HITCSC's Aerial Vehicle Solution for the Mission 7 of the International Aerial Robotics Competition

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ABSTRACT

This manuscript introduces the scheme and progress of HITCSC Team for the International Aerial Robotics Competition in 2016. To finish the task, we utilized a quadrotor aerial vehicle equipped with N1 autopilot, onboard computer NUC and visual cameras. The overall architecture is constituted by Navigation and Flight Control, Obstacle detection and avoidance and Localization and Robot Detection. The safety measures and the experimental tests are also introduced.

INTRODUCTION

1.1 Statement of The Task

Mission 7 of the International Aerial Robotics Competition, requires a highly intelligent aircraft to drive autonomous robots towards a specific side of the confined indoor square arena [1]. Under the circumstances of a GPS-free indoor arena with obstacles moving around, the aircraft are required to do accurate interaction with robots on the ground to herd the robots out of the arena from the green line, by physical collision or magnetic induction.

1.2 Conceptual Solution to The Task

A vision based system is designed to accomplish the task. We make full advantage of the grid lines and optical flow technology to navigate in the area. The robots are to be detected by mono and stereo cameras, and then according to the results, the aircraft finish the herding and avoidance task. All the computing task is processed by onboard computer installed in the aircraft.

1.3 Yearly Milestone

This is the second year for HITCSC Team to take part in the International Aerial Robotics Competition. We developed a new design of the obstacle detection system and survivable airframes. The framework of software and the platform of hardware were completed. Up to now, our vehicle can interact with the robots and herd them to the grid line.

AIRCRAFT CONFIGURATION

2.1 Aircraft Platform

M100 made by DJI innovations is utilized as the main platform for the task. The autopilot, battery, structure and motors were used with no change. M100 can load up to 1kg and enables us to configure the desired sensors and processors. N1 autopilot integrates IMU and other devices, and provides many interfaces for developers to use. Our onboard computers can link to the autopilot and send it attitude or velocity commands.

2.2 **Onboard Hardware**

2.2.1 *Sensors*

Except for the sensors loaded by the autopilot, we installed 3 sets visual cameras on the unmanned air vehicle, to measure the velocity, position of aircraft and the position of robots in the arena.

The stereo vision system developed by DJI innovations was installed on the aircraft with four modules around and one beneath the body. The stereo module beneath the body has a 320x240 resolution and calculates optical flow up to 20hz. The sonar on the module below can be used to estimate the height of aircraft. The devices around the body are used to measure the motive robots with poles.

The R200 designed and developed by Inter Corporation was installed around the body cooperating with the four the stereo vision system to detect the obstacles. And the mono camera of R200 is used to scan the area to capture the position of robots.

A RGB mono camera was installed on the aircraft with optical axis pointing to the ground. The mono camera has a 640x480 resolution and serves to detect robots and to locate in the arena.

2.2.2 *Computers*

Our aircraft installs an onboard computer to be the main controller to process image and plan the mission. The computer, named NUC, has a powerful core i7-5557U with 16GB DDR3L RAM. It has 3 USB3.0 ports and 1 USB2.0 port enough for communicating with rich visual devices and autopilot.

2.2.3 *Communication*

Communications between the autopilot and our onboard computer is achieved by a USB-UART connector at a rate of 230400bps. We utilize the 5GHz WIFI link to exchange data between ground computer and onboard computer. The ground computer mainly contributes to supervising the aircrafts' status and controls the aircraft's running modes.

2.3 **Security Measures**

2.3.1 *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.

2.3.2 Survivable Airframe

To avoid hurt people, securely flying in environments with obstacles is an essential ability for air vehicles. Some other measures are also to be utilized. This time, we install the safety button, which can be shut down in an emergency, to protect people from the air vehicle. Also, we design a set lightweight survivable airframes to protect the aircraft from being damaged by the obstacle. The mechanical design of survivable airframe is as follows.

