Autonomous Quadrotor for the 2017 International Aerial Robotics Competition

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ABSTRACT

This paper describes SYSU IARC team's entire system for Mission 7a of the International Aircrafts Competition (IARC). The basic system involves an M100, an airborne computer, different kinds of sensors, communication devices and a remote control. We make full use of the optical flow, IMU data and grid pattern recognition to construct a positioning and flight control system. The vision component processes the cameras input to identify and track the ground robots, generating an effective path in real time while avoiding obstacles with threat avoidance system. To realize top-down control, we utilize simulation module to determine a practical strategy for chasing the targets. Besides, the safety measures and experiments are also discussed in detail.

INTRODUCTION

Mission 7a of the IARC challenges participators to develop a high intelligent aerial robotics which can choose and drive robots to a specific side in an indoor arena. In the environment without external navigation aids such as GPS or large stationary points of reference, the aerial robotics are required to launch accurate interaction with robots while avoiding obstacles and limiting flight height. A practical system architecture and new strategy should be developed.

To fulfill the task, we design a vision-based system which consists of several modules, including positioning and flight control, robot detection, obstacle avoidance, trajectory planning and safety system. Since there are multiple targets, strategy should be first designed and tested in simulation system. We score targets according to their directions and positions. After choosing a specific target with the highest score, the UAV will launch tracking and interaction. The action will continue until the target is out of specific side or the score decreases below the threshold.

To achieve the above functions, optical flow, IMU data and grid pattern recognition are combined to construct a positioning system. Then, we implement flight control based on PID rather than the original one from M100. Decent image procession and feature extraction ensures the accuracy of target identification. Besides, PID algorithm is also introduced in target tracking.

AIR VEHICLE

Concerning the requirement of the competition tasks, we choose Matrix 100 made by DJI as the platform of the aerial robot. The quadrotor aircraft has four propellers, which is simpler and more robust than many other structures. The aircraft has a maximum size of 90cm, which is within the competition limitation. With strong lifting power, it can load up to 1 kilogram, which is able to set required onboard devices.

[1] Supervisor: Hui Cheng

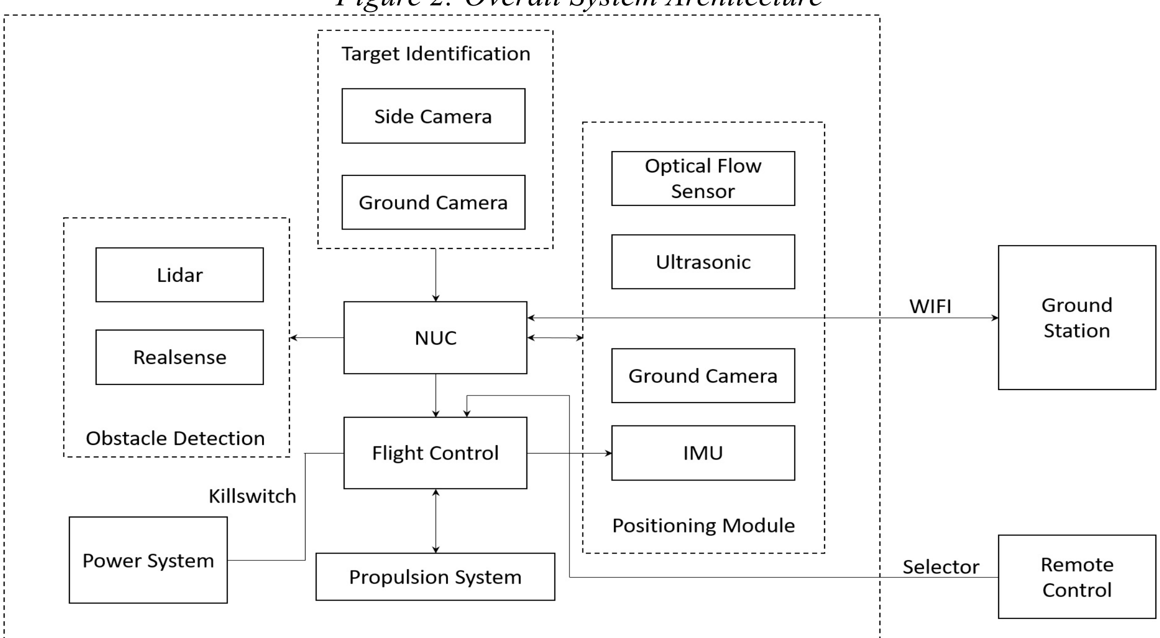
Figure 1. Platform

The airborne computer and different kinds of sensors are fixed on the center of aircraft symmetrically, which is good for balance control as well as the positioning. For the convenience of installation and replacement, some devices, such as lidar and airborne computer, are placed on the specific plastic board made by 3D printer, which has decent weight and mechanical strength.

