HITCSC's Aerial Vehicle for IARC 2015

Hualin He, Yibei Li, Qifeng Wu, Zhuang Liang
Harbin Institute of Technology

ABSTRACT

This manuscript reports the detailed scheme and progress of *HITCSC Team* for IARC 2015. An autonomous aerial vehicle equipped with DJI autopilot, Odroid XU3 onboard computer and vision cameras is designed to interact with the ground robots and cruise around the arena. Based on the computation vision and image processing technique, a vision positioning algorithm is developed to provide relative position with respect to target robots and navigate the aerial vehicle in the arena. A platform on Linux OS is established to maintain the overall system. Large amount of experiments have been designed to ensure the robustness of the aerial vehicle.

1. INTRODUCTION

1.1 Statement of the problem

In the seventh mission of IARC, a highly intelligent aircraft is required to be designed to drive ground autonomous robot towards a specific side of the square arena with only grid lines on the surface [1]. Under the circumstances of a GPS-free indoor arena and dangerous environment with obstacles moving around, the aircraft still has to complete accurate interaction with robots on the ground, including physical hit and magnetic induction, and to manage optimized strategy to drive robots as more as possible.

1.2 Conceptual solution to solve the problem

A vision navigation based system is designed to accomplish the task. We make full advantage of the grid lines to navigate our vehicle in the Arena. While relative position is detected by vision when executing interaction with ground robots. All the computing is processed by onboard computer assembled in the aircraft. The overall system architecture is shown in Figure 1.

The attitude stabilization of aircraft is managed by DJI N1 auto pilot, and the DJI Vision Guidance is equipped with ten vision cameras and five sonars, giving out the obstacle position and vehicle velocity. Target detection is accomplished by mission camera, which is classified into long distance target detection and close target detection. Vehicle position in the arena is achieved by the position camera. Meanwhile, a ground station is built on PC to monitor the status of aircraft in real time.

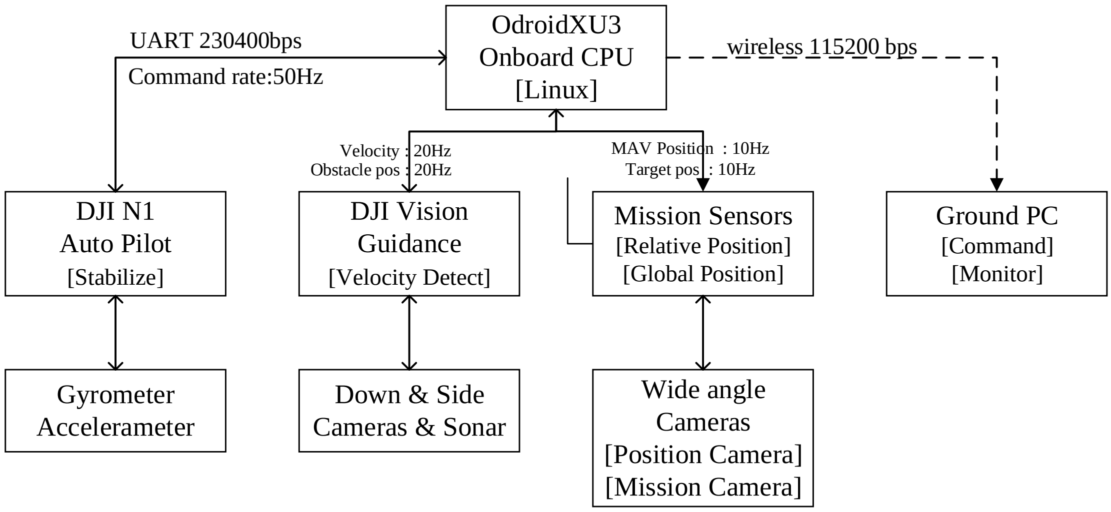

Figure 1. The overall system architecture

1.3 Yearly Milestones

This is the first time for *HITCSC Team* to take part in IARC. Though we possess few experience and technology accumulation, we still take our best efforts to stabilize our vehicle and to develop a vision positioning algorithm. We are aiming at interacting with ground robots and driving several of them to the specific side this year.

