:

$$\begin{cases} \ddot{\phi} = \dfrac{1}{I_x}\left\{\dot{\theta}\dot{\psi}\left(I_y - I_z\right) + dU_2\right\} \\ \ddot{\theta} = \dfrac{1}{I_y}\left\{\dot{\phi}\dot{\psi}\left(I_z - I_x\right) + dU_3\right\} \\ \ddot{\psi} = \dfrac{1}{I_z}\left\{\dot{\theta}\dot{\phi}\left(I_x - I_y\right) + U_4\right\} \\ \ddot{x} = \dfrac{1}{m}\left\{\left(\cos\phi\sin\theta\cos\psi + \sin\phi\sin\psi\right)U_1\right\} \\ \ddot{y} = \dfrac{1}{m}\left\{\left(\cos\phi\sin\theta\sin\psi - \sin\phi\cos\psi\right)U_1\right\} \\ \ddot{z} = \dfrac{1}{m}\left(\cos\phi\cos\theta\right)U_1 - g \end{cases} \tag{5.1}$$

where U_1, U_2, U_3 and U_4 are the control value for height, roll, pitch and yaw channels. They are linear combinations of the 4 thrusts generated by 4 propellers:

$$
\begin{bmatrix} U_1 \\ U_2 \\ U_3 \\ U_4 \end{bmatrix} = \begin{bmatrix} F_1 + F_2 + F_3 + F_4 \\ F_4 - F_2 \\ F_3 - F_1 \\ F_2 + F_4 - F_3 - F_1 \end{bmatrix} = \begin{bmatrix} k_p \sum_{i=1}^{4} \omega_i^2 \\ k_p(\omega_4^2 - \omega_2^2) \\ k_p(\omega_3^2 - \omega_1^2) \\ k_d(\omega_1^2 - \omega_2^2 + \omega_3^2 - \omega_4^2) \end{bmatrix} \tag{5.2}
$$

Where k_p and k_d are the lift coefficient and torque coefficient respectively.

(2) Simulation

To reduce the risk, we simulated the flight controller by simulink before actual tests. The results of height channel and roll channel are shown in fig 5.3 & 5.4, where the initial status is: $x_0 = 0, y_0 = 0, z_0 = 0, \phi_0 = 0, \theta_0 = 0, \text{and } \psi_0 = 0$, and the desired status is: $x_0 = 0, y_0 = 0, z_0 = 1, \phi_0 = 0, \theta_0 = 0, \text{and } \psi_0 = 0$.

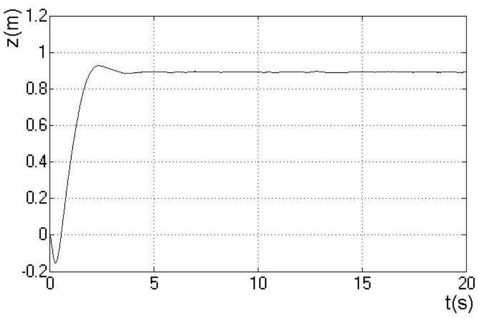


fig 5.3 simulation result for height channel

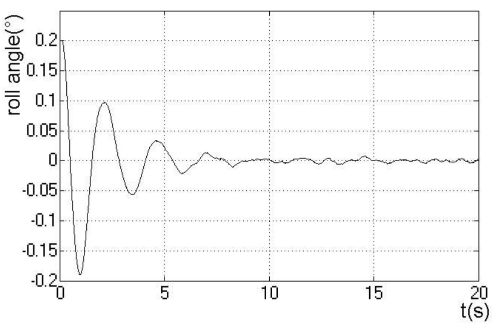
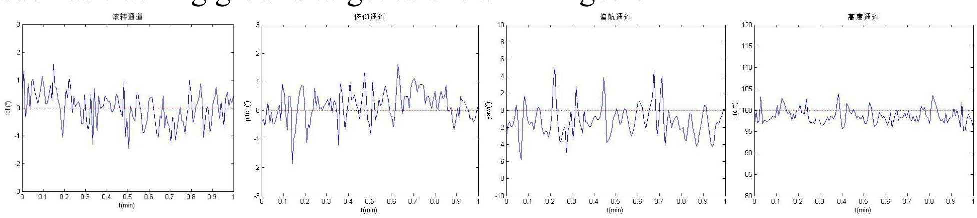


fig 5.4 simulation result for roll channel

VI. Testing

The environment same as the real environment of the mission is built and the aircraft is tested in it. Attitude control and position control have been finished and the data is obtained during the tests and are shown in fig6.1. Furthermore, more other tests such as tracking ground target as shown in Fig6.2.



(a)Roll (b)Pitch (c)Yaw (d)Height

fig 6.1 Attitude control results

Fig6.2 The experiment of tracking ground target

VII. Conclusion

In this paper, the technical details of a quadrotor system are presented, and it can avoid the obstacles to make ground robots attain the desired position, without rely on any external navigation aids. The quadrotor platform with three subsystems is developed. The information from the laser range finder and ultrasonic range finder is used to perceive the environment. Two video cameras are mounted on the vehicle, which are used to detect specific targets.

So far, Control architecture development hace been finished, corresponding test and simulation are currently in progress. The CAUC Aerial Robotic Team intends to compete in the 2014 IARC with this vehicle.

Acknowledgments

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