HARDWARE STRUCTURE

The hardware system is the electronic base of the aerial robotics. It is of great importance to choose proper devices and construct a hardware system with low power consumption, low cost and decent performance suitable for the task. The system includes several parts: airborne computer, control unit, obstacle detection system, vision system, communication system and safety devices.

Figure 2. Overall System Architecture



Airborne Computer

The aircraft utilizes an onboard computer as the main intelligent processor for information integration. The modal of airborne computer is known as NUC6i5SYK, which has a powerful Intel® Core™ i5-6260U Processor with 8G DDR4 internal storage. The computer is driven by 19V power supply. Besides, NUC has a small size of 4 inches, which suits for the aircraft board.

All the data collected by the sensors are gathered together and processed in the NUC. Image processing, trajectory generating and upper layer strategy are implemented in this powerful core.

IMU and Control Unit

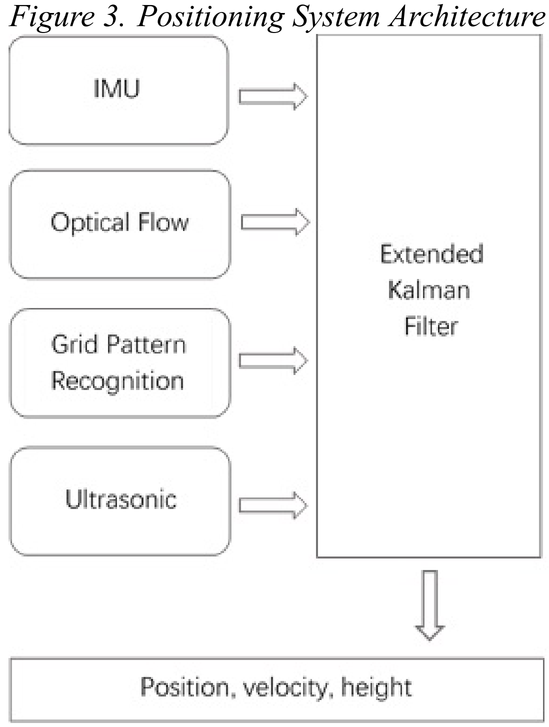
While the control algorithm is designed by ourselves, control unit is constructed in M100 with no change. It is responsible for executing commands from the NUC. Besides, remote control can take over control of the flight since there is a selector of control method in the control system. This method can ensure safety when something unexpected happens.

An IMU combining accelerometers, gyroscopes and magnetometers is also embedded in M100 platform, offering data of attitude and acceleration, which is the basic information about the state of an aircraft. The IMU module is accompanied with control unit in M100. The frequency of data transmission from the IMU to NUC is 100Hz in single floating-point. The data from IMU is utilized and integrated with other information, such as optical flow, to realize location.

Positioning System

Positioning is the basis of flight control, obstacle avoidance, strategy implementation and thus the basis of aerial vehicle to accomplish the mission 7. Positioning system should be stable and reliable enough. The mission 7 excludes GPS and SLAM positioning solution and recommends competitors optical flow to obtain position of aerial vehicle indoor. And we come up with a solution based on optical flow combined with IMU data and grid pattern recognition.

Figure 3. Positioning System Architecture



Sensors

1. Camera: mvBlueFOX-MLC
2. Ultrasonic: HC-SR04
3. IMU: DJI M100 autopilot

Specifically, color camera heads towards the ground to collect images of the ground. With the data of attitude from IMU and height from ultrasonic ranging module, airborne computer can execute optical flow calculation and grid pattern recognition to obtain horizontal velocity and displacement. Optical flow and grid pattern recognition are discussed further in the chapter of software structure.