2. AIR VEHICLE

2.1 Propulsion and Lift System

We choose quad-rotor helicopter as the flight platform for the mission. Several factors need to be considered while designing the air vehicle. First of all, the vehicle has to carry the payload of about 450g, including the Odroid onboard system, protect shells, 3 cameras and some other supporting apparatus. Secondly, the overall weight of the air vehicle should be limited as much as possible to guarantee the agility of the quad-rotor. Balancing the above two factors, we choose an airframe from DJI with four 350 KV brushless motors and four 13 x 45 carbon fiber propellers. The overall takeoff weight of the quad-rotor is 3300g. With sufficient power supported by a 6S LiPo battery, this propulsion system can provide lift force of about 8400g in maximum. The air vehicle designed for the mission is shown in Figure 2.

Figure 2. Aerial vehicle of HITCSC Team

2.2 Guidance, Navigation and Control

2.2.1 Control system of the aerial vehicle

We choose an autopilot from DJI as our low-level stability augmentation system. The DJI quad-rotor flying platform has modular hardware, and is an open platform for developers to expand and build upon. There are several built-in sensors with decent precision in the DJI N1 Autopilot, such as 3-axis accelerometers, gyros, magnetometer, and barometer. Thus, we use the N1 Autopilot to realize the attitude control of the quad-rotor. Meanwhile, as the position and velocity are estimated on the Odroid onboard system, the position controller is designed on Odroid as well to avoid the hardware asynchronous problem.

The architecture of our control system is shown in Figure 3. As the aerial vehicle is an under-actuated robot with only four actuators, two cascade PID controllers are designed to drive the quad-rotor to a desired state (position, orientation, velocity and angular velocity) in state space [2]. In addition, the horizontal and vertical channels are designed separately with different architectures and parameters to realize different performance requirement.

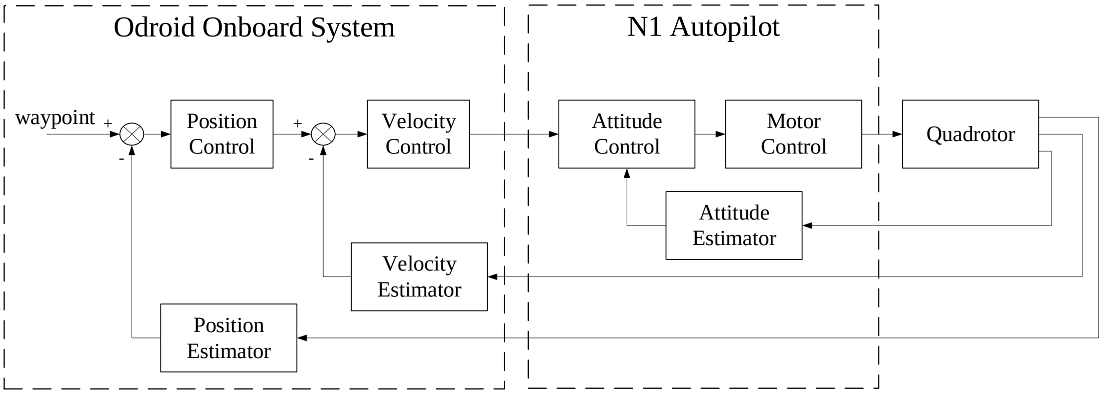

Figure 3. Control system architecture

2.2.2 Indoor navigation

To achieve mission 7, the air vehicle must have the ability of indoor self-locating without GPS or any other assisting equipment. In the special setting of Mission 7, traditional stereoscopic vision methods do not work anymore without distinct landmarks [3]. Under this circumstances, a navigation algorithm of visual odometry is presented based on optical flow and visual location.

With the velocity information estimated from the optical flow and IMU sensors, the vehicle can localize itself timely. However, the optical flow algorithm is susceptible to ground conditions and the error of visual odometry tends to accumulate when the air vehicle travels a long distance. Therefore, another visual location algorithm based on the grids is proposed to compensate the location error. We present a vision-based navigation strategy for the aerial vehicle using a single downward embedded camera observing manual landmarks.

