SYSU Swift TECHNICAL REPORT MISSION 9

Sun Yat-sen University*

Guangzhou, Guangdong Province, 510006, P.R.China

Abstract

A rotorcraft system with grab platform is designed to accomplish the Mission 9 of the International Aerial Robotics Competition by the Sun Yat-sen University Swift Aerial Robotics Team. In the complex outdoor environment, our designed system integrated multiple sensors and a high-precision positioning system, while relying on a powerful onboard processor for decision making to ensure the stability and reliability of the vehicle control system. A set of grab platforms with high-capacity batteries and high-power motors and manipulators with gripping function is designed to accomplish long-distance high-load motion and high-precision disassembly and replacement of parts.

1 Introduction

A powerful intelligent aerial robot system which can carry a grab platform equipped with a robot and other transmission devices is developed by the challenger of mission 9. The rotor flight system carries the mechanical grab platform system to quickly reach the location of parts. Finally, the flight system and the mechanical system cooperate with each other to complete the parts replacement.

Our vehicle is required to have high stability and positioning accuracy, and the mechanical system is required to have high precision operation level and enough power to replace 2kg parts on this task. To meet these requirements, IMU inertial sensors, GPS, and RTK fusion positioning system are integrated into the vehicle. The depth camera is also used to sense the surrounding environment in real time to give visual information to help the vehicle reach the designated position precisely and complete the part replacement task with high accuracy. Besides, the control algorithm called center of gravity prediction compensation is developed to ensure the stability of the aerial robot when performing the task and a software system framework based on ROS is established for distributed management.

2 Hardware architecture

The hardware system is the basic electronic foundation of an aerial robot. It is important to choose right equipment to build a hardware system with low cost, low power consumption and excellent performance. An aerial robot platform suitable for completing mission 9 is reasonably designed according to the requirements of the competition.

2.1 Flight platform

2.1.1 Main flying machine

The quadcopter has the advantages of simple operation and fast movement. The M300 flight platform provided by DJI is used for the high-precision mechanical control of mission 9 and the demand of

***Team Leaders:** Botao Zhang, was a third-year undergraduate majored in Opto-Electronics Information Science and Technology from Sun Yat-sen University, China, since 2019. He would receive the B.E. degree in 2023.

large weight load. The M300 has many excellent points such as 55 minutes long endurance, powerful machine intelligence and six-way positioning and obstacle avoidance. The M300 provides an extra 2kg of load. It can carry our grab platform and 2kg parts to complete the mission combined with the gravity compensation system.

Figure 1: flying machine

2.1.2 On-board computer

DJI's Manifold2 -c with NVIDIA Jetson TX2 GPU and Intel Core I7-8550U CPU is used as the central processor. It has sufficient arithmetic power and image processing capability, while being the right size for our flight tasks. All the data collected by the sensors are gathered together and processed in Manifold. Image processing, trajectory generation and upper layer strategies are implemented in this powerful core.

Figure 2: on-board computer

2.1.3 Positioning System

1) RTK (Real Time Kinematic) real-time dynamic measurement technology is a real-time differential GPS (RTKGPS) technology based on carrier phase observation. It consists of three control units: the reference station receiver, the data chain, and the mobile station receiver. Our vehicle has a built-in RTK module, this module provides strong anti-electromagnetic interference capability. Consequently, it can guarantee reliable flight even under strong magnetic interference environment such as high voltage lines and metal buildings. What's more, it can obtain high-precision and accurate positioning with DJI D-RTK2 high-precision GNSS mobile station or network RTK service.

2) General GPS module

3) DJI IMU

4) Visual camera positioning module

2.1.4 Flight Control System

The M300 is integrated with DJI flight control and has a rich sdk interface. The official OSKD interface provided by DJI is used to communicate with M300 on Manifold. It sends control commands and receive various data provided by M300 sensors to us and finally decision is made on Manifold. In the case of stable GPS signal, the aircraft has high stability and accuracy under DJI flight control.