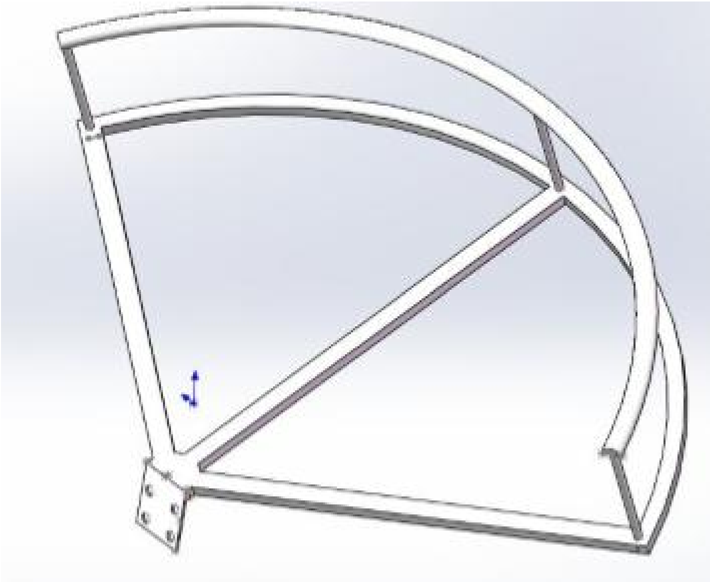

Figure 1: Structure of Survivable Airframe

SYSTEM FRAMEWORK

3.1 **Navigation and Flight Control**

Quadrotor is widely used in military and civil applications, thanks to its high maneuverability and low maintenance cost. In practice, waypoint control based on the outdoor GPS or indoor visual positioning is hot. How to attain smooth and efficient performance for the quadrotor waypoint control in a variety of conditions attracts a lot of researchers.

According to the rules of IARC, the aerial robots can be herded by physical interaction or magnetic induction to change the direction of the ground robots, by which to drive robots out of edge of the green line or prevent robots from running out of other boundaries. To accomplish herding robots, the aircraft and robot must satisfy some constraints about pose and attitude, which need high precision.

N1 autopilot has excellent performance for attitude control, the structure of control system is as figures below. We adopt double close loop structure to control the position and velocity of aircraft. The controller was designed to use PID method. The PID controller is widely used in cases where mathematical models of system cannot be gotten accurately because of nonlinear factors. Through tuning the parameters of PID controller, we can make system stable and satisfy our demands.

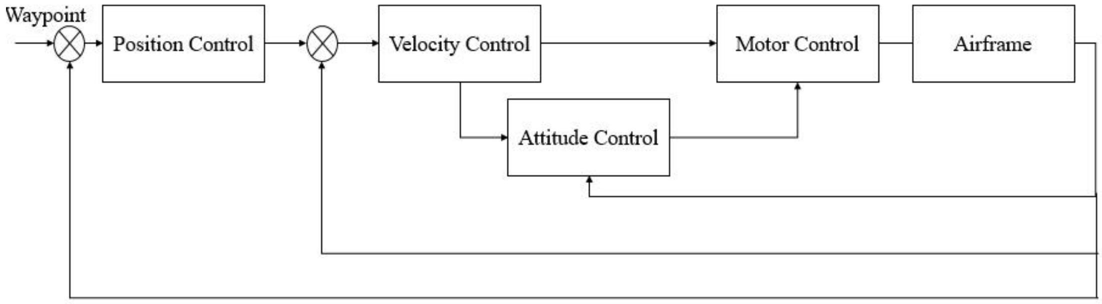

Figure 2:Structure of Control System

By processing images coming from mono camera, we can get the value of relative distance between ground robot and aerial robot. By adopting the PID controller, the value of velocity input is as follows.

