Unmanned Quadrotor Helicopter of NUAA for 2015 International Aerial Robotics Competition

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International Aerial Robotics Competition Symposium on Indoor Flight Issues

ABSTACT

The Nanjing University of Aeronautics and Astronautics team designs and develops an unmanned quadrotor helicopter to complete the seventh IARC mission. The unmanned quadrotor helicopter is designed to autonomously fly in the arena without GPS, interacting with the ground robots, and sensing and avoiding the presence of moving special ground robots. Pixhawk Autopilot is a high-performance autopilot-on-module suitable for fixed wing, multi rotors, helicopters, cars, boats and any other robotic platform that can move. In the case without GPS, orientation and navigation of quadrotor helicopter is based on vision and optical flow sensor, through catching and tracing the ground robots and the lines of arena. Besides, to herd the ground robots toward the green side of the arena such that as many as possible cross over the green line in the shortest amount of time, optimization control algorithm is used to quadrotor helicopter.

1 INTRODUCTION

1.1 Problem Statement

Mission 7 of IARC is just like shepherd action, which means the Aerial Robot controls the trajectory of ground robots by interacting with them. Based on the mission, a control process is divided into three critical stages. Stage 1 begins when the unmanned quadrotor helicopter autonomously takes off, keeps a certain height, and determines the position and motional tendency of ground robots. Stage 2 requires quadrotor helicopter locks target to control, makes a control strategy. Stage 3 requires quadrotor helicopter traces the target, completes to herd the target. Stage3 also consists of sensing and avoiding the presence of moving special ground robots. Quadrotor helicopter repeats above process until all of the ground robots go out of bounds of the arena or the time is run out of.

1.2 Solution Scheme

To complete the mission, the NUAA team designs an unmanned quadrotor helicopter, which has autonomous control system, sensors, navigation equipment and wireless data transmission module. The seventh IARC mission pushes new areas of aerial robotic behavior. So the design and development of quadrotor helicopter is divided into three points based on the IARC rules. They are interaction between unmanned quadrotor helicopter and ground robots, the navigation system based on vision, and control strategy of herding.

1.2.1 Interaction between Unmanned Quadrotor Helicopter and Ground Robots

To realize the interaction with ground robots, it is important to improve the stability of quadrotor helicopter. At the same time, the random way of ground robots makes it hard to be touched.

On the one hand, the attitude control system of quadrotor helicopter should be improved. When quadrotor helicopter is close to the ground, it is a kind of ordeal to quadrotor helicopter with larger airflow disturbance. The open source code of PIXHAWK has PID control algorithm, which can ensure that the attitude is stable when closed to the ground. Based on the results of test, other control algorithm could be used to improve the robust of quadrotor helicopter.

On the other hand, tracing moving ground robots and accurately touching them is a great challenge for vision navigation and image processing. The method in detail is provided in next section.

1.2.2 The Navigation System based on Vision

Mission 7 eliminates off-the-shelf navigation solutions by being conducted in a GPS-free indoor environment that is devoid of obvious physical cues. The NUAA team use vision and optical flow sensor to realize the navigation, which means quadrotor helicopter is installed with camera and optical flow sensor, and use those information to navigate. Because of ground robots moving randomly, quadrotor helicopter passive receives the discriminable signal from ground robots when it captures object, to capture and trace ground robots. To realize the tracing based on vision, quadrotor helicopter captures real-time information from camera, finds the target through a series of image processing, and realizes real-time tracking. At the same time, velocity information is given by optical flow sensor and messages of grids are given camera by image information from camera provide navigation message. Through the position of quadrotor helicopter in the arena and motional tendency of ground robots, the control system makes a control strategy to herd ground robots.

1.2.3 Control Strategy of Herding

To herd the ground robots toward the green side of the arena such that as many as possible cross over the green line in the shortest amount of time, optimization control algorithm is used to complete target selection. Strategies are to redirect robots which move between white edges of the arena before contending with robots which move toward the green or red grids of the arena.

2 THE UNMANNED QUADROTOR HELICOPTER

An unmanned quadrotor helicopter includes the following parts: brushless motors, electronic governors, flight control system, navigation system, frame, propellers, dynamical power, wireless data transmission and ground station. The hardware structure diagram is shown in figure1.