The vision navigation method is based on the homograghy equation in our computer vision system. The homography matrix describes the relation between the camera coordinate and the world coordinate [4]. By solving the equation we can obtain the most important relation of the vision-based navigation process. Hence, in order to solve for the relation, we need to obtain the accurate values of both the feature points in the image coordinate and in the world coordinate correspondingly. Therefore, the most important part is to extract the feature lines quickly and reliably.

a. Image Processing and Line Extracting

On the ground there is line marker along both horizontal and vertical directions. And there is random texture inside the 1×1 grid. These textures will cause negative effects on line extracting. We use the Gauss Smooth method to deal with the image and then the Canny edge detection is adopted. After that we obtain a roughly frame of edges of the horizontal and the vertical lines.

Line extracting involves two steps: lines detection, fitting and filtering. For the lines detection problem, the Hough transformation is used. We noticed that the result of the Hough transformation involves plenty of inaccuracies. To guarantee the accuracy of positioning, we must ensure the lines extracted are correct. Thus, the lines filtering algorithm is proposed to cope with this problem. The algorithm mainly contains two parts: sortation and classification. The flow of the line filtering algorithm is given in Figure 4.

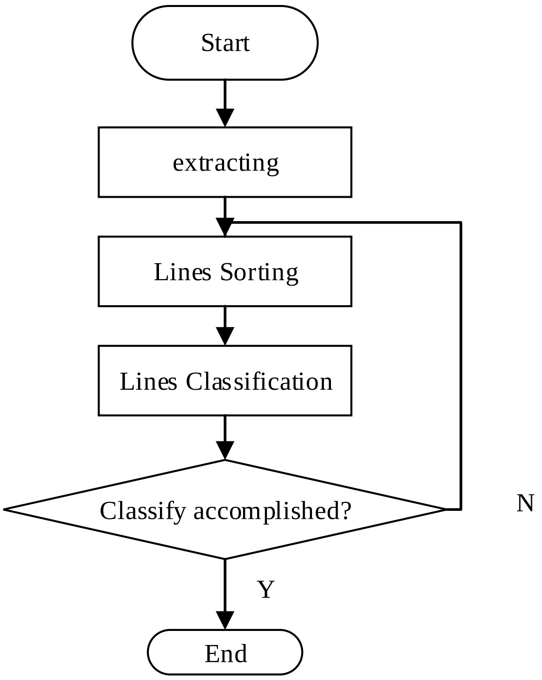

Figure 4. Lines filtering algorithm

By the end of the image processing and line filtering processing, and we calculate the points of intersection as the feature points to be used. The final effects is shown in Figure 5.

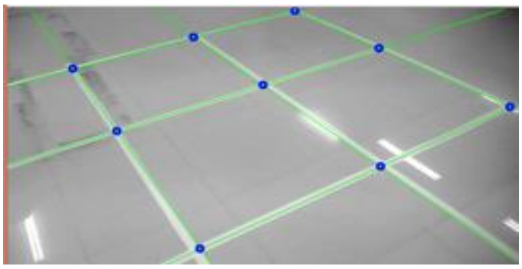

Figure 5. Processing result

b. Relevant Analysis and Positioning Method

Now we have obtain the information of lines and feature points. Before the position calculating, the position values of feature points in the world coordinate are required. We need to analyze matched point pairs according to the continuity between two frames of the video captured. And we match the lines and points by the FLANN rules, we will get the world coordinate message of the feature points.

Next, we will derive the homography equation for the position information. The homography relation is as follows.

$$\tilde{q} = sH\tilde{Q} \tag{1}$$

where H is the homography matrix;

s is the scale factor;

$\tilde{q}, \tilde{Q}$ are the position vectors.

Transformations are as follows:

$$\begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = sM_{in}M_{out}\begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix}, \tag{2}$$

$$\begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = M_{in}R_{\gamma}(\gamma)R_{\theta}(\theta)R_{\varphi}(\varphi)\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} + M_{in}\begin{bmatrix} X_c \\ Y_c \\ Z_c \end{bmatrix}, \tag{3}$$

where $\begin{bmatrix} X_c & Y_c & Z_c \end{bmatrix}^T$ is the position vector of camera in the world coordinate;

$\begin{bmatrix} u & v & 1 \end{bmatrix}^T$ is the points position in image coordinate;

M_{in} is the intrinsic matrix of camera;

M_{out} is the parameter matrix of camera;

$R_\gamma(\gamma)R_\theta(\theta)R_\varphi(\varphi)$ is the rotation matrix of Euler angles.

