Naval Aeronautical and Astronautical Institute Team Entry for the 2014 AUVSI International Aerial Robotics Competition

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ABSTRACT

This paper describes the details of an autonomous aircraft capable of navigating in a sterile environment with no external navigation aids such as GPS or large stationary points of reference such as walls and interacting with autonomous ground robots. The vehicle localizes itself by the downward-looking camera and optical flow, stabilizes its attitude (pitch, roll and yaw) and altitude using PID controllers. The vehicle identifies the autonomous ground robots by the forward-looking camera and avoids obstacle ground robots by setting the area near the paths of obstacle ground robots as hazardous area. The vehicle is intended to be Naval Aeronautical Engineering Institution's entry for the International Aerial Robotics Competition in 2014.

Ⅰ. INTRODUCTION

The use of GPS, and to a lesser extent, SLAM, has become prevalent in the world of aerial robotics. Many of the same missions have been flown with these navigation aids. Mission 7 eliminates these off-the-shelf navigation solutions by conducted in a GPS-free indoor environment that is devoid of obvious physical cues. Other methods for stability and control, as well as navigation should be devised.

This paper describes technological details of our Quadrotor system, which is designed to be Naval Aeronautical Engineering Institution Team Entry for the 2014 AUVSI International Aerial Robotics Competition.

With the help of various onboard sensors, the MAV are expected to identify autonomous ground robots, implement obstacle avoidance flight, communicate with ground station, and achieve the mission.

A. Statement of the Problem

The objective of the IARC 7th Mission is to demonstrate three new behaviors that have never been attempted in any of the past six IARC missions. First, achieve interaction between aerial robots and autonomous ground robots. Second, navigation in a sterile environment with no external navigation aids such as GPS or large stationary points of reference such as walls. Third, achieve interaction between competing autonomous air vehicles.

B. Conceptual Solution

Our Team has developed a MAV system to accomplish the task. The aircraft identifies the gridding and detects the passed line by the downward-looking camera, then calculates the flown distance. With the data from the optical flow, the aircraft can localize itself. The aircraft identifies the autonomous ground robots by the forward-looking camera, determines and predicts trajectory of the autonomous ground robots, then chooses the target. After choosing the target, the aircraft executes position closed-loop control to track the autonomous ground robot, and descends upon it when the collision condition is meeting. The aircraft avoids obstacle ground robots by setting the area near the paths of obstacle ground robots as hazardous area. The aircraft will avoid the hazardous area by position control. The System architecture is shown in fig 1.

Figure 1:System architecture

C. Yearly Milestones

This is the second time for our team to participate in IARC. In last year’s competition, we have achieved good result and gained some good experience and knowledge. As the host of 2014 AUVSI International Aerial Robotics Competition, we hope we can achieve better results in this time.

II.AIR VEHICLE

Quadrotor is a good choice for MAV due to their relatively high flexibility and maneuverability. In 2014 IARC, Our quad-rotor is assembled by ourselves. The vehicle can achieve autonomous flight control. The flight attitude of the vehicle is measured by AH100B flight attitude module. The flight altitude of the vehicle is measured by Ultrasonic altimeter. The drift velocity of the vehicle is measured by optical flow. The size of quad-rotor is 45cm×45cm×18cm with a safety margin, and with a 2200mAh Li-Po Battery. The quad-rotor weighs about 1.46kg.