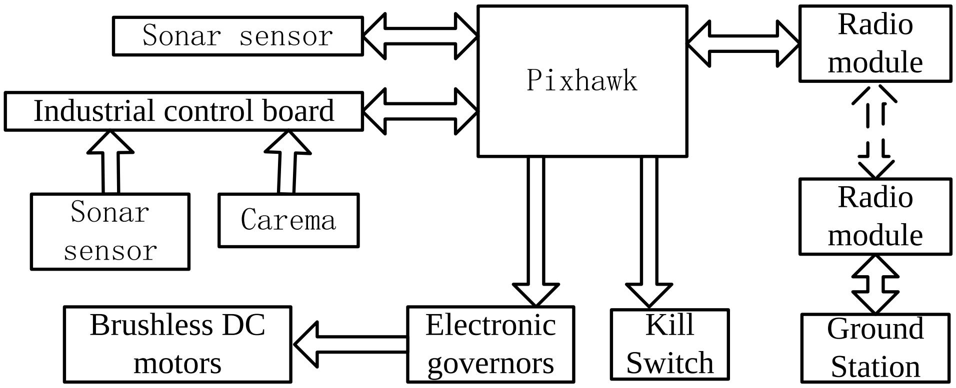

Figure1. Hardware structure diagram of unmanned quadrotor helicopter

2.1 Frame

Frame is the main structure of quadrotor helicopter. Its size and material strength determines the stability and load capacity. Taking into account load capacity, endurance, anti-wind ability, mobility and so on, the NUAA team chooses frame with 670 mm wide wheelbase, frame arms and undercarriage used carbon fiber tube, and centre plate used carbon fiber sheet.

2.2 Propulsion and Lift System

Propulsion and lift system of quadrotor helicopter includes brushless motors, electronic governors, propellers and dynamical power. The system determines the maximum load capacity, endurance and mobility. Considering the quadrotor helicopter with a load capacity more than 3.5Kg and a endurance time more than 10 min, our team uses T-motor 4014 as brushless motors, with propellers（1555）and lithium battery(10 000mAh 25C 22.2V).The parameters of T-motor 4014 KV330 is shown in table1. Due to the above configurations, and the load currency is 11.9A when the throttle is 100%, our team uses Hobbywing 30A as electronic governors.

From table1, when the throttle is 65%, the pull is 1150g，which means all of motors can provide lift with 4.6Kg. Therefore, this design meets the need of load capacity.

TABLE1. PARAMETERS OF T-MOTOR 2014 KV330

Propeller (inch)	15×5.5				
Voltage (V)	22.2				
Throttle	50%	65%	75%	85%	100%
Load-Currency (A)	3.6	5.9	7.8	10.1	11.9
Pull (G)	830	1150	1430	1690	1920
RPM	3900	4600	5100	5600	6000
Watts(W)	79	126	169	221	262
Efficiency	10.51	9.13	8.46	7.65	7.33

(G/W)					
Operating Temperature ($^{\circ}C$)	45				

2.3 Flight Controller

PX4 is an independent, open-source, open-hardware project aiming at providing a high-end autopilot to the academic, hobby and industrial communities (BSD licensed) at low costs and high availability. It is a complete hardware and software platform, much like a computer, and can run multiple autopilot applications. Hardware of APM is shown in figure2.