The position can be obtained by vision of our quad-rotor after a simple transformation.

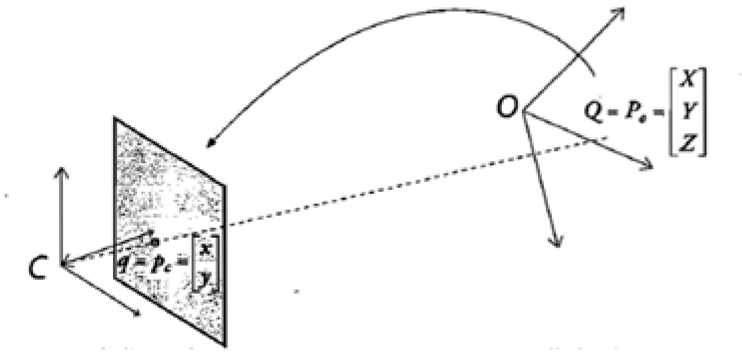

Figure 6. Homography formulation

2.3 Flight Termination System

We have two ways to achieve the flight termination. When the autonomous flight of our aerial vehicle goes wrong, the participator can always take over control by a switch on the RC transmitter. Furthermore, there is a kill-switch circuit between the power module and motors. Under some extreme cases for instance the vehicle is threating the people's safety around, the power can be cut off by the judger through a radio controller immediately.

3. PAYLOAD

3.1 Sensor Suite

We choose quad-rotor helicopter as the mission platform. Our own sensor suite is adapted to satisfy the requirement of flight mission.

3.1.1 Mission Sensors

a. Target Identification

Target identification is an important part of all the issues. We combine several algorithms together to obtain a better result.

First, as the scene that is a little far from aerial vehicle, we detect the ground robots by focusing on the feature of movement. We plan to use the mean background modeling to separate the background and the foreground, which contains the ground robots. These methods can guarantee the real-time performance. And on condition of further scene, it almost has no negative effects on accuracy.

Then, for the closer scene, also the scene showed in the image from downward camera, we use a different way. We make use of the histogram information of the image and obtain the statistics data about the current scene, which will be used later in matching process and target extracting. We match the contour of the ground robots and the “T” part of its upper surface. We still use the homography method [5] mentioned above to solve the positioning problem of the ground robots. The equation is as follows.

$$\begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix} = s^{-1} M_{in}^{-1} M_{out}^{-1} \begin{bmatrix} u \\ v \\ 1 \end{bmatrix} \quad (4)$$

We will use the translation vector obtained before in the extrinsic matrix.

A motion detection result is shown in Figure 7.

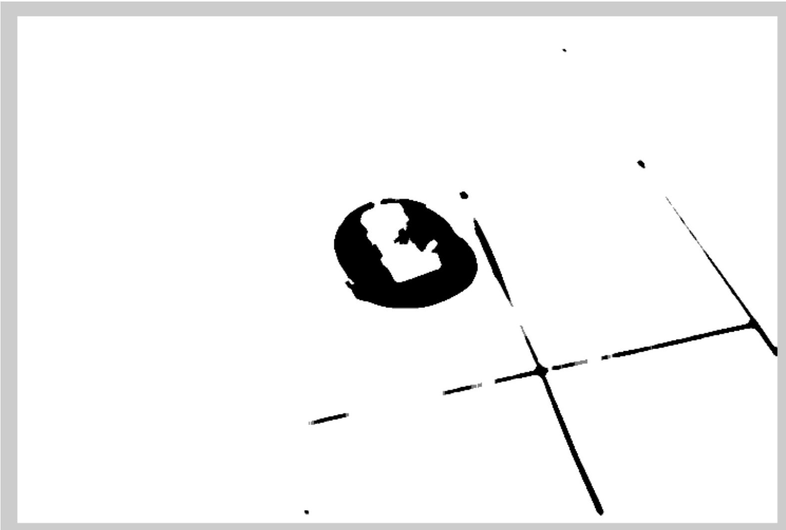

Figure 7. Motion detection of the ground robot

b. Threat Avoidance

There are four obstacles in the arena, running around a 10m-diameter circle. Using laser range finder for obstacle detection is simple, but most laser range finders are expensive and heavy, so we use cameras to detect obstacles. Several different obstacle avoidance strategy are compared to survive our vehicle in this environment [6].