Obstacle Detection System

Considering that there are four obstacle robots in the competition, we construct an obstacle detection system to detect obstacles in all directions and deal with crash threat, which is made up of lidar and RealSense camera.

UTM-30LX is a lidar sensor using laser source to scan 270º semicircular field. It measures distance to objects in the range and co-ordinates of those point calculated using the step angle. The measuring accuracy is high enough for precise obstacle detection. Sensor's measurement data along with the angle are transmitted via communication channel.

Lidar is capable of detecting obstacles reliably with high accuracy, nevertheless it can only detect those are higher than its scanning plan and in its scanning region. Moreover, the blind area of 90 degrees with lidar deserves carefully considering and compensating. Therefore, as a complement, another sensor, Intel® RealSense™ camera R200, is utilized to obtain depth information and detect the objects in the blind area. The measuring range is 51-400cm. It captures depth image which could be used to detect and calculate distance of obstacles by algorithm.

Vision System

Since the aerial robot is a vision oriented system, we choose cameras for vision information with broader horizon and less smear.

To capture the ground robot images, we choose MvBlueFOX color camera which has high enough resolution of 752×480. It has a maximum frame rate of 93Hz and global shutter.

Communication System

The aircraft communicates with ground computer with WIFI. A ground router is connected to the dual band wireless network card in airborne computer with WIFI and the ground computer by twisted wire, so that the airborne and ground computer are located in the same LAN. Within the LAN, the data of the status, position, pose of the aircraft and the obstacles are shared from airborne computer to the ground computer. In this way, the flight status will be monitored and the safety can be guarded.

USB-UART module is used to connect the airborne computer and the control unit, which ensures the reliability of communication and control.

SOFTWARE STRUCTURE

Software system is the brain of aerial robot, which can be generally divided into five parts: positioning, flight control, target detection and tracking, and obstacle avoidance.

Positioning System

With the positioning hardware shown in figure 2, we can obtain precise position with the following algorithm combined with optical flow, grid pattern recognition, and extended Kalman filter.

Optical Flow

The optical flow estimation in our design is based on SAD template matching. Traditionally, SAD template matching is a time consuming dense optical flow method. Inspired by previous work on px4flow[1], we make several modifications and improvements in this algorithm and obtain excellent performance despite of limited computing resource.

The efficiency is improved by template selecting and SSE acceleration. We choose templates only with distinctive pattern so as to make the algorithm sparse without loss of accuracy. Moreover, template selection and SAD computation are implemented by SSE instructions offered by x86 architecture. SSE instruction set provides parallel and efficient vector operations, which is utilized in our algorithm to obtain high efficiency.

Additionally, Kalman filter used in our positioning system provides prior information before performing the optical flow algorithm. The prior information of displacement can help us reduce the size of search window in template matching, which is also the key in our design to further improve efficiency.

The algorithm outputs delta x and delta y in pixels. We then convert it to actual movement of the aerial vehicle by intrinsic parameter of the camera and vehicle attitude data.

$$V_x = -w_x H - \frac{V_{cx}}{f} H$$
$$V_y = -w_y H - \frac{V_{cy}}{f} H$$

In which, V_x and V_y are velocities in body frame, w_x and w_x are angular rate in body frame obtained by IMU data from autopilot, V_{cx} and V_{cy} are velocities in pixels obtained by optical flow algorithm, f is the focus length of the camera in pixels obtained by calibrating the camera, and H is the height of the autopilot.

We also have another optional optical flow sensor ADNS-3080 which is an optical mouse sensor. By modifying its hardware structure slightly (add lenses and enlarge its aperture), it is capable of navigating aerial vehicles with very good performance. The sensor outputs delta x and delta y in 1600 counts per inch. We obtain actual movement by similar approach as described above.

Grid Pattern Recognition

The field is covered by grid pattern which can be regarded as land marks to navigate the aerial vehicle. We use a downward camera to collect images of the field and recognize the grid pattern by our grid recognition algorithm running on the onboard system.