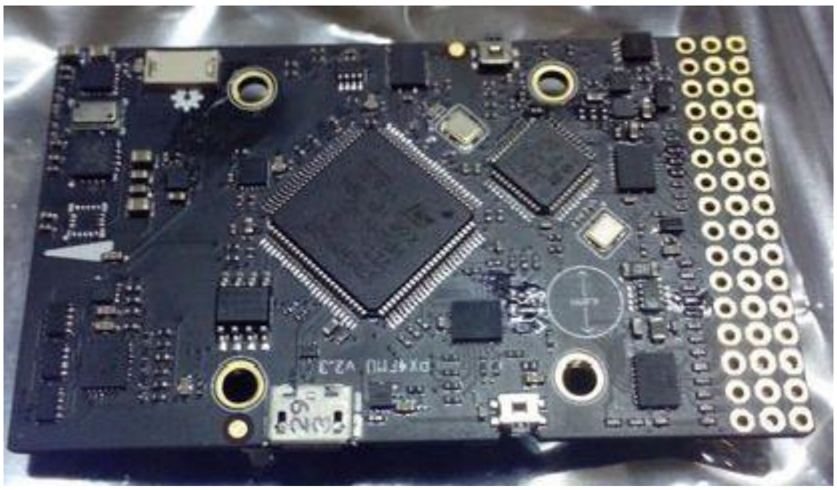

Figure2. Flight control board

Pixhawk uses 32bit STM32F427 Cortex M4 core with FPU. It also integrates a variety of sensors, including ST Micro L3GD20H 16 bit gyroscope, ST Micro LSM303D 14 bit accelerometer / magnetometer, Invensense MPU 6000 3-axis accelerometer/gyroscope, and MEAS MS5611 barometer, which dispenses with the trouble that external sensors is circumscribed by jumper wire.

Attitude controller is the most important controller in the flight control system. We use the basic and practical double loop PID controller in attitude loop. The outside loop is angle loop which is relative to the geodetic coordinates system, using the P controller. Though coordinate system transformation, the information is input to the inner loop, which is the angular velocity loop relative to body axis system, using the PID controller. Roll, pitch and yaw are controlled by different controllers. The structure diagram of roll controller is shown in figure4.

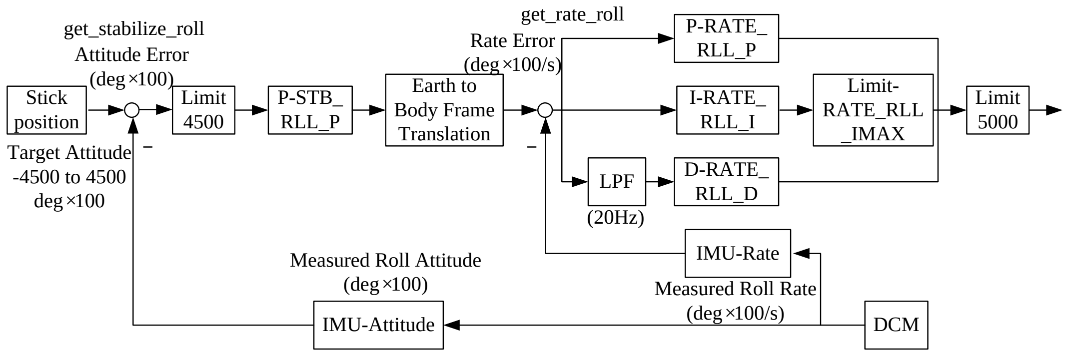

Figure4. Structure diagram of roll controller

2. 4 **Selection of Wireless Data Transmission**

Wireless data transmission is the only remote control measure of ArduCopter flight, the control range of which directly determines the radius of aircraft flight. It fulfills the communication between ground station and flight control system. Our team chooses 3DR data transmission module, which supports UART communications. Its transmission frequency is 433 kHz, and the maximum transmission distance is 700m outdoors. The material object of 3DR is shown in figure5.

Figure5. Material object of 3DR

3 VISION NAVIGATION

3.1 Navigation of the Unmanned Quadrotor Helicopter

According to the existing machine vision technology for navigation, there are two ways to complete the mission. First, in the competition, the arena is composed of many squares, whose side length is known. Our team uses the camera to take pictures, process these pictures and obtain the number of squares that the quadrotor helicopter gets through in the air. Through continuous recording, the ground robot's position relative to the competition arena can be obtained. The second is through the optical flow algorithm, which is a relatively new way to navigate. Optical flow is the concept of detecting the movement of objects in the visual field. Actually optical flow is a method that infers the direction and moving speed of the object by detecting the intensity changes of the image pixel with time.

