Naval Aviation University Entry for the 2019 AUVSI International Aerial Robotics Competition Mission 8

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ABSTRACT

This paper describes the details of a system composed by a human and four autonomous aircrafts. The vehicles are fully autonomous and can be controlled by the human voice. The vehicle localizes itself by the low-cost IMU module and optical flow module, stabilizes its attitude (pitch, roll and yaw) and altitude using an open-source controller named pixhawk2 with a laser height sensor. The human takes a hand-held computer with the ground control station showing the information of the drones and making task planning. The vehicle avoids obstacle by an onboard computer with laser sensor, and the computer receives the commands from the ground control station and pass them to the controller. The communication between drones and human is based on a wireless router. The system is intended to be Naval Aviation University's entry for the International Aerial Robotics Competition in 2019.

Ⅰ. INTRODUCTION

This paper describes technological details of our system, which is designed to be Naval Aviation University Team Entry for the 2019 AUVSI International Aerial Robotics Competition. The system fulfills all the technologies to be demonstrated. With the help of various onboard sensors, the MAVs are full autonomy and are capable of positioning, obstacle avoidance, tracking. Besides, the ground control station can show and process the captured videos by the vehicles, and achieve the swarm interaction. The human can control the vehicles by voice too. As a result, the system is able to complete the mission.

A. Statement of the Problem

The objective of the IARC 8th Mission is to demonstrate five new behaviors that have never been attempted in any of the past seven IARC missions, includes [1]:

1. Man-machine interaction (non-electronic command and control)
2. Fused sensory enhancement of a human operator by a fleet of aerial robots
3. Swarm interaction
4. Aerial target designation
5. Head-to-head interaction with opposing aerial robots

B. Conceptual Solution

Our Team has developed a man-vehicle coordination system to accomplish the task. The overview of the system is shown in fig 1. There are mainly three parts, four quadrotors, a wireless router and a hand-held computer.

Each quadrotor is with,

1. A flight controller pixhawk2 with a laser altimeter and an optical flow module. The flight controller mainly fulfills the positioning without GPS and obvious cues, and the attitude control. It also executes the commands passed from the onboard computer.
2. An onboard computer stick connects to the TELEM2 port on the pixhawk2 by an USB2TTL converter. The computer gets the vehicle state information, commands from ground control station, and the obstacle information from the laser radar, and sends vehicle movement commands to the pixhawk2.
3. An obstacle sensor that is a laser radar connected to the onboard computer. The laser radar measures the distance away from it in 360° range, and sends the information to the computer.
4. A camera located on a three-axis gimbal. The three-axis gimbal is mounted on the bottom of the vehicles. The camera keeps looking down due to the gimbal.
5. An image transmission equipment connected to the camera. The image transmission is used to send the video captured by the camera to the ground control station.
6. A laser emitting device. This is used for cure the human is controlled by the onboard computer.
7. A telemetry module connects to the TELEM1 port on the pixhawk2. The telemetry module sends the vehicle state information to the ground control station.

The wireless router is a communications relay. It connects the four onboard computers and the hand-held computer accomplishing the information transmission between the vehicles and ground control station.

The hand-held computer with：

1. Four image receiving equipment. They are used for the reception of the analog videos from the camera on the quadrotors.
2. Four modules that transfer the received analog video to digital video.
3. A recording equipment. It is used for get the voice command.
4. Four telemetry modules that receive the vehicle information.