Figure 4. Procedure of Grid Pattern Recognition

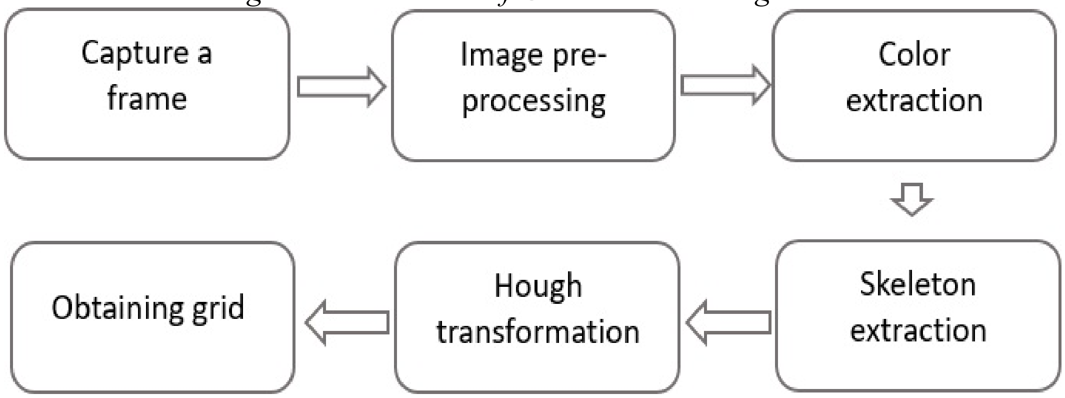
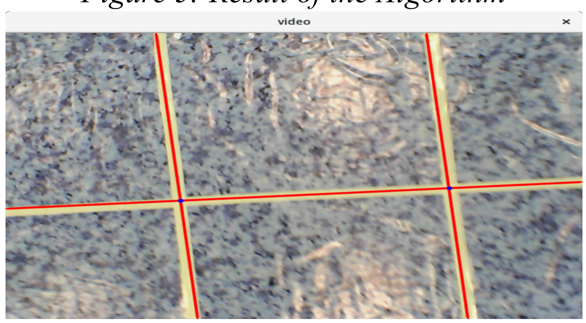


Figure 5. Result of the Algorithm



Each grid point can be projected to camera coordinate by pinhole camera model and intrinsic parameters of the camera and further be projected to global coordinate by attitude and prior position of the aerial vehicle. With global position of the recognized grid points, we can match them with actual gird points and obtain offset between actual grid points and recognized grid points and finally correct the position data with this offset.

Extended Kalman Filter

In order to obtain higher accuracy of positioning, we use an classical extended Kalman filter to fuse multiple sensors' outputs. The state variable of the aerial vehicle is a vector combining position and velocity, which is updated once one frame of sensor data is captured by the extended Kalman filter. The extended Kalman filter can output position and velocity data with higher accuracy and reliability and then broadcast data to other modules.

Control System

The control system is shown below. We chose a traditional but effective control theory, PID algorithm, to realize the flight control after trying kinds of methods, leading to a quite stable control effect[3].