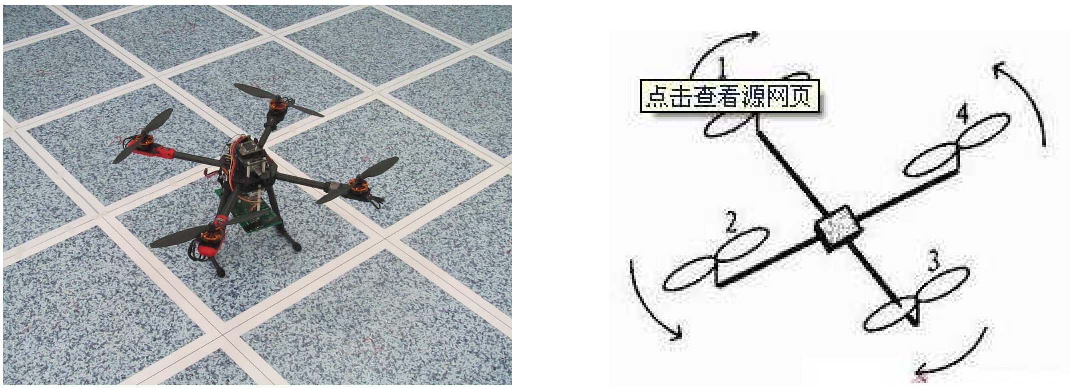


Figure 2:quadrotor and the propeller action

A. Propulsion and Lift System

The quad-rotor equipped with four brushless DC motors and four10in propellers, which distribute symmetrically at the end of four arms. And Unlike normal helicopters, the propellers of quadrotor shave fixed pitch angles. While the rotation of the motor 1 and the motor 3 are counterclockwise, the rotation of the motor 2 and the motor 4 are rotated clockwise, so when the aircraft flights evenly, the gyroscopic effect and the aerodynamic torque effect are offseted. It has six degrees of freedom in space (translational and rotational movements along the three axes), and the control of six degrees of freedom can be achieved by adjusting the motor speed. The basic state of movement: the vertical movement, the pitching movement, rolling movement, yaw movement, front and back movement, lateral movement. In short, we can control the quad-rotor by changing the motor speed.

B. Guidance, Navigation, and Control

(1) Stability Augmentation System

The quadrotor, by nature, is an under-actuated system, it can determine its movement when the number of control input is less than the space dimension, the problem lies: the degree of freedom of direct excitation parts is coupled with the under-actuated non-linear. In order to make it move as expected, an attitude and heading controller is needed. Our flight controller's input is pulse wave, through sending the vehicle direct pulse wave, and when the duty cycle is 50%, it can balance. After our experiment, we find that PID control is the best control algorithm for our quad-rotor, the control block diagram is shown in Fig 3 .

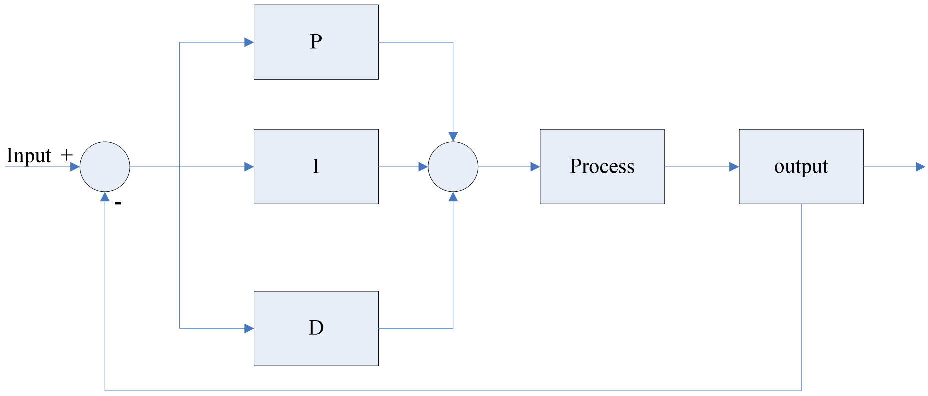


Fig.3 PID control block diagram

(2) Navigation

A new method for navigation is devised. The vehicle identifies the gridding and calculates its distance to the white line, then detects the passed line. With the velocity information from the optical flow, the vehicle can localize itself timely. When the vehicle determines to track the autonomous ground robot, it uses forward-looking camera to achieve visual navigation. In this process, velocity closed-loop control is used. After localizing its location, the aircraft avoids obstacle ground robots by setting the area near the paths of obstacle ground robots as hazardous area. The aircraft will avoid the hazardous area when planning its path and using visual navigation.