2.1.5 Vision Module

The vision system is a component of the aerial robot of mission 9 that assists the control of the robotic arm. It needs to have high accuracy in the sub-task of target module loading and unloading under conditions with some shaking interference. Therefore, a depth camera with high frame rate, high accuracy, and depth-aware information is chose to collect visual images. We chose the Intel RealSense D435i stereo vision depth camera, which has a depth resolution of 1280×720, an $87° \times 38°$ viewing angle range and a maximum depth perception range of up to 2.8m, a depth estimation accuracy of no more than 2%, and a frame rate of 90fps. And it is suitable for working under various outdoor lighting conditions.

Figure 3: vision module

2.1.6 Obstacle avoidance system

The vision system and infrared sensing system of M300 are distributed in the front, back, left, right, top and bottom of the fuselage. The vision system is an image positioning system, which perceives obstacles and obtains aircraft position information through visual image ranging. The infrared sensing system perceives obstacles and determines the current height of the aircraft through infrared ranging. It ensures the precise positioning and safe flight of the aircraft through the combination of vision system and infrared sensing system.

2.2 Grab Platform

2.2.1 Manipulator and transmission device

The grab platform is an important part of the rotorcraft system. As the whole UAV wobbles during flight, this noise has a destructive effect on the grasping structure. If a direct connection is used without separation, all instabilities are transferred to the grasping structure, which has a great impact on the stability and accuracy of the grasping.

Consequently, the grab platform that can be separated from the UAV is designed, and the grab platform can grasp the mast to sway with the mast, so that it is easy for the gripper to operate.

And the grab platform can be roughly divided into three parts, which are the mast gripper part, the module gripper part, and the slide rail part. The three systems cooperate with each other to accomplish the task of gripping and lowering together.

2.2.2 Tilting motor section

For the reason of gravity imbalance to the aircraft when the mechanical gripper in the front section of the grab platform grabs a 2kg heavy module, additional tilt motors are added to the front section of the grab platform to provide lift and maintain the center of gravity balance of the whole flight system.

Figure 4: tilting motor section

3 Software Architecture

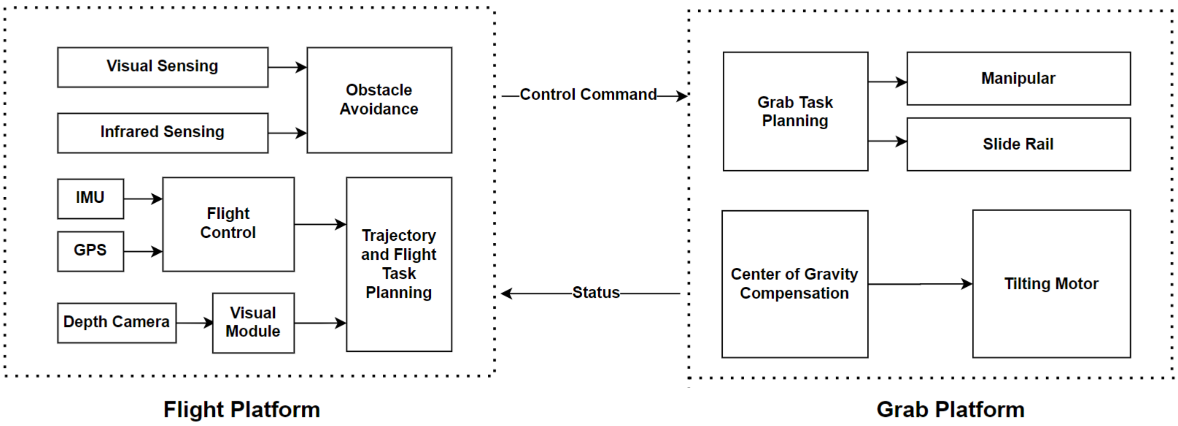

Figure 5: software architecture

The entire system is built on top of the ROS framework with all sensors, mechanical motion components, and software modules of the system running as ROS nodes. These nodes communicate transparently with each other using the provided ROS communication protocol. The main vehicle software runs on the Ubuntu 18.04 on-board computer platform. And the control software for the grab platform relies on an embedded platform which running on the STM32F series.