Figure 6. Control System

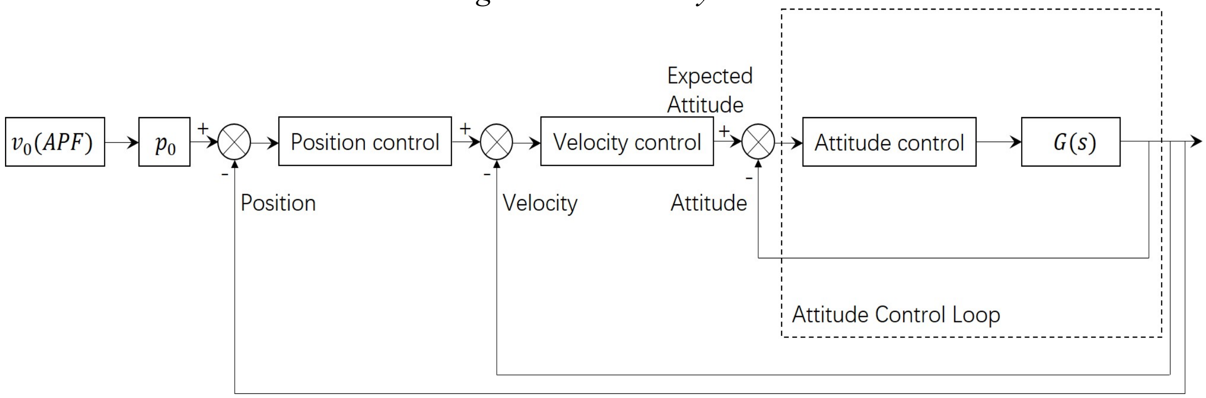
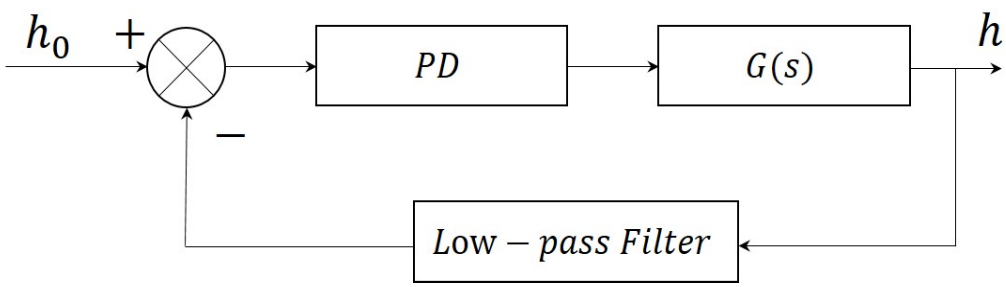


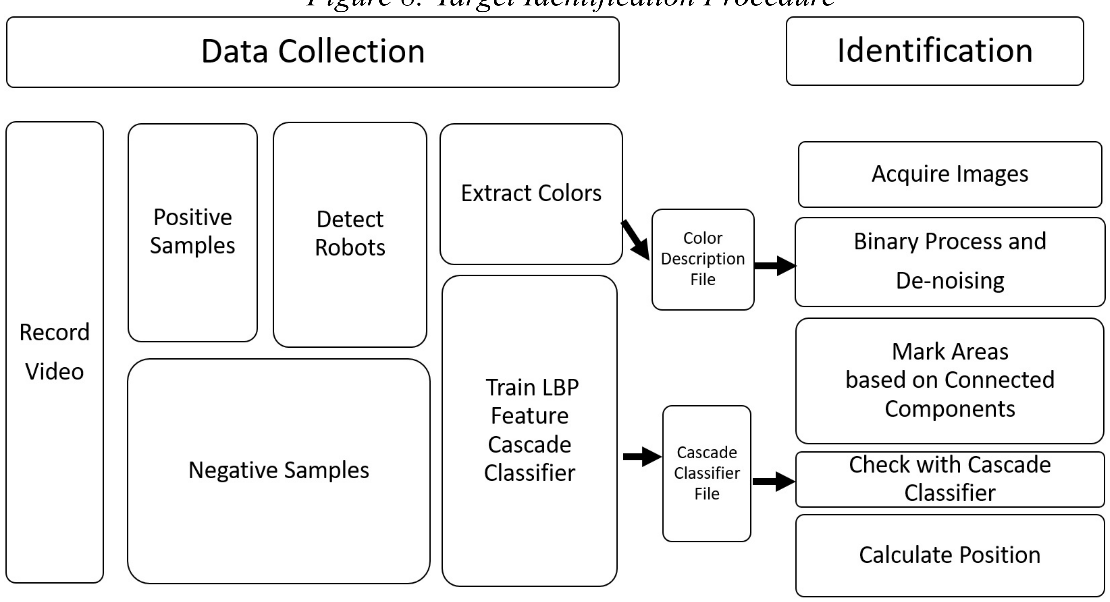
Figure 7. Height Control Block



Target Identification

The aircraft utilizes the color camera and airborne computer to realize target identification, in which the color and LBP features of the images are extracted and used.

Figure 8. Target Identification Procedure



First, the color of target and non-target ground robots should be chosen from the sample images, which is used to train the linear SVM. Then the trained SVM can be applied to classify the color area in the real-time images to obtain a binary image. In the binary image, the area with target is marked in the first time. Next, the LBP feature will be calculated and thrown into a cascade classifier trained before to verify if there are targets in the binary marked area. Having determined the target, the boundary will be extracted from the area with some mathematical morphology methods. The center of the boundary will be recognized as the center of ground robot target. With the information of position, pose and flight height, the position of the target can be accurately calculated.