The basic principles of optical flow method to detect moving objects are: give a velocity vector to each pixel of the image, which formed an image stadium. At a particular moment of movement, points on the image and points on three-dimensional objects correspondence. This correspondence can be obtained by projected relations. Then according to the characteristics of the velocity vector of each pixel, we can analysis the image dynamically. If there is no moving object in the image, the optical flow vector of the entire image area is a continuous change. When there are moving objects in the image, objectives and background of the image exist relative motion. The velocity vector of the moving object and the inevitable formation of the velocity vector background are different, which can detect moving objects and locations. Advantages of optical flow method is that not only carries the optical flow motion information of moving objects, but also carry a wealth of information about the three-dimensional structure of the scene. It can detect moving objects without any scene information.

3.2 Target Acquisition and Tracking

There are two ways to capture the target through machine vision. One is pattern matching, and another is color matching. Pattern matching is based on the shape template of the goals established. Then find shapes in camera which is matched with template, and realize to capture the target. Color matching is based on target-specific color. It finds the same color in the camera, and captures the target. Both methods have their advantages and disadvantages. Our team intends to adopt the color matching method. Paste special colored paper on the surface of the ground robots, the use the camera to capture and track the targets.

3.3 Hardware

To realize the real-time navigation and tracking, there are a higher requirement to the quality of visual signal and processing speeds. Because of that, a higher pixel camera and a chip are used to meet the requirement. There is a processing speed limit of general chip. So our team chooses an industrial control board.

3.4 Algorithms and Software

Computer vision is only a part of the mission. Our team uses more mature image processing library functions OPENCV as a basis for software development. OPENCV, as an open-source application platform, is characterized by fast execution, and the greatest degree to satisfy real-time applications.

3.4.1 Navigation

In OPENCV, there is a specialized function in the realization of optical flow.

Void cvCalcOpticalFlowPyrLK(const CvArr* prev, const CvArr* curr, CvArr* prev_pyr, CvArr* curr_pyr, const CvPoint2D32f* prev_features, CvPoint2D32f* curr_features, int count, CvSize win_size, int level, char* status, float* track_error, CvTermCriteria criteria, int flags).

Function cvCalcOpticalFlowPyrLK implements sparse iterative pyramid Lucas-Kanade optical flow calculation. It calculates the coordinates of the feature points on the current video frame, based on the feature point coordinates which is given by previous frame. It has a function to find the coordinates of the sub-pixel accuracy, which can calculate the speed of the camera relative to the vision and displacement.

3.4.2 Target Acquisition and Tracking

Target acquisition and tracking uses the color matching method. First, a particular color is set to be an object. Then successive frames of images taken by camera are processed. Each frame of image is matched with the color, to find the target. According to the motional tendency of the target, system estimates the target location in the next moment, to save time.

Our team mainly uses the function(cvCamShift (IplImage * imgprob, CvRect windowIn, CvTermCriteria criteria, CvConnectedComp * out, CvBox2D * box = 0)) of OPENCV, which is based on color to capture and track targets.

3.4.3 grid recognition based on vision

We have successfully detected and tracked the target robot last year, however, we have not achieved Indoor positioning. On the basis of the achievement of the last year, the grid recognition combined with optical flow algorithm based on vision is joined. The core algorithm we used to achieve grid recognition is Hough image transform, through which we can draw the lines of the grid in the captured video using Opencv, of course, some other image processing methods are needed to improve the effect of grid recognition. The grid recognition plays an important role in this competition. The image captured by camera is shown in figure6 and the image after Hough image transform is shown in figure7.

