ZMART Technical Report

International Aerial Robotics Competition 2017

ZJU's Micro-Aerial Robotics Team (ZMART)[1]

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Abstract

The Zhejiang University Micro-Aerial Robotics Team (ZMART) has prepared to participate the 2017 International Aerial Robotics Competition (IARC). Our team aims to demonstrate interaction with one moving object while autonomously navigating in a sterile open environment. The basic system architecture consists of a quadrotor helicopter platform, control units, different kinds of sensors, communication module and a base station. The hardware structure, as well as the algorithm structure, will be introduced in this report.

1. Introduction

Since the intent of the International Aerial Robotics Competition (IARC) is to push new technology of aerial robots, Mission 7 challenges participators with interaction with moving robots and navigation without external aids. This mission requires the unmanned aerial vehicle (UAV) to herd ground robots to one side of arena, avoid obstacles, keep height within limitation and compete with other aerial vehicles in second part of the mission.

The key factors of this mission are moving object tracking, quick control and strategy. In our solution, once moving object is captured correctly by the camera, the velocity of target is linked to the UAV. By calculating UAV's velocity, we can make the decision whether interaction is needed or not. All processes, including information fusion happen in a short time, next controller output may come to the actuator before UAV reach stable, so a quick control algorithm needs to be designed. Since there are multiple targets, strategy should be composed first. After choosing a specific target, the UAV can operate tracking or interaction.

Since it is the third time for our team to take part in this type of competition, all work can be done by our groups based on previous experience and hardware setup. We will try some aggressive strategies or design. By now, we finished building our own UAV system, implementing the parallel mechanical arm, vision tracking algorithm, the localization method and so on. We anticipate for an attempt in this coming August.

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2. Aerial Vehicle

2.1 Platform

The Matrix 100 is a stable, flexible, and powerful platform developed by DJI, which consists of an flight controller, propulsion system, GPS, DJI Lightbridge, a dedicated remote controller, and a rechargeable battery. This system automatically manages the most complex tasks required for flight.

Figure 1: DJI Matrix 100

2.2 Guidance

Guidance is a revolutionary visual sensing system, including five sensor modules and one central processor. Even without GPS, achieve hovering that is accurate to within centimeters. Guidance's vision positioning system is effective at altitudes of up to 65 feet (20 meters). Guidance continuously scans the nearby environment and detects obstacles in real time. When used with a DJI flight controller, it can tell our flight system to automatically avoid collision, even at high speeds.

Figure 2: DJI Guidance

2.3 Manifold

The Manifold is a high-performance embedded computer specially designed for the DJI Onboard SDK. It enables developers to transform aerial platforms into truly intelligent flying robots that can perform complex computing tasks and advanced image processing literally on the fly. Designed for developers, the Manifold's built-in Ubuntu operating system supports Linux, CUDA, OpenCV, and ROS. It is ideal for research and development of professional applications. The Manifold can natively run the DJI Onboard SDK, access flight data and perform intelligent control and data analysis. With

CUDA, the Manifold can be used to accelerate your applications to achieve unprecedented levels of performance.

Figure 3: DJI Manifold

2.4 Intel NUC

Next Unit of Computing (NUC) is a small-form-factor personal computer designed by Intel. The Intel® NUC is a powerful 4x4-inch mini PC with entertainment, gaming, and productivity features, including a customizable board that is ready to accept the memory, storage, and operating systems that you want.

2.5 Scanning Rangefinder

UTM-30LX is a 2D laser scanning rangefinder of HOKUYO company, with 30m, 270 degrees measurement range, IP64 protection level, can be used for outdoor installation, DC12V input, 25ms scanning time, suitable for robots with higher moving speed because of the longer range and fast response.

Figure 4: HOKUYO Rangefinder

3. Mechanical Structure

The platform adopted by ZMART in IARC 2017 is based on 2016 ZMART platform solution. The mechanical structure has been rearranged to optimize the dynamic features of the UAV. The sequence of control board layers has also been adjusted to minimize takeoff weight of the platform.

The most significant modification in mechanical structure is that new ZMART platform is equipped with a 2DoF parallel robotic arm. To upgrade the platform as an aerial manipulator is an experimental attempt to find out a feasible solution of “top touch” performance. The robotic arm is driven by two servos mounted to the main frame arms, and can be folded when the UAV is on its cruise mission with little interference on aerial dynamics. When the UAV approaches the overhead area of the ground target, the arm is able to reach the top touch board of the target. Compared to the normal top touch solutions, ZMART platform is able to maintain its height at around 1m when reaching for the target, which, in other words, prevents the loss of visual information due to insufficient height. Thus the look-down camera would be able to recognize and track the target continuously. Generally speaking, the aerial manipulator solution would make UAV more capable of interaction with dynamic target. The platform has been tested to ensure the touch, even in the worst-case scenario, would not lead to instability of the flight.

This 2DoF parallel robotic arm as follow consists of a white platform, 4 carbon fiber shafts, 2 steering engines and some adapting pieces concretely.