3.2 Communications

3.2.1 Data link

Communications between the auto pilot and our onboard computer is achieved by a USB-UART connector in a rate of 230400bps. The communications between onboard computer and ground station is realized by a wireless radio transmitter in a rate of 57600 bps, providing the data link between aerial vehicle and our ground station.

Protocols between the autopilot and our onboard computer are based on DJI M100 data link protocol. The MAV protocol MAVLINK is applied in communications between our onboard computer and ground station.

3.2.2 Security

Electromagnetic interference disturb communication process sometimes, which could sometimes breakdown whole system. Data communicate between different modules are all uniformed into data frames in some protocol, checksums are calculate to ensure a correct and accurate data communication.

3.2.3 Data sharing in multithread program

There are several threads running on onboard computer including the vision processing thread, strategy thread and autopilot thread. Data sharing can be obtained by defining global variable. Thread lock is used to avoid data collision, especially those that can be modified by different threads, such as the status variable and vision positioning result.

3.3 Power Management System

We choose a 5700mAh LiPo battery to support all the electric cost of our aerial vehicle system. The battery is connected to a power distribution board which redistributes the power from the battery to the 4 ESCs. In addition, a voltage regulator module is added to provide 5V voltage for the onboard processor and other sensors.

4. OPERATIONS

4.1 Flight Preparations

Flight preparations are very essential to a safe flight procedure. A series of preparation procedure is developed to ensure a successfully flight.

4.1.1 Checklists

a. Battery check

Battery check is obligatory in case that a lower charged battery is used.

b. Vehicle check

Vehicle check is essential for a safety flight, including motor, propeller, gyroscope, accelerometer, magnetometer and ultrasonic check. Motors and propellers are checked manually, while sensors are checked automatically by system software.

c. Safety button

In order to ensure safety start of the system and avoid accidental vehicle taking off, a safety button is designed in the very beginning of system boot procedure. Only certainty and specific manual press can activate our vehicle.

d. Ground station

A ground station is developed for monitoring the status of our vehicle, and setting necessary parameters for the system. Preparation of the vision subsystem, autopilot subsystem and strategy subsystem synchronously.

e. Taking-off command

After all the preparations, our vehicle takes off and executes tasks automatically with a single command.

4.2 Man machine interface

4.2.1 Hardware interface

Our hardware interface includes buttons in onboard computer for mode selection and channels in RC remote controller for security issues.

4.2.2 Software interface

A human friendly GUI ground station is designed for communications between our aerial vehicle and the operators. Operator can send the taking-off command and the emergency stop command to the vehicle, and can also set some parameters, or even switch the system to manual control. The ground station can also show status of vehicle. The functions of our software interface is shown in Figure 8.

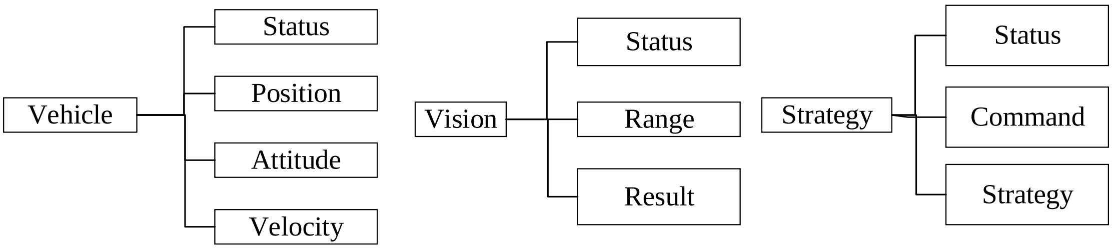

Figure 8. Software interface

With the help of GUI ground station, the aerial vehicle status can be monitored in real time, information can be recorded automatically which is very helpful for the analysis after experiments.