The whole software system is divided into the following modules: flight path planning module, flight platform control module, sensing module and grab platform control module.

The main difficulty of the task is divided into 3 points: precise maneuvering control the gravity shift caused by the grasping of 2kg heavy objects the perception and recognition of the mast in motion.

In order to solve the above difficulties, a center of gravity compensation scheme and a depth camera recognition scheme are designed for the robot.

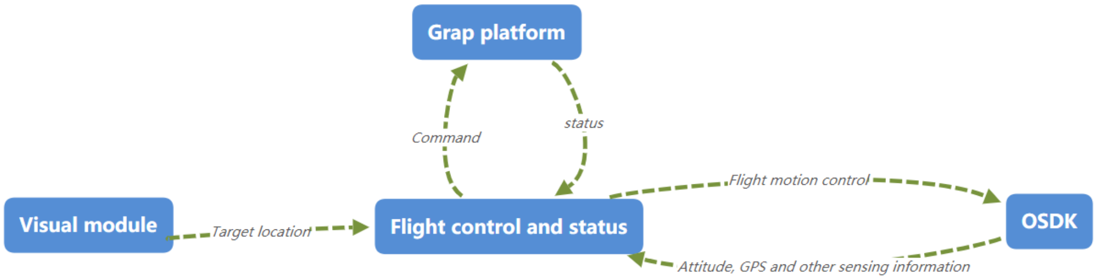

Figure 6: Software Framework Based on ROS

3.1 Flight Platform

3.1.1 OSDK

The official OSDK provided by DJI is the interface between the onboard computer and the M300 flight control, which can control the attitude, speed, position and movement of the airframe through the OSDK. At the same time, it can receive various sensing data (altitude, attitude, GPS position, etc.) from the flight control, and communicate through the serial port at 961200 baud rate for stable and efficient operation.

3.1.2 Flight Control

This node is the central node that directs the aircraft to complete the trajectory of this mission. The entire mission process is divided into the following parts. The power of the M300 is not enough to transport our entire robot. To carry a 2kg weight and run the 4kg grab platform, the two tilt motors on the grab platform are used to compensate for the gravity of the grab platform. The specific compensation algorithm will be introduced in the next part.

1) Approximately 8km round trip According to the requirements of the competition, 2 poles will be set up in the playground with 400m runway. With the real-time accurate positioning information from RTKGPS, our aircraft will follow our pre-defined trajectory to complete the circle.

2) Target Approach When flying to the location of the grabbing task, our vehicle will control the movement of our aircraft to the best location for our grabbing task. It is based on the error between the target orientation and the current position which calculated by the visual node recognition. Then vehicle will evacuate the location and return the way it came. Next, our grab platform will complete the module replacement task.

3.1.3 Vision Module

The vision module needs to accomplish two parts work

1) When the vehicle arrives near the target mast with GPS guidance, the vision module needs to perform the target detection task. Include finding the blue base plate with the target module in its field of view, and guiding the vehicle to the appropriate position on the front of the mast by returning a rough estimate of the target position, to make the vehicle ready for loading and unloading operations.

2) During the process of loading and unloading of the target module, the robot arm is assisted to complete the task of gripping and docking by returning the precise position information of the base plate where the target module is located.

Although the module is strictly rectangular, due to its relative small size, we chose to utilize a larger, simpler feature vision module. We use a blue base plate with the module and characteristic words on it as the primary object for visual positioning.

A. capture images The first step in the work of the vision module is reading images and pointing clouds from the camera. For the images, we first calibrate the camera using a pre-estimated internal reference matrix to obtain the radial and tangential aberrations of the camera, and then calibrate the images based on this.