$$u(t) = K_p e(t) + K_d \dot{e}(t) + K_i \int e(t)$$

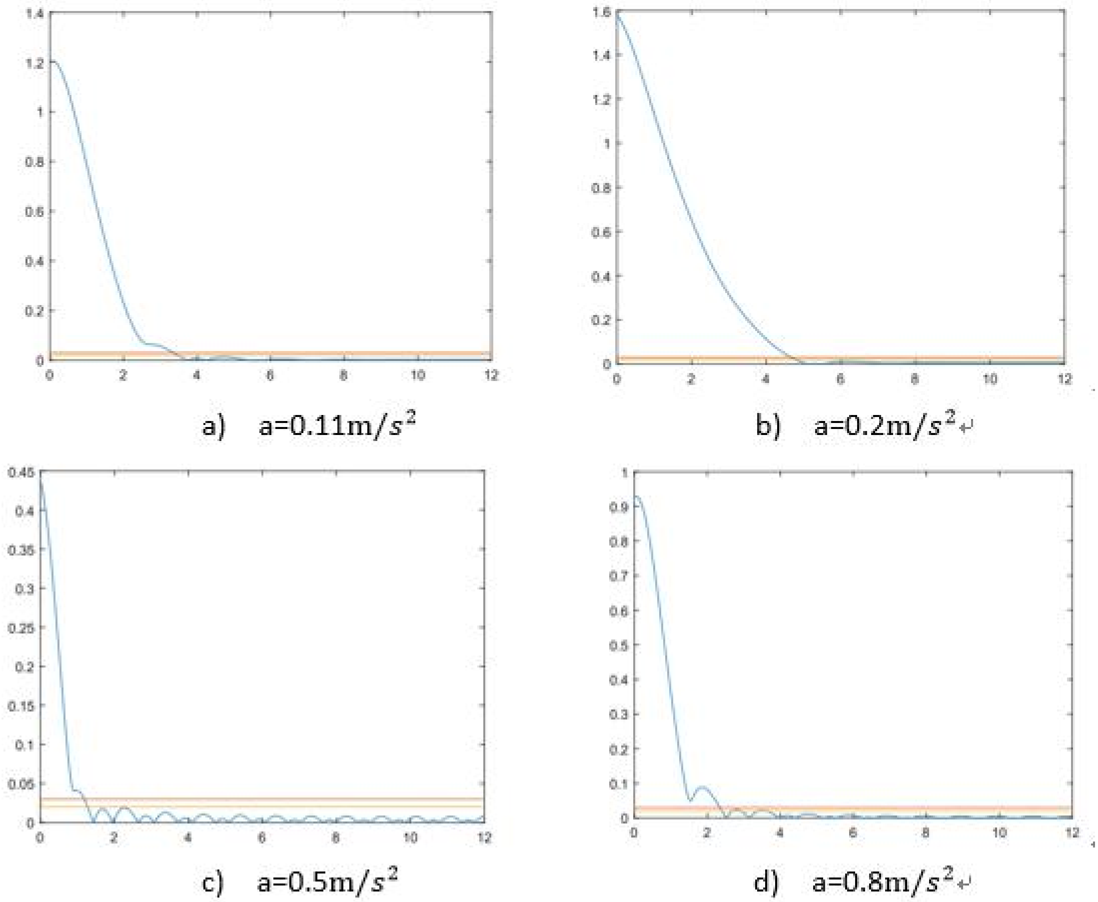

Figure 3: Time Domain Response with Different Acceleration

During the process of interacting with robots, we set the acceleration as a constant to plan the path along the horizontal plain and change the value of the acceleration of aircraft to evaluate the performance of this process. Figure3 and Table1 illustrate the effect of acceleration.

TABLE1 THE SIMULATION WITH DIFFERENT ACCELERATION

Acceleration	Adjustment time	Overshoot amount
a=0.11	4.4s	3cm
a=0.2	3.8s	2cm
a=0.5	3.5s	3cm
a=0.8	3.9s	3cm

For the vertical direction, the task requires the aerial robot which carries magnet can touch upon the surface of the ground robot, so the vertical control is as important as horizontal control. Because of the hardware configuration of our system, downward-looking view makes the control of horizontal direction and vertical direction have a lot of constraints. Firstly, in the procedure of interaction, we hope the ground robot appears in the middle part of the view of downward camera. Based on analysis and test, 80% target information in the field of vision is more reliable, so given distance r between target and the aircraft, the upper limit of height can be gotten. In the same way, when the boundary of the vision and ground targets just tangent, the height of this is a time when r the minimum height requirement, therefore we are planning a maximum height and minimum height. Schematic diagram is as follows:

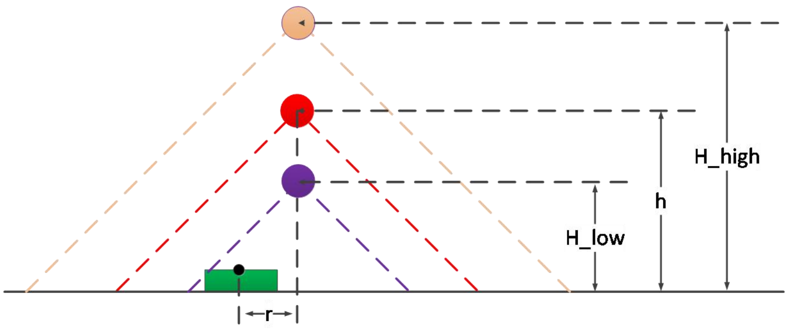

Figure 4: Vertical Command Planning

According to the geometric relationship, the value of h_{high} and h_{low} are as follows.

$$h_{high} = \frac{r + 0.214}{0.8}$$

$$h_{low} = r + 0.23$$

Based on the horizontal and vertical planning method, a Matlab simulation analysis of this method can ensure the efficiency of interaction and the ground robots in sight. Through the simulation of this method, this interaction way is feasible.

3.2 **Obstacle Detection and Avoidance**

3.2.1 *Obstacle Detection System Design*

To detect motive obstacles in real time, we use four binocular cameras and two RealSense depth cameras to achieve 360 ° view, as figure below indicates. Then relying on this design, we can do path planning in real time and lower the possibility to collide with the obstacles.

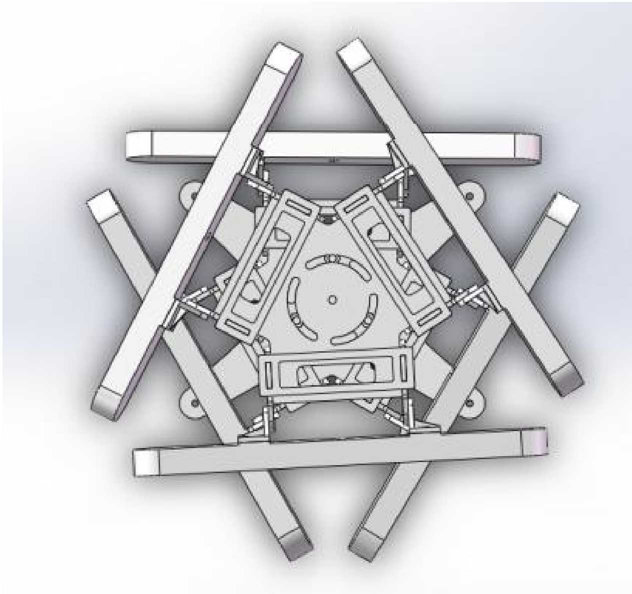

Figure 5: Obstacle Detection System

3.2.2 *Obstacle Detection*

To schedule the 6 stereo cameras, we choose to circulate to process the data to reduce the consumption of progress or thread resource. We utilize morphological operator to get rid of the noise of image and according to the height of pixels, remove the ground area which may disturb our detection. Draw histogram of the depth image and calculate the peak of histogram, which is the depth information of obstacles.

3.2.3 *Real Time Path Planning*

Our aircraft's diameter is about 1.2 meters, and to avoid colliding with obstacles, we set 0.8 meters far away from the outer of aircraft as safety distance. To be able to track the ground robot and avoid the obstacle in the same time, we use a method called artificial potential field to design our flying path. The gravitational field potential function is related to the relative distance with objects, and the longer the distance is, the more potential energy is consumed. We can move in the negative gradient direction of the gravitational potential function to minimize the energy consumed.