5. RISK REDUCTION

5.1 Vehicle Status

Since all of our algorithms are executed by Odroid XU3, ground station is only used to monitor the status of the aerial vehicle. The messages between N1 flight control system, the Guidance module and Odroid XU3 including IMU, sonar, camera and magnetometer.

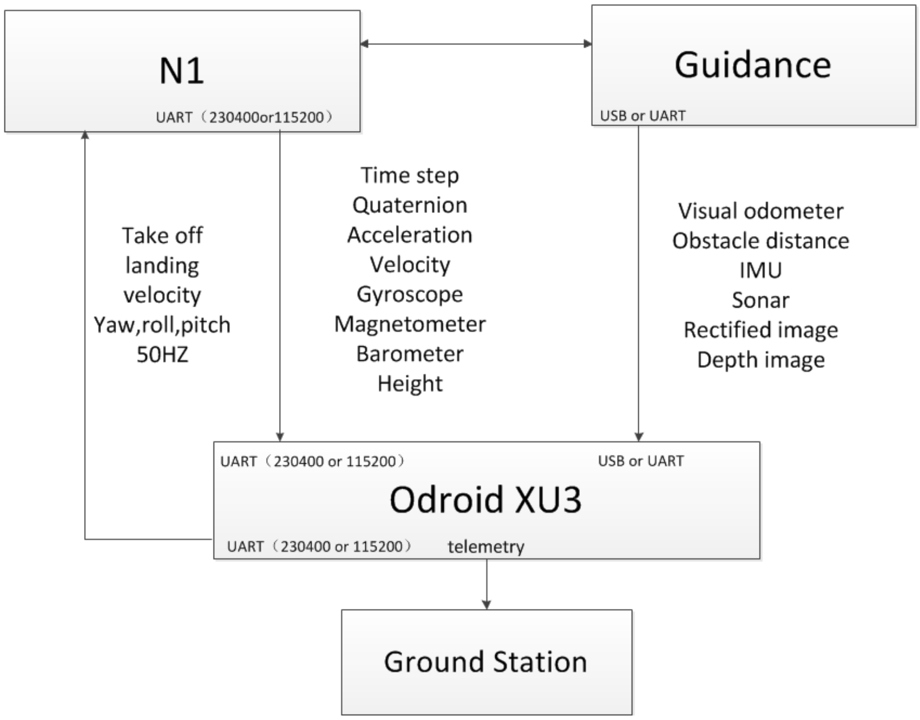

Figure 9. System communication

Odroid can fusion these information and then send commands to the flight control system. There is a telemetry communication with ground station, which will send back the ground robots' and obstacles' position, the vehicle's attitude and its height.

5.1.1 Shock/vibration isolation

Electrical isolation, magnetic shielding and vibration isolation are considered in our system. The two main processing units are: electrical influence from motors is well isolated by DJI pilot already, and we assemble a DC-DC converter to stabilize voltage from battery. We found that increase distance can decline influence of magnet obviously. Thus, our magnet is assembled around a support pipe at a distance of 30cm.

Vibration isolation is necessary for autopilot IMU units, and can also influence our camera quality. For those vibration-sensitive sensors, 3M adhesive and dampers are used for shock isolation.

5.1.2 EMI/RFI Solutions

At the beginning of our design, we tended to send images to ground station for processing and then send back control command to the flight control system. This way should be simple but does not work well because of RFI. Therefore, we turned to process images with the onboard computer, and send command via wired serial port. The 3DR Radio telemetry will be used for monitoring the state of the aerial vehicle.

EMI from motors and magnets will influence the performance of onboard magnetometer. To solve this issue, we use external magnetometer from GPS module and keep it away from magnets.

5.2 Safety

We have designed four measures to protect people nearby and the aerial vehicle itself. First, there are four protection shells prevent the propellers from hitting other objects, and the landing gear will protect the on-board sensors and the equipment when landing on the ground. The landing gear also can be used for keeping magnets away from the magnetometer in GPS module. Second, we can use 3DR radio telemetry to send landing command from ground station. Third, the participator can always take over control by a switch on the RC transmitter when the flight of the vehicle goes wrong. Finally, a kill switch between power module and motors can take over control of the aerial vehicle at any time to override the flight control system.