C. Flight Termination System

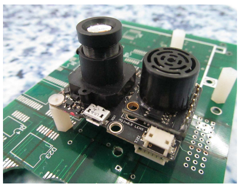
There are two ways to achieve flight termination. The vehicle can be changed from autonomous to manual control by a switch on the RC transmitter, then the participator can take over control of the vehicle. When the height control goes wrong, threat the people's safety around, the participator can always take over control through one channel of the RC controller, then make an emergency landing. There is also a flight termination button in our ground station, if any emergency happens, the participator can click the button to control the vehicle right now.

III. PAYLOAD

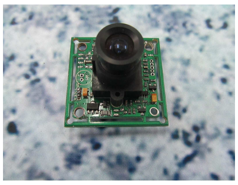
A. Sensor Module

The onboard sensors include optical flow, two cameras and ultrasonic altimeter. The ultrasonic altimeter is connected to the onboard core board; the data of two cameras are transferred to the ground station computer. The onboard core board is a kind of SCM, has small size and light weight.

a1) Sensors



(a) Optical flow



(b) Camera

(c) Ultrasonic altimeter

Figure 4. Various onboard sensors.

The optical flow gets the velocity information by detecting pixel movement, as shown in fig.4.a

The forward-looking camera and downward-looking camera can provide 720×576 gray scale images as a speed of 30 fps, as shown in fig.4.b.

An ultrasonic altimeter is used for attitude stability, as shown in fig.4.c

a2) Mission Sensors

The vehicle uses forward-looking camera to identify, catch and track the autonomous ground robot, as well as guidance for itself. The vehicle uses downward-looking camera to localize itself by detecting the white line gridding.

a3) Threat avoidance

The aircraft avoids obstacle ground robots by setting the area near the paths of obstacle ground robots as hazardous area. The aircraft will avoid the hazardous area by position control.

B. Communications

Our vehicle communicates through long range 5.8GHz transreceiver module used for cameras and 433MHz transreceiver module used for telemetry. The frequency of our RC transmitter is 2.4GHz that used for kill switch.

C. Power Management System

The power management system is based on a dedicated microcontroller which provides energy to the four motor controllers, the on-board core board and a variety of sensors. Its energy source consists of a single Li-Po Battery (12.6V, 2200mAh) which allows approximately 15 minutes of autonomous flight. There is a power monitor, when the voltage is under 5V, a warning message will be sent to the ground station, and meanwhile the vehicle will land by itself.

IV. OPERATION

A. Flight Preparations

a1) Checklist(s)

1. Check the hardware;
2. Make sure the power of battery is full;
3. Check ground station;
4. Get on power; check the switch of control rights;
5. Check the software;
6. Make a simple test flight to make sure the vehicle works well.

B. Man/Machine Interface

There are two man-made interfaces in the vehicle system. One is the RC transmitter, and the other is the ground station. The RC transmitter is used to take over the control of Quad-rotor when emergence occurs, such as wrong ultrasonic altimeter's data, the discrete data of laser. The ground station is used for real-time display of Quadrotor flight status, including attitude, position, angular velocity, accelerated speed, the voltage of battery and so on, when above data is abnormal, the participator can enforce the vehicle land through the ground station.

V. RISK REDUCTION

A. Vehicle Status

a1) Shock/Vibration Isolation

The vehicle's equipments and sensor have limits of vibration. Apart from these, many measures have been applied when mounting the sensors, and if there is severe vibration in the vehicle when some sensors are measuring, it is likely affected by the vibration. So we have taken some protective measures. The vehicle can withstand a certain degree of impact; it is also fitted with soft pads below the arms to cushion impacts. The barycenter is in the center of the vehicle, to reduce the disturbance from the vehicle, and all sensor installation is very reasonable.

a2) EMI/RFI Solutions

EMI does harm to the vehicle, and we have taken some measures to protect the vehicle. The vehicle equips with brushless motors, so the EMI is relative smaller. Furthermore, the flight controller is mounted in the center of the vehicle where is relatively far from the interference source. Different sensors are installed in different part of the vehicle for the sake of reducing the EMI. Our RC transmitter and WIFI module work in different frequency, it can reduce the RFI.