3.3 **Localization and Robots Detection**

3.3.1 *Localization*

To finish mission 7, the air vehicle should have the ability of self-location under GPS free area or with no other assisting equipment. In the particular environment with no distinct markers, traditional stereoscopic vision methods won't work. Under this circumstance, a navigation algorithm based on optical flow technology and visual location method is presented. Visual location algorithm based on the detected grids is proposed to compensate for the location error of aircraft. The algorithm flow and the grid line extraction result is as follows.

1) Obtain the camera's approximate location by optical flow method.
2) Convert images to grayscale image, and then extract the grids through threshold technique.
3) Extract structure of the grids, and get the straight lines by using Hough Transform algorithm.
4) Choose two points in each line randomly, and calculate the coordinate of the chosen points to attain the expression of lines in the world coordinate system.
5) Rectify the equations in the world coordinate system, and then we get the offset of the air vehicle.

Figure 6: The Grid Lines Extraction Results

3.3.2 *Robots Detection*

The mono camera we use for target detection is wide field camera. Therefore, the calibration and distortion correction of the wide field camera is necessary due to serious barrel distortion. The calibration of mono camera is to derive the intrinsic parameters, distortion coefficient, through which we can correct the image.

Threshold method was used to segment the image and extract special zones with red or green color. Due to the three components of RGB space are highly correlated, we use hue, saturation and brightness to describe the color of target. Then, the target will be separated from background through threshold method. The result of color threshold is shown as figure 7.

To track the moving targets, camshift method was utilized. By calculating the histogram of targets using its hue channel, the probability distribution of the target is obtained by the histogram back projection, and then automatically adjust center of the target and size of the window by executing camshift algorithm of the CV library. Then we can track the targets in the image.

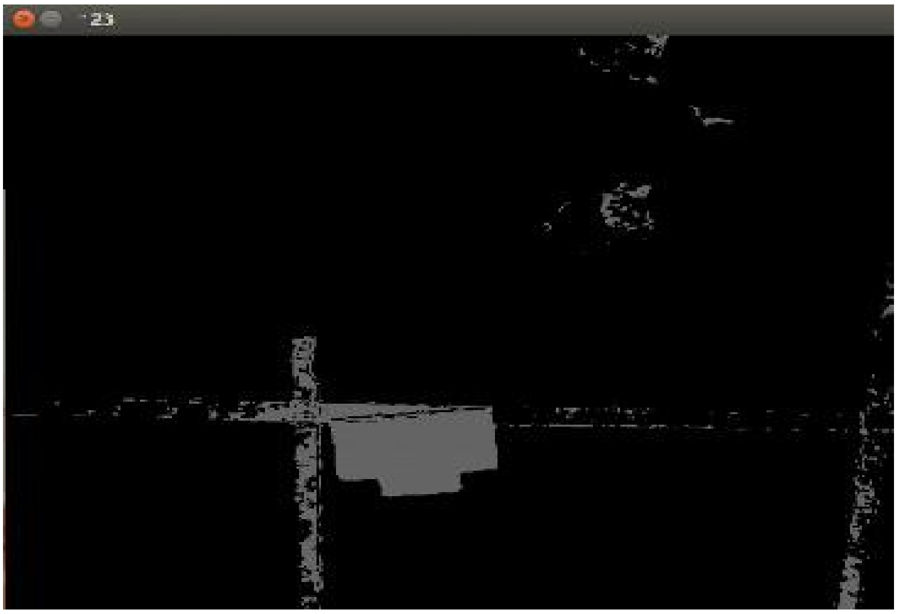

Figure 7：The Color Threshold Result

The moving target has a T-plate upon the top surface which has a T shape. we use key point matching method to estimate the moving direction of robot. We choose Harris corners to be the key point feature. The detection result is shown as figure 8.