Figure 7: left: RGB image; Right: aligned depth image

B. Target detection Feature point matching has been used to achieve target detection and coarse bit pose estimation.

The feature extraction is performed using a modified SURF feature extractor with a SIFT feature extractor. And a KD tree is also used to achieve near real-time performance for image feature extraction and matching.

When the number of matched pairs is insufficient, it is assumed that there is no target in the camera's field of view, and the vision module will wait for the vehicle to move and scan until a target is found in the field of view.

When there are enough matching pairs, the vision module calculates the position of the target relative to the vehicle based on the camera coordinate system. And then guides the vehicle to a position close enough to the front.

C. Precise posture estimation When the vehicle arrives directly in front of the mast the blue base plate are fully in the field of view, the vision module enters the exact matching mode. We first do pre-processing of the point cloud: octree to discretize the point cloud to reduce the computational complexity; direct-pass filtering to remove the interference points with excessive depth, and filtering the blue interference from the environment.

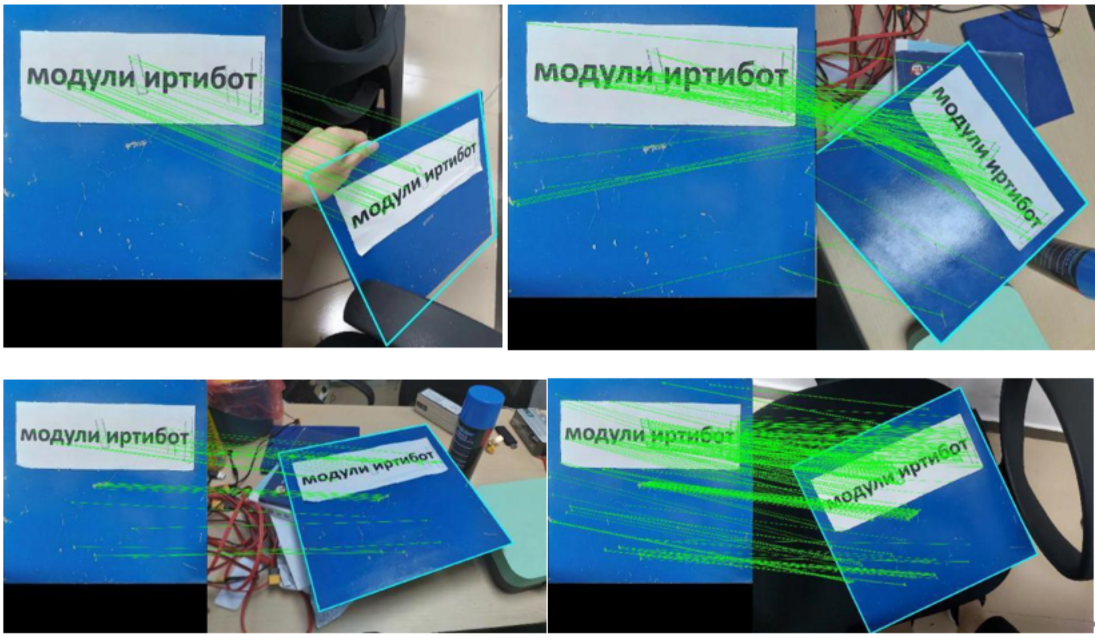

Figure 8: target detection and rough pose estimation based on SURF feature point matching

Second, using the color features, the threshold operation in HSV space is performed for hue and saturation, and coarse extract the point cloud of the base plate area.

Third, outlier removal is performed on the baseboard region point cloud to eliminate noise.

Then, RANSAC plane fitting is performed to obtain the more accurate plane normal vectors.

Finally, the exact boundary information of the base plate is determined: since the base plate is known to be square, a RANSAC coarse fit of the boundary line is performed first. After removing the outliers, a least squares based exact fit is performed to obtain the exact boundary points.

Once the exact boundary points are obtained, the exact base plate position can be calculated using the corner points of the four corners of the base plate.

At last, since the mounting position of the module on the blue base plate is known in advance, the exact position of the module and the pins can be calculated based on the blue base plate position.