Figure 5: Parallel Mechanical Arm

4. Software system overview

We develop the software structure of UAV in Ubuntu 14.04, and the system frame is based on Robot Operation System (ROS). Briefly, the software structure of the UAV system could be divided into five functional part: localization, tracking, detection, navigation and obstacle avoidance, as show in Figure 6.

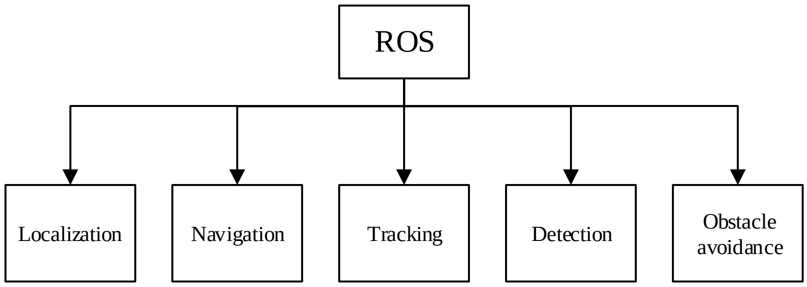

Figure 6: Modules of software in UAV system

Using ROS as the system frame is due to its handy communication. The ROS has three communication modes, topic, server and action. The way of our system belongs to topic, which each node publishes or subscribes the topic to obtain their necessary message from other nodes. Therefore, we don't need to spend time on how the module is communicated with others, and just focus on the algorithm itself.

The AGV system needs to provide with the basic modules for the mission 7. First, the aircraft needs to equip with the localization which is the all robot's basic function. Then, the system should assure that aircraft performs the task within the arena. It can be achieved by the boundary detection module. Moreover, the mission 7 requires the aircraft to crowd out the ground robot, so the object detection module is necessary. There are some obstacle robots on the ground, which the aircraft cannot touch. The obstacle avoidance module can guarantee it. Our software consists in all above modules, and other detail modules is not repeated here. Figure 7 is the graph of system structure.

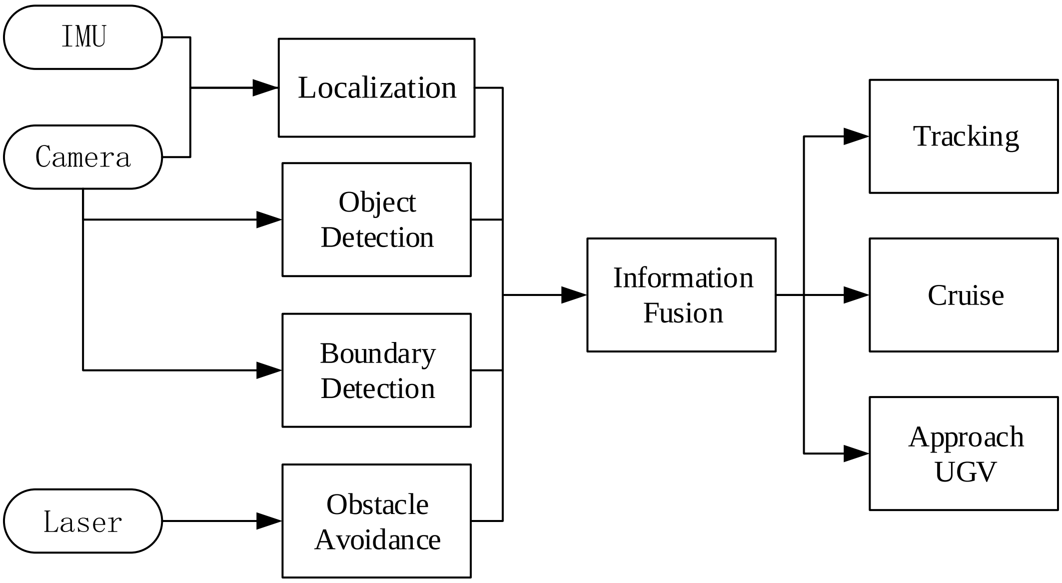

Figure 7: AGV system structure

In addition, the decision algorithm adopts to Finite State Machine to perform the tasks according to different cases. We set the state machine to four states, free state, tracking state, cruise state and approach state, as show in Figure 8. Our mind is simple but efficient. For example, the aircraft is in the cruise state. When a ground robot is into the view, the aircraft will be in track state. Once the conditions satisfied, it will enter the approach state and land on the ground to change the ground robot.

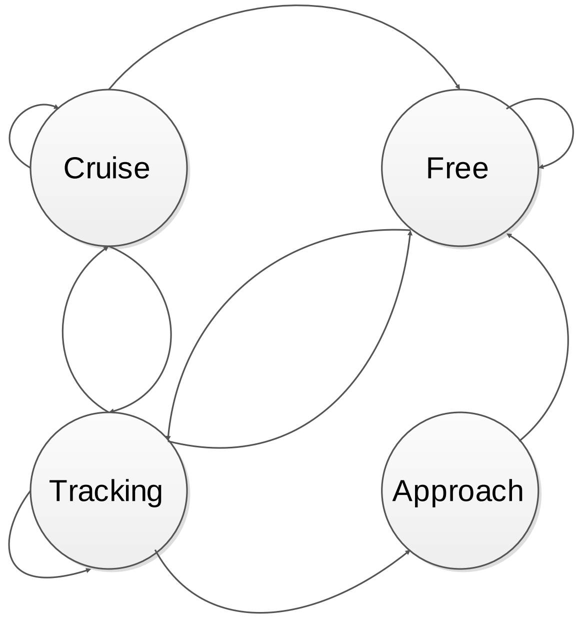

Figure 8: System Finite State Machine Graph

In this section, we have introduced system's frame, system's basic modules and decision algorithms. The structure described above is cursory. The next sections will introduce the detail of whole system structure's modules.