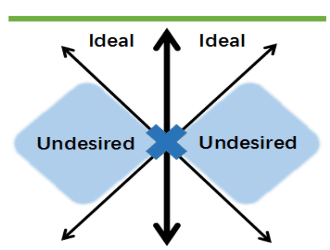
Obstacle Avoidance
The aircraft takes the advantage of a lidar and depth image cameras to avoid threat. By aggregation algorithm, data of lidar and Realsense are processed to detect obstacles in a high precision. With the position and relative distance of the obstacles around the aircraft, the aircraft can change its attitude to avoid the obstacles in the method of artificial potential field.

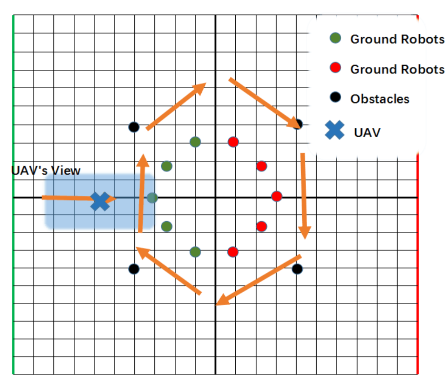
Artificial Potential Field(APF) is a real-time planning method[2]. With this method, aircraft can find a collision-free path by searching the route along the decline direction of potential function.

Trajectory Planning
To find robot suitable for interaction, we score targets according to their directions and positions. After choosing a specific target with the highest score, the UAV will track and interact with it until it is out of green side or the score decreases below the threshold. If the robot cannot reach the green edge in current direction, it is regarded not suitable to be driven. Otherwise, the one with the shortest distance to the green edge gets the highest score.

The aircraft patrols in a fixed path until the optimal ground robot is found. A decent direction of target robot is shown in the figure below.

Figure 9. Strategy





When tracking the optimal ground robot, the aircraft predicts when it will change the direction, and determine whether to interact with it. The aircraft will land in front of the ground robot and change its direction. After the aircraft takes off, it will keep on interacting with it until herding it out of the green side. However, if the score of robot is getting too low in the process of tracking (probably because the robot gets parallel to the green side), the aircraft will stop tracking and return to patrol state.

Simulator

We developed a simulator to analog the competition. The simulation module contains 3 components, including UAV flight simulator, 3D simulator, and Communication module. In the simulation, we integrated target detection module, obstacle avoidance and strategy together, to find that approximately 6 ground robots will be chased out of the green side if the system normally behaves.