3.1.4 Obstacle avoidance section

In order to ensure the safety of the experimenters and the people nearby during the flight and avoid accidents outside, our flying machine has a powerful six-way obstacle avoidance function. Warp M300TRK can sense the obstacle position information within 40 meters, after opening obstacle avoidance mode not only the flight speed is not affected, and can fly safely in the environment of insufficient light, or no GPS signal.

3.2 Grab platform

The whole part of the grab platform is controlled by the STM32F103, which is divided into a center of gravity compensation part and a grasping task part. And it will receive control commands from the on-board computer to control the movement of each robot and the servo motor.

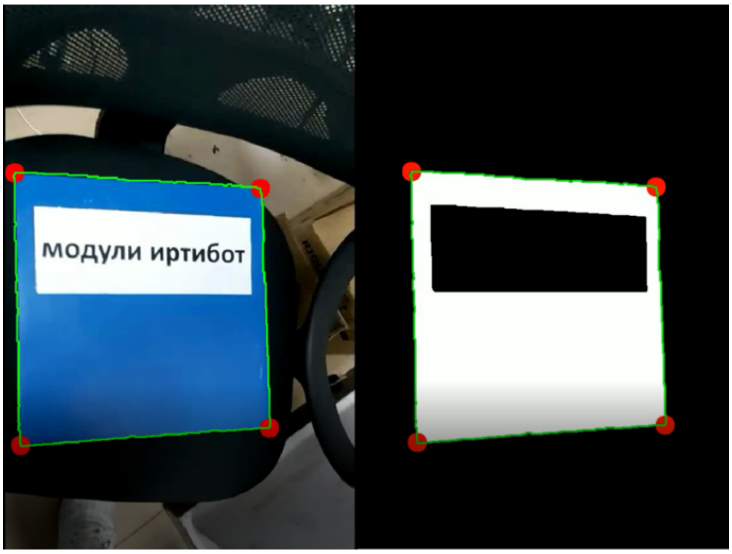

Figure 9: Synthesis method of high-precision pose estimation based on corner points

3.2.1 Crawl task section

We divide the motion state of our modules in different states according to the task state, and preset the position of the servos and slides in each module in different states. When performing the task, the grab platform master will judge the task state and command the movement of each module.

1) Mast grip The mast gripper section is as follows.

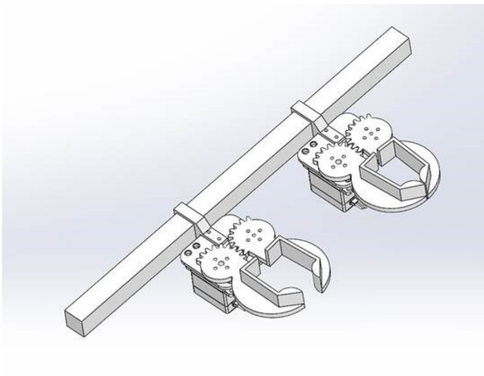

Figure 10: Mast grab part

The mast gripper is driven by two high-torque servos to support the weight of the entire grab platform, with a pressure sensor placed in the middle to allow for closed-loop control to prevent the motor overheating. And the gripper width is slightly larger than the mast width, which reduces the difficulty of system control and the need for accuracy. Each gripper is driven by gears. If the drive slips or other problems, fixed parts can be added to improve system robustness.

2) Module Grips Divided into grasping and relaxing states.

Since the antenna of the communication module is not in the horizontal plane, A special treatment has been made for the mechanical claw structure. The mechanical claw can hold the module firmly, and the servo drive claw can be fixed exactly when it is closed.