4.1 Localization

In this mission, a prior map can be built into micro-processor, so the pressure for localization is not main concern. The purposes of localization are keeping the UAV remain in the arena and computing the velocity orientation for decision making.

The foundation of localization algorithm is an odometer. The data from IMU and electronic compass are processed by the odometer. Based on the prior map, the odometer can provide basic position information. However, the quality of odometer is not high enough to provide reliable position and validation should be applied. We use the lines on the arena as landmark to implement validation. Due to the linear feature, simple edge extraction is adequate.

Position information is used to prevent the UAV from crossing the boundary. Another

application of localization information is to compute the velocity orientation of ground robot. This orientation is the key factor for deciding whether interaction with target is necessary.

4.2 Tracking and Detection

In this UAV system, two cameras will be installed onboard, camera A for forward-sight, camera B for down-sight. Videos taken by camera A will be processed in DJI Manifold which is a TK1 board and Videos taken by camera B will be processed in intel NUC with i5 CPU.

The camera A is used in searching mode. When UAV is hovering, forward-sight camera is used to search and locate ground robots roughly. After detecting and locating camera A is used to lead the UAV to approach target until the ground robot enter the scope of down-sight camera. One function of Camera B for down-sight is detecting and locating the target robot precisely. Camera B is also used to detect the boundary of competition area for adjusting UVA location and avoiding UVA fly out.

Camera A is installed onboard for forward-sight. HOG (Histogram of Oriented Gradient) and SVM (Support Vector Machine) method is used to detect iRobot and obstacles. As a famous traditional detection method, HOG and SVM method has good performance in pedestrian detection. Fortunately, we find that this method is also effective for detecting iRobot and obstacles. In detail, we implement two stages in our method. In first stage, we regard iRobot and obstacles as one class named foreground class. HOG and SVM with sliding window method is used to detect foreground. In second stage, we use HOG and SVM method to distinguish iRobot and obstacles from foreground. Now, we can get the positions of iRobot and obstacles in image coordinate system.

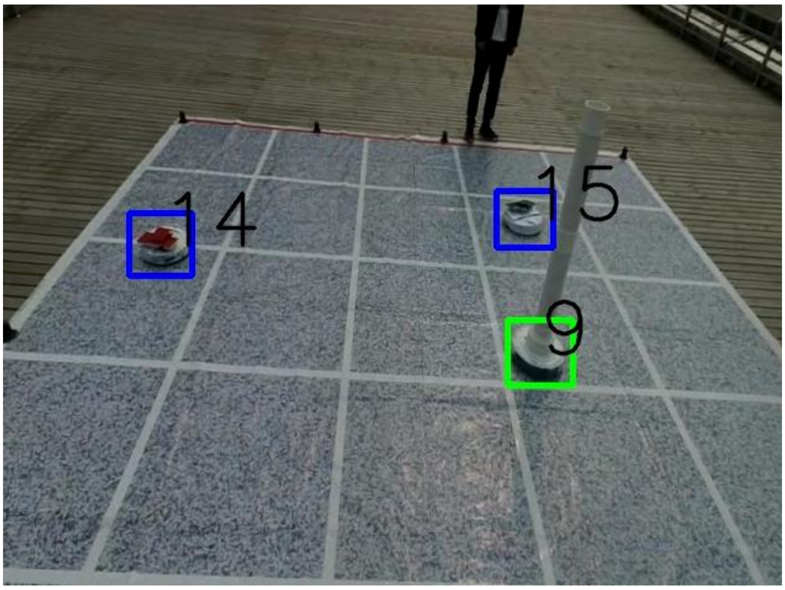

Figure 9: A snap of iRobot and obstacles detection from forward-sight camera

To get the positions of iRobot and obstacles in UAV body coordinate system, we need some information of camera. Since the camera is fixed on UVA, the height, poses and calibration parameters of camera are known, with simple camera calibration and geometry knowledge, it is easy to converse the positions of iRobot and obstacles from image coordinate system to UAV body coordinate system. Now, we can get the positions of iRobot and obstacles in UAV body coordinate system.

Camera B is installed onboard for down–sight. One function of Camera B is detecting and locating the target iRobot precisely. Since the color of board on iRobot is always red or green which is obvious and stable in the vision of down-sight camera, it is fast and robust to detect iRobot by using color feature, so we just set a threshold in RGB space to detect iRobot. Moment method from image processing is used to get direction of iRobot. We use PnP method which always used for UAV location with known position labels to converse the positions of iRobot from image coordinate system to UAV body coordinate system precisely.