Figure 10. Simulator

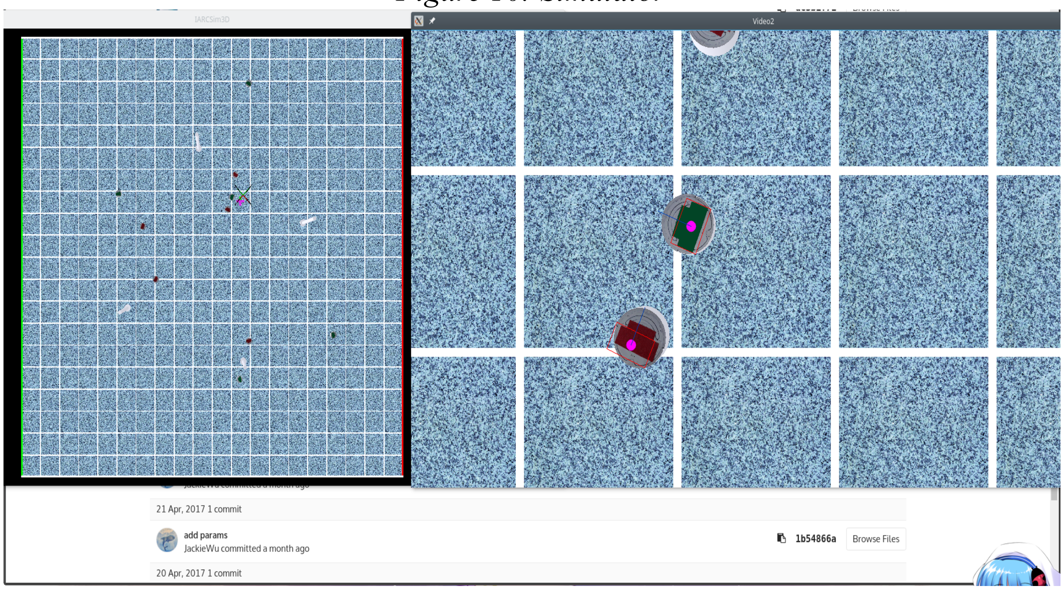


Table 1: Simulator Software Components

Component	Description	Addition
UAV Flight Simulation	Simulate the flight of UAV	Based on the strategy
3D simulation	Build a simulation scene	Provide views of global map and cameras
Communication	Simulate with hardware	Using Onboard-SDK with M100

OPERATIONS

Flight Preparation

We defined court coordinates for strategy implementation. The court coordinates originate in the center of the court with x-axis pointing from green side to red side and y-axis pointing to the right of x-axis.

We place the aircraft on the green side heading towards red side, so that the UAV can obtain rotational angle between global coordinates and court coordinates right before taking off. Moreover, it is also necessary to set the takeoff spot with respect to the origin in court coordinates.In addition, to ensure each module can running correctly, it is of great importance to carefully check mechanical structure and all the functional modules. Checklist is shown in following table.

Table 2: Checklist

Item/module	Checking
Propellers	whether propellers are attached stably
Ultrasonic	output of ultrasonic
Cameras	images of cameras
Realsense	output of images and data
ADNS3080	check the data while moving UAV slightly
Lidar	data of detection
Position module	check the position while moving UAV slightly

Man/Machine Interface

Since the aircraft carries out flight mission automatically, it is necessary to develop Man/Machine interface for monitoring and in case of emergency. In the system, the onboard computer will accomplish the computation and the ground station is just set to monitor the aircraft status. We use a WIFI router to connect aircraft to the ground station. VNC remote desktop is applied to observe the data of sensors and modules, launch the aircraft and stop it in emergency. It is a flexible and convenient solution for man-machine interface, which saved much time for developers during the preparation.

RISK REDUCTION

The vehicle status includes Euler angle, acceleration, velocity, position and height. The status watchdog in our design will monitor each status and alert ground station when abnormal status occurs. If severe operation error is observed from data, the program will terminate all the missions and force the UAV to land.

Shock/Vibration Isolation

A sponge is used in vibration isolation in the connection between the aircraft and airborne computer as well as lidar. As for color camera, there is no need to isolate vibration because the shock has few influence on the camera which uses global shutter.

EMI/RFI Solutions

The sensors and airborne computer have EMI suppression circuit and shielding device, which can help avoid the EMI. The communication between the aircraft and ground station is based on 5.8GHz wireless spectrum. The spectrum is now used less often, leading to a higher communication quality and less interference from other wireless device.

Safety

To guarantee safety, some safety devices play an important part in an emergency. We designed a killswitch as the system termination device. It can cut the connection between the power and other part of the aircraft. The killswitch consists of a wireless receiver, remote control, voltage conversion module, micro controller and n channel MOSFET. Among these components, the voltage conversion module is responsible for transforming voltage from flight battery to the required level, while the wireless receiver delivers the instructions from remote control to micro controller. If the micro controller receives an instruction of termination, the N channel MOSFET will be cut, which results in the power off and flight terminated. In addition to the killswitch, remote control can also change the auto-flight mode to manual operation, which can pull the aircraft back from an unexpected circumstance to safety place.

To avoid hurting people, a set of lightweight survivable airframes is installed around four propellers. They can protect people and objects close to the propellers from getting hurt.

Testing
Up to now, each functional module has been tested separately and has satisfactory performance. We have prepared several iRobot Create 2 to test the entire aerial system. The interaction experiments will be carried out soon in the following days.

CONCLUSION
In this paper, the technical details of an air vehicle system are presented. The Mission is divided in some subproblems at different levels to overcome. We solve each subproblem separately and combine the modules at the end to complete the mission. Up to now, most of the modules are almost finished and need to be tested and combined. The system are expected to operate normally in the competition.

References

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