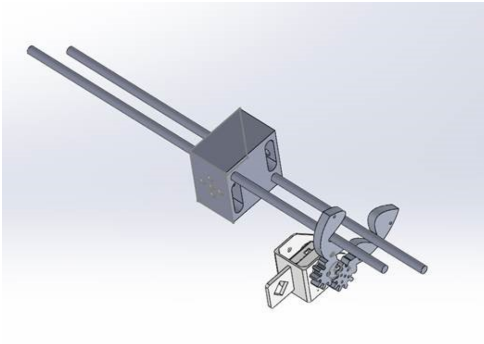

Figure 11: Module gripper

3) Slide Rail

Since we only need to operate the module in one dimension after the grab platform is fixed on the mast, so we only using a single-axis slider instead of heavy multi-joint manipulator. It can reduce the complexity and weight of the overall mechanical structure. The slide rail is mainly composed of guide rail and reducer brushless motor. The reducer brushless motor drives the slide to move in one axis, and at the same time drives the module gripper on top to move, and cooperate with the gripper to pull and insert the module operation.

3.2.2 Center of gravity compensation section

Center of gravity compensation: In order to calculate how much compensation to give, we need to model our mechanical system. To facilitate the control and calculation, the UAV and the robot arm are modeled separately, the robot arm is treated as a disturbance term of the UAS and the UAV is treated as a movable reference coordinate system for the robot arm. So that when the robot arm changes, only the robot arm needs to be re-modeled to output the appropriate amount of compensation. And to ensure that compensation lift is always oriented vertically upward (to facilitate the calculation of the compensation amount), the controller of grab platform will adjust the tilt motor's servo according to the current attitude of the grab platform. When we perform the grabbing task, the grab platform will be firmly gripped on the mast and separated from the vehicle, so we only need to pre-calculate the appropriate compensation amount for three states: flying around the circle, approaching the mast, and grabbing the mast with the mast grabber.

1) Angular sensing: The grab platform has a separate 6050 sensor that provides accurate angular posture information.

2) Servo control: The tilt motor will adjust the motor direction according to the current aircraft angular attitude to ensure that the motor always provides vertical upward and efficient lift compensation.

3) Motor control: In order to compensate the center of gravity, we pre-calculate the best compensation required in different flight states based on the modeling information of the robot, and control the motor at different speeds in different states.

4 Experiment

4.1 Flight Simulation

In order to simulate the actual flying task, we used the simulator provided in DJI-Assistant to simulate the flight of the aircraft. With this simulator, we simulated the whole flight range in advance, and we could use it to test the visual positioning accuracy. As simulated, we were able to complete the whole flight in about 8 minutes.

However, the differences between the simulated environment and the real environment are mainly in terms of positioning errors, hardware performance of the aircraft and control parameters. Therefore, other modules should not be tested in the simulation, but debugged in the actual test.

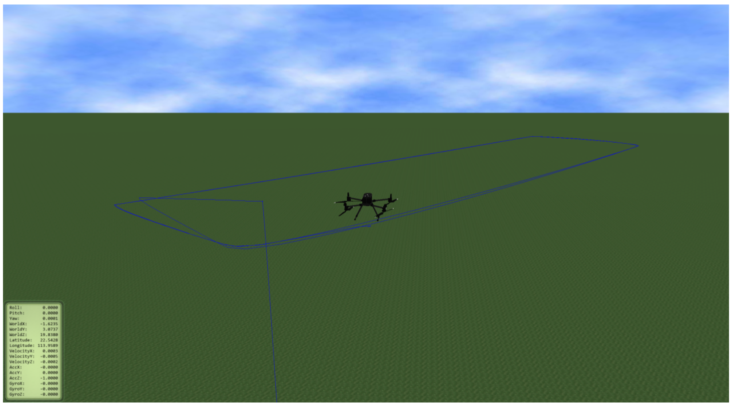

Figure 12: flying in a simulated environment

4.2 Sensor and Module Testing

Vision Module Testing In order to verify the accuracy of the target attitude and position data provided by the vision module, we tested the performance of the vision algorithm under different lighting environments. During the continuous testing, we improved the key parameters in image processing to provide the vehicle with accurate attitude and position of the blue target during the mission.