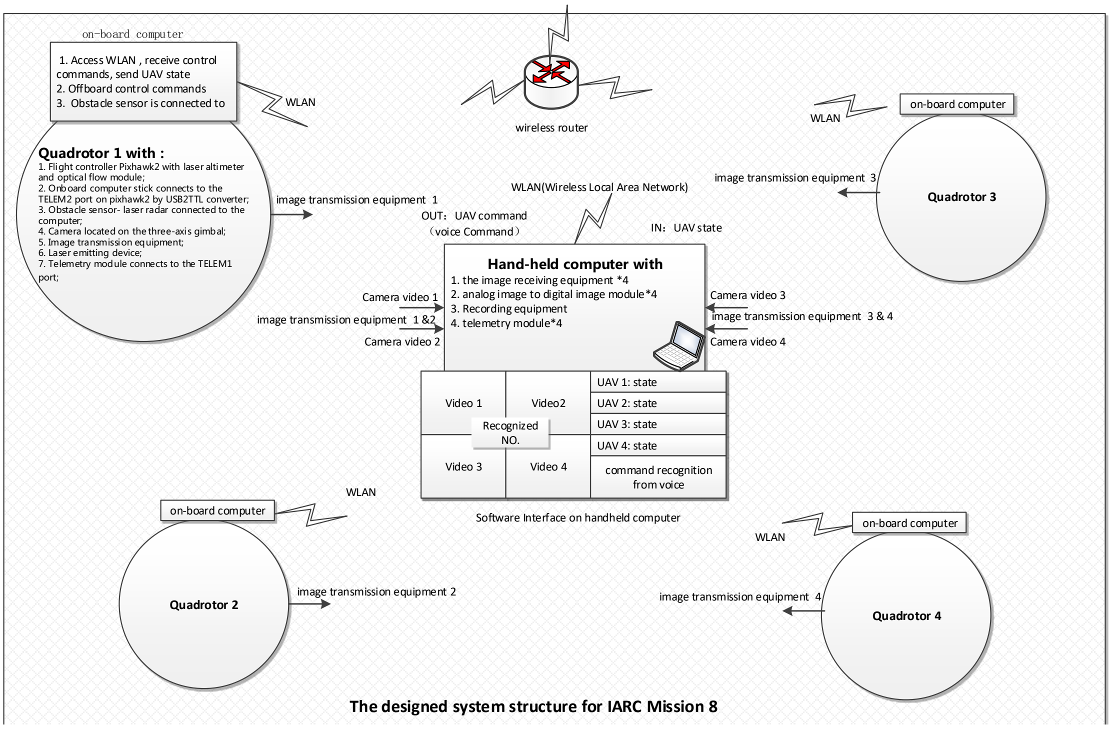


Figure 1: System Overview

C. Yearly Milestones

This is the second time for our team to participate in IARC. In last Mission 7 competitions, we have achieved a good result and gained some good experience and knowledge. As the first Mission 8 competition, we hope we can achieve a better result this time.

II. AIR VEHICLE

Quadrotor is a good choice for MAV due to its relatively high flexibility and maneuverability. In 2019 IARC, our quad-rotor is assembled by ourselves, as shown in fig 2. The vehicle can achieve autonomous flight control. The flight attitude of the vehicle is measured by pixhawk2 module. The flight altitude of the vehicle is measured by a laser height sensor. The drift velocity of the vehicle is measured by pixhawk2 with an optical flow module too. The size of quad-rotor is 45cm×45cm×18cm with a safety margin, and with a 5300mAh Li-Po Battery. The quad-rotor weighs about 1.46kg.

Figure 2: The quadrotor

A. Propulsion and Lift System

The quad-rotor equipped with four brushless DC motors and four 10in 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 balanced. 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) Flight Controller

The vehicle control is accomplished by a commercial flight controller name pixhawk2 (fig. 3). The pixhawk2 is a flexible autopilot intended primarily for manufacturers of commercial systems. It is based on the Pixhawk-project FMUv3 open hardware design and runs PX4 on the NuttX OS [2]. The pixhawk2 autopilot has been reliable by various failsafe functions integrated by the opensource community.

Fig.3 The pixhawk2 flight controller

(2) Navigation

The robust velocity and position estimation at high update rates are achieved by the IMU in pixhawk2 and an optical flow module named Here Flow (fig. 4). Here Flow is a finger size optical flow sensor. Compared with other optical flow sensors, it is even smaller. It can be installed easily at any position without taking much space. A LiDAR component, an optical flow camera and a 6D IMU (ICM20602) are integrated in the Here Flow [3].

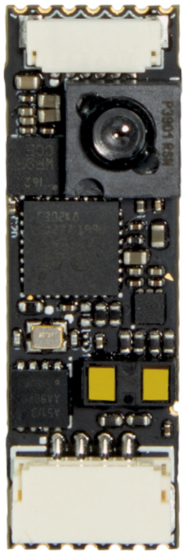


Fig.4 The Here Flow Module

(3) Guidance

Instead of modifying the autopilot software, we use an onboard computer stick (fig.5) manufactured by Intel to command the autopilot using high level commands. For the companion computer to communicate with the flight controller, a USB2TTL converter (fig. 6) is needed to convert the voltage of the communication levels. The onboard computer uses ROS to control the autopilot.

Fig.5 The computer stick

Fig.6 The USB2TTL converter

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.

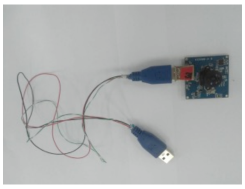
III. PAYLOAD

A. Sensor Module

The onboard sensors include laser obstacle sensor, camera and laser height sensor. The laser height sensor is connected to the onboard computer; the data of camera is transferred to the ground station computer.