5.3 Modeling and Simulation

Our strategies for tracking and cruising depend on the simulation of the competition environment. It plays an important role in strategy planning. We established a simulation platform based on Gazebo since it is capable of simulating physical features of real world, e.g. collision and friction base on Open Dynamics Engine (ODE). Our simulation platform has the ability to simulate the distributions of the ground robots in complex environments accurately and efficiently, and rapidly testing algorithms, designing robots, and performing regression test. Our simulation platform is shown in Figure 10.

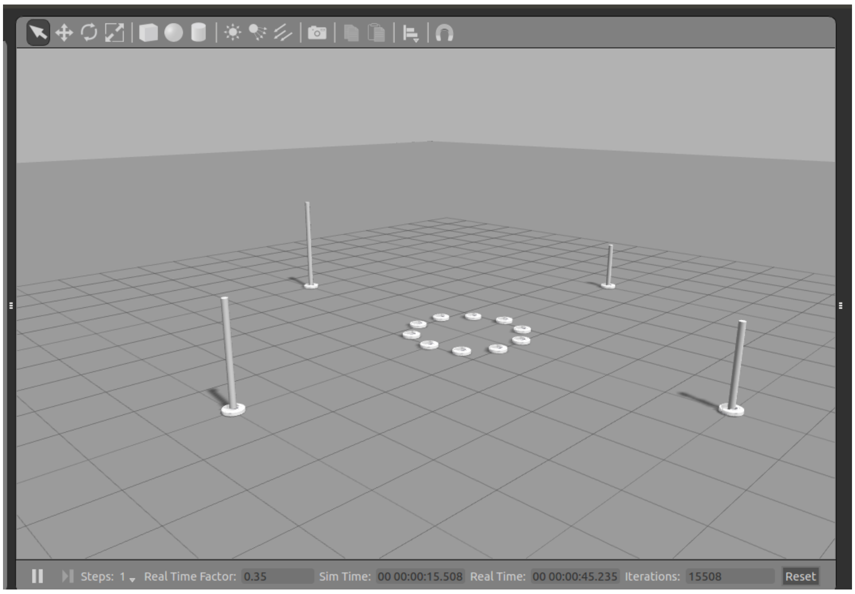

Figure 10. Simulation platform

5.4 Testing

In order to test the performance of our algorithms, we prepared five iRobot Create 2 and pasted masking tape of $1m^2$-grids on our lab ground.

Figure 11. Testing environment

6. CONCLUSIONS

The HITCSC Team has developed an aerial vehicle platform based on quad-rotor and Odroid onboard processor. Several modules have been designed to satisfy the requirements of Mission 7, including the indoor location, obstacle avoiding, navigation strategy and target interacting. Additional tests are still needed before the whole system become robust enough.

REFERENCES

[1] Junwei Yu. Vision-aided Navigation for Autonomous Aircraft Based on Unscented Kalman Filter. Indonesian Journal of Electrical Engineering, ISSN 2302-4046, 02/2013

[2] Zhang, Dewei, et al. The Quadrotor Dynamic Modeling and Indoor Target Tracking Control Method. Mathematical Problems in Engineering 2014 (2014).

[3] Kang Li Wang, Shu Peng Lai, et al. An Efficient UAV Navigation Solution for Confined but Partially Known Indoor Environments. IEEE International Conference on Control & Automation (ICCA), 2014.

[4] Courbon, Jonathan, et al. Vision-based navigation of unmanned aerial vehicles. Control Engineering Practice 18.7 (2010): 789-799.

[5] Feng Lin, Ben M. Chen, et al. Vision-based Formation for UAVs. *IEEE International Conference on Control & Automation (ICCA)*, 2014.

[6] Mellinger, Daniel, Nathan Michael, and Vijay Kumar. Trajectory generation and control for precise aggressive maneuvers with quadrotors. The International Journal of Robotics Research (2012): 0278364911434236.