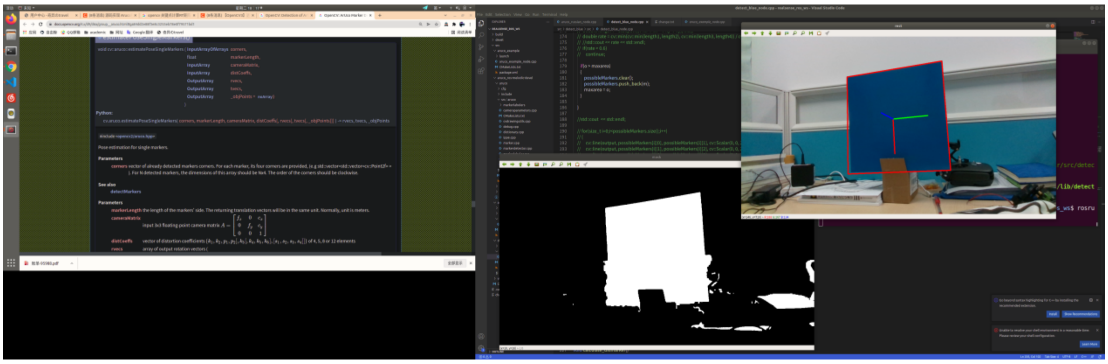

Figure 13: vision module testing

Grab platform crawl testing We need to design our own robot model for the mast and pin module grasping task. And test the performance of the servo and the grasper for grasping strength and stability. We are improving the manipulator structure and the performance of the servo so that the grab platform has the ability to perform the task of replacing the module.

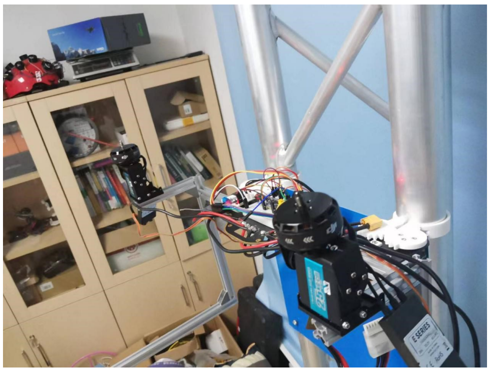

Figure 14: grab platform crawl testing

4.2.1 Flight Testing

We conduct actual flight tests several times a week to test the aircraft's large range performance outdoors and whether the speed is up to standard. We also measure whether the accuracy of the vision module can meet the requirements of guiding the aircraft to grab the module. During the tests, we continuously optimized our algorithm and code structure, and the aircraft performed the mission with good stability

Figure 15: M300 performing circling mission at high altitude

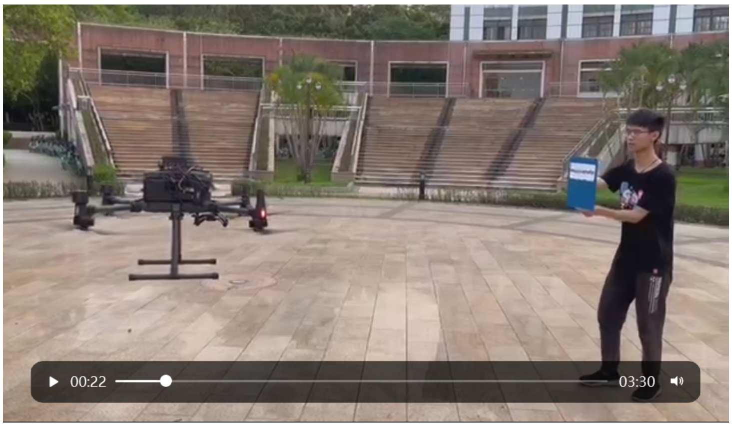

Figure 16: test the efficiency and accuracy of vision module

5 Conclusion

This paper presents the technical details of an aircraft system for mission 9. The task is divided into different levels of sub problems to overcome. We solve each sub problem separately and combine the modules to complete the task. So far, most of the modules are almost complete and need to be tested and combined. The system is expected to operate properly in the competition.