B. Safety

In order to make sure the safety of the vehicle, we have taken many tests before this competition. Apart from this, we have designed two protection measures. If the vehicle is out of control in the flight in competition, we have taken some effective measures. First, we use RC transmitter to take over the control of the vehicle, and if it is still out of control, we can cut off the electricity supply through the ground station.
In a word, we have a safety operator who has the manual override capabilities to ensure safety.

C. Modeling and Simulation

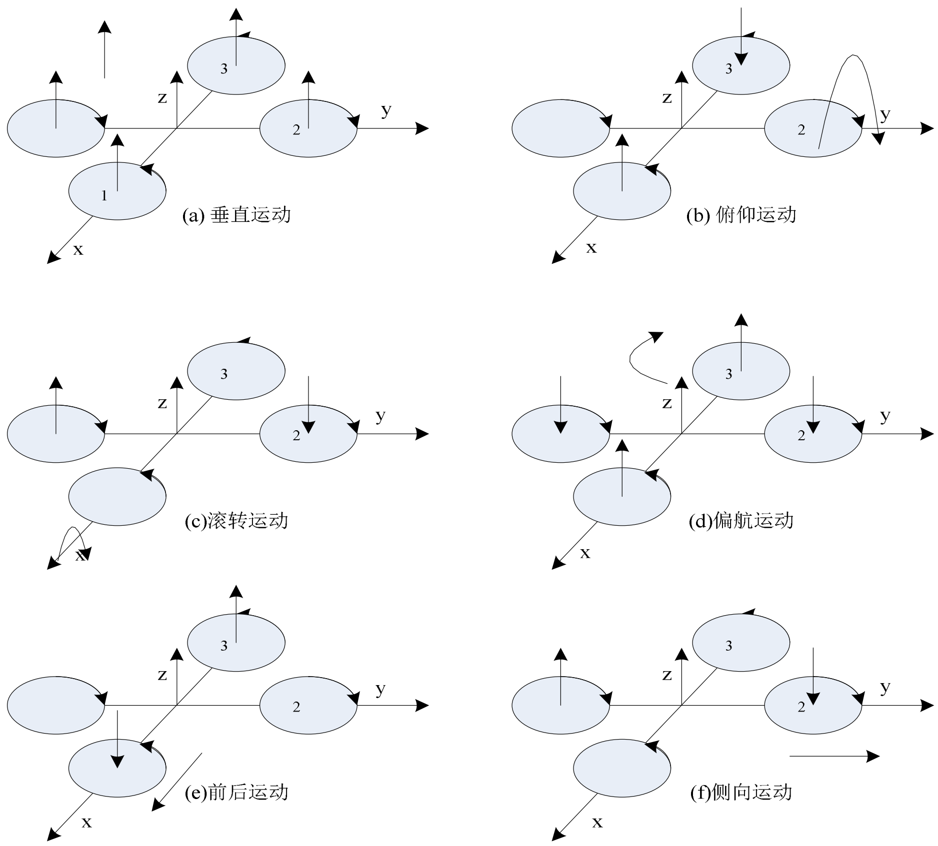


Figure 5. The quad-rotor along the various degrees of freedom of movement.

The vehicle can be regarded as a rigid body with six degree of freedom, which includes the movement along the line of body's three axial and the angular motion around the three axes of the vehicle. World frame is related to the ground, and the body frame is fixed to the quad-rotor. The vehicle's movement model was shown in figure 5.

（1）Vertical movement: vertical movement is relatively easy, as shown in Fig.5.a, because two of the motor is turned to the contrary, it can balance the body's anti-torque, while increasing the output power of the four motors, the rotor speed increases, so that the total pulling force increases, when the total pulling force is sufficient to overcome the weight of the four-rotor, the four-rotor can be off the ground vertically; Conversely, while reducing the output power of the four motors, four-rotor aircraft vertical drop until balance landing, along the vertical motion of the z-axis. When external disturbances zero, simultaneous the lift is equal with the weight of the aircraft, the aircraft can maintain a hover state. Guarantee the four rotor speed increase or decrease synchronous is the key of the vertical movement.

（2）Pitching movement: In Fig.5.b, the speed of the motor 1 is increased, the speed of the motor 3 is decreased, and the speed of the motor 2 and motor 4 remain unchanged. In order not to cause four-rotor torque and pulling force overall change because of the change of rotor speed, the speed changes of motor 1 and motor 3 should be equal. Due to the lift of the rotor 1 is increased, the lift of the rotor 3 is decreased, the unbalanced torque which is generated by it will make the machine rotate around the y-axis direction (direction shown), the same, when the speed of the motor 1 is decreased, the speed of the motor 3 is increased, the machine will rotate around the other direction of the y-axial rotation.

（3）Rolling movement: the same as the principle of the Fig.5.b, in Fig.5.c, when the speed of the motor 2 and the motor 4 are changed while the speed of motor 1 and motor 3 are unchanged, the machine to rotate around the x axis (forward and reverse).

（4）Yaw movement: Four-rotor yaw movement can make use of the anti-torque. The process of the rotor will form the anti-torque which is contrary to the rotational direction due to the role of the air resistance, in order to overcome the effect of the anti-torque, we can make the two of four motors rotate forward, the other two inverse, and the rotation of the respective rotor on the diagonal direction are the same. The anti-torque is related with the speed of the rotor, when each rotor has the same speed, the anti-torque can balance, four-rotor does not rotate; When four motor speed is not exactly the same, the imbalance of the anti-torque cause four-rotor rotate. In Fig.5.d, when the speed of the motor 1 and the motor 3 is increased, the speed of the motor 2 and the motor 4 is decreased, the anti-torque of the rotor 1 and the rotor 3 on machine is greater than the anti-torque of the rotor 2 and the rotor 4 on the machine, the machine will rotate around the z-axis under the action of the surplus anti-torque, so that achieve the yaw movement of the aircraft, the direction is opposite to the motor 1 or the motor 3.

（5）Front and back movement: In order to achieve aircraft move back, forth, left, right in a horizontal plane, a certain force is put on in the horizontal plane. In Figure 2e, increasing the speed of the motor 3, so that the pulling force is increased, decreasing the speed of the motor 1, so that pulling force is decreased, while maintaining the two other motor speed be constant, the anti-torque still maintain balance. According to the theory of Figure 2b, at first the aircraft must be in a certain degree of tilt, so that the rotor pulling force generated horizontal component, therefore four-rotor can achieve the forward flight. Backward flight and forward flight are just the opposite. Of course, in Fig.5.b and Fig.5.c, while the aircraft generates pitch, rolling movement, it can also generated along the x, y-axis horizontal movement.

（6）Lateral movement: In Fig.5.f，due to the structure is symmetrical, lateral flight is the same as front and back movement.

The vehicle’s navigation algorithm is tested in matlab and C++.

D. Testing

Before the navigation system is completely done, we test our height control in our lab firstly, then position control of the vehicle in an environment which is similar to the competition field is tested by detecting the white line gridding; finally, identify to the autonomous ground robot is tested.

VI. CONCLUSION

In this paper, we presented the technical details of an autonomous aircraft capable of navigating in a sterile environment with no external navigation aids and interacting with autonomous ground robots. The vehicle localizes itself by the downward-looking camera and optical flow, stabilizes its attitude (pitch, roll and yaw) and altitude using PID controllers. The vehicle identifies the autonomous ground robots by the forward-looking camera and avoids obstacle ground robots by setting the area near the paths of obstacle ground robots as hazardous area. We also take some measures to prevent contingency happening effectively.

So far, we have acquired some achievement, but we still have a long way to go, and we are confident in our own. The Naval Aeronautical and Astronautical Institute Team intend to compete in the 2014 IARC competition with this vehicle.

VII. REFERENCES

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