(a) Laser height sensor

(b) Laser sensor



(c) Camera

Figure 7. Various onboard sensors.

A laser height sensor is used for attitude stability, as shown in fig.7 (a). The laser sensor gets the obstacle robots information by detecting distance during 360 degree, as shown in fig.7 (b). The downward-looking camera can provide 720×576 gray scale images as a speed of 30 fps, as shown in fig.7 (c).

The vehicle uses downward-looking camera to find and reveal the code for the human. The aircraft avoids obstacle by setting the area near the paths of obstacle 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 (14.8V, 5300mAh) which allows approximately 15 minutes of autonomous flight. There is a power monitor, when the voltage is under 12V, 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 height laser'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 the video captured by the down-looking camera 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

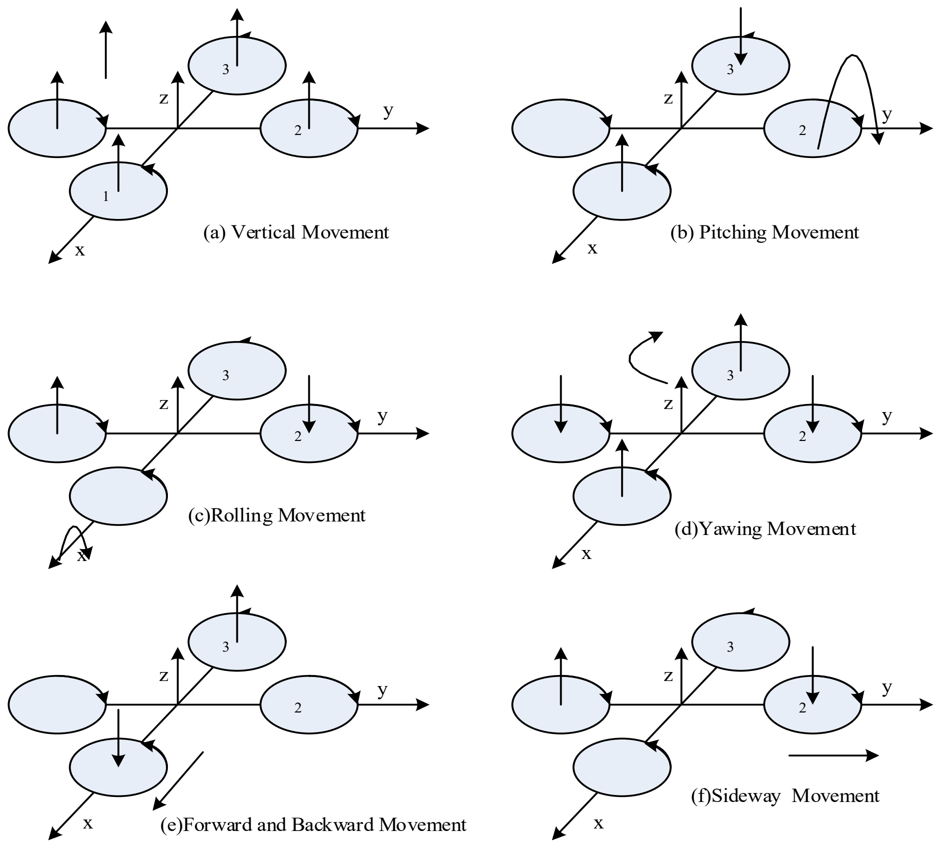


Figure 8. The quad-rotor along the various degrees of freedom of movement.

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 8.

（1）Vertical movement: vertical movement is relatively easy, as shown in Fig.8.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.8.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.8.b, in Fig.8.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.8.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 8.e, 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 8.b, 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.8.b and Fig.8.c, while the aircraft generates pitch, rolling movement, it can also generated along the x, y-axis horizontal movement.

（6）Lateral movement: In Fig.8.f，due to the structure is symmetrical, lateral flight is the same as front and back movement.

The vehicle’s navigation algorithm is simulated by matlab and C++.

VI. CONCLUSION

In this paper, we presented the system details of a human and four autonomous aircraft capable of cooperation in a sterile environment with no external navigation aids and interacting with non-electronic command. The vehicle localizes itself by the optical flow, stabilizes its attitude (pitch, roll and yaw) and altitude using PID controllers. The vehicle identifies the code and avoids obstacle 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 Aviation University Team intend to compete in the 2019 IARC competition with this system.

VII. REFERENCES

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