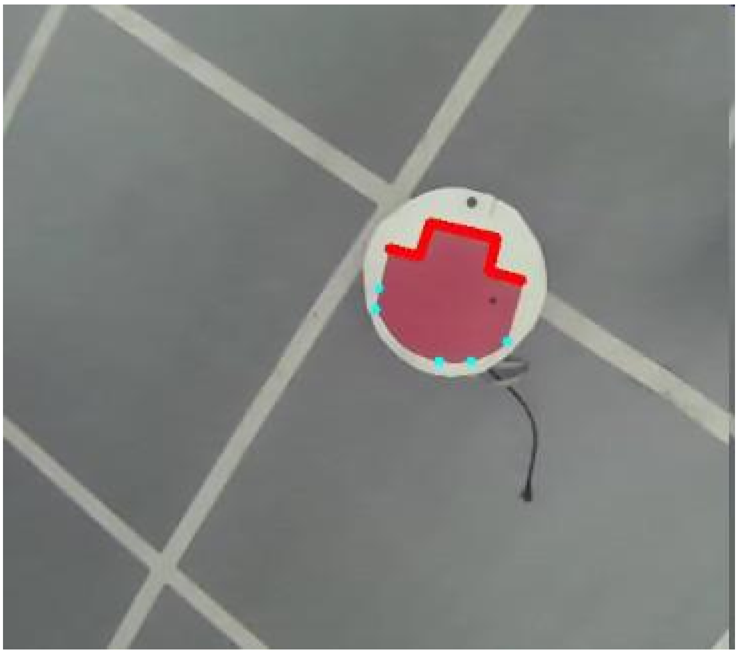

Figure 8：The Direction Estimation Result

SYSTEM VALIDATION

4.1 **Simulation**

We established a simulation platform based on Gazebo framework since it is capable of simulating physical features of real world, e.g. collision and friction based on Open Dynamics Engine (ODE). Our simulation platform has the ability to simulate the distributions of the moving ground robots in complex environments, and can rapidly test our algorithms. It plays an important role for mission planning and strategy testing.

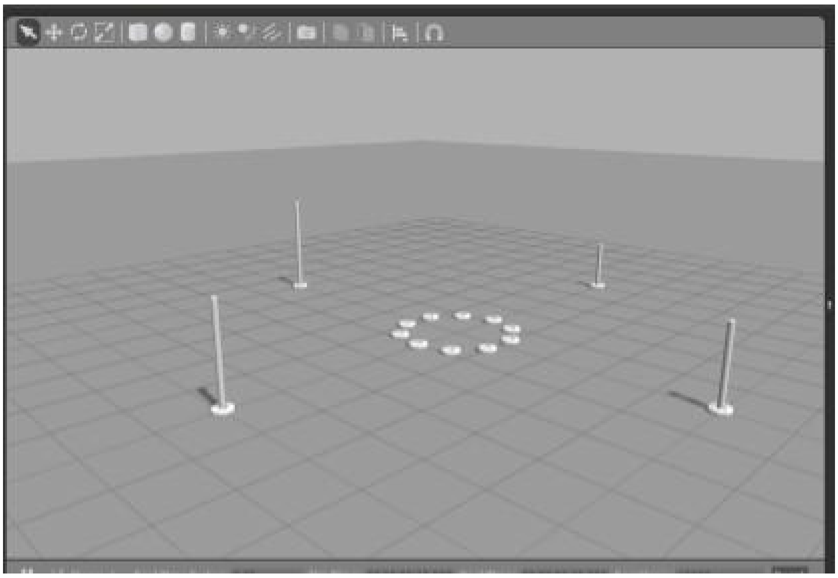

Figure 9：Simulation Environment

4.2 **Real Testing**

In order to test the performance of our aircraft, we prepared several iRobot Create 2 and pasted white tape on the ground to simulate the actual competition area. We designed some experiments to test the interaction planning with robots and the path planning when there are obstacles. The figure below is the scene of testing interaction planning with robots.

Figure 10：Interaction Experiments

CONCLUSIONS

This paper presents the proposed solutions and architectures of our aircraft for mission 7 of IARC. Among other topics, it introduces the safety measures and test procedures by simulation or real testing. Up to now, the configuration of hardware and software was almost finished, and partial planning task has been tested. In the following days, the planning task to avoid obstacles should be tested and the mission planning module also need to be tested. To accomplish the task, we need to improve the efficiency of interaction and upgrade the strategy.

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.