Figure6: Image captured by camera

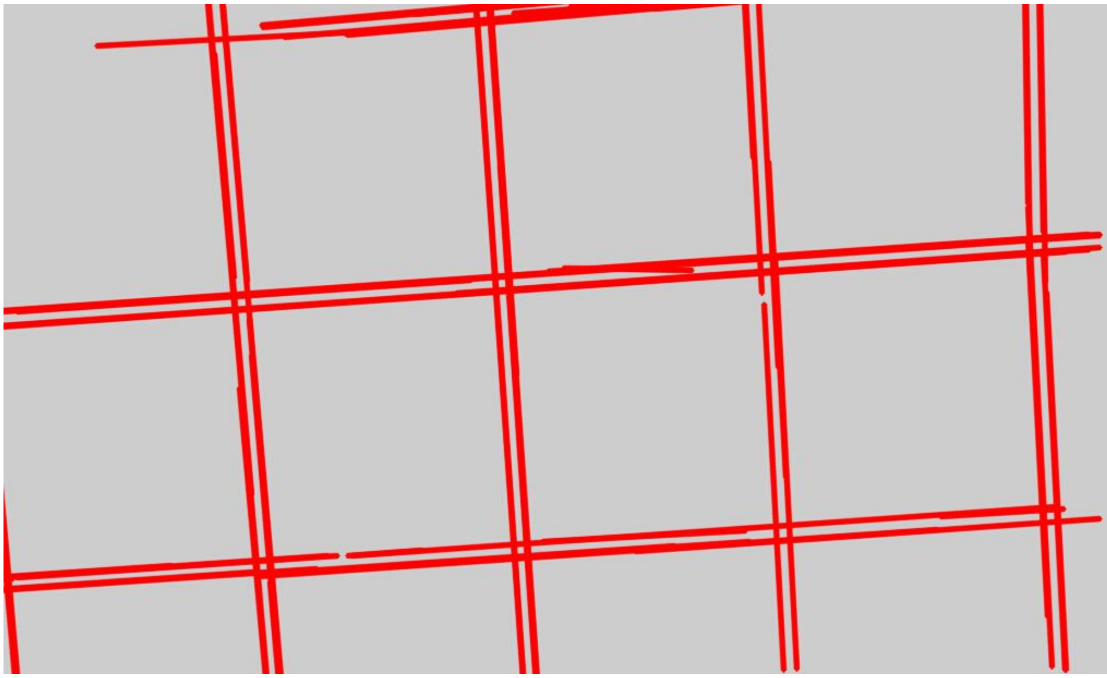

Figure 7: Image after Hough image transform

Optical flow algorithm is a kind of indoor localization algorithm, but we all know that the localization errors will sustained accumulate in the course of the quadrotor helicopter performs its tasks， so we must take measures to correct localization errors. Grid recognition can improve the positioning accuracy of Optical flow algorithm by correcting localization errors. In this way, it can help quadrotor helicopter achieve automatic flight more smoothly and determine its positions in the arena more accurately. This is very important for the quadrotor helicopter knows which direction to drive the robot to improve the efficiency of driven ground robots. At the same time, it is helpful to avoid the quadrotor helicopter beyond the arena resulting in failure in the competition finally. The pictures followed is the images before processing and after processing.

4 CONTROL STRATEGY OF HERDING

The strategy of this competition is very complex. Because the number of controlled objects---ground robots are more than 1. The initial state of these robots is random, and is very likely to be changed by the cylinder obstacles. Besides, the aerial robot has 2 options: touch the top of ground robots to change the direction by 45 degrees, or land in the front of a ground robot to change its direction by 180 degrees.

To simplify the strategy, our team assumes the flight speed of the aerial robot is high enough, and just finds the ground robot which should be drive first, according to the current state of ground robots, and ignores the possibility of collision between robots.

Because landing in the front of a ground robot is simpler than flying follow with the ground robot. So, the aerial robot should deal with ground robot, which are moving towards the red line side. Firstly find the nearest ground robot, fly to its front and land, waiting for a collision. Then takeoff, deal with the next robot. Ground robots that move towards the left white side should be handled second. Aerial robot needs to touch the top of these robots twice, in order to change their direction by 90 degrees. These ground robots will move towards the green side.

The simple strategy mentioned above is easy to achieve, but it is unlikely to get high scores with that strategy. Some important rules can be considered in the strategy. Such as ground robots will redirect themselves after about 20 seconds of travel. The ground robot can move about 6.6m in 20 seconds, which is shorter than half of the competition area. So, at the beginning of the game, robots which move to the red line side needn’t deal with. Besides, take account of the possible collision between robots will be better. But it may be hard to get this information by sensors.

5 CONCLUSION

The NUAA team has developed an autonomous unmanned quadrotor helicopter capable of flying above the arena with vision navigation, sensing and avoiding the presence of moving special ground robots, interacting with the ground robots, and herding them toward the green side of the arena such that as many as possible cross over the green line. Based on above design, the NUAA team intends to complete the mission 7. The technology of mission has broad application prospect, such as reconnaissance, disaster relief, and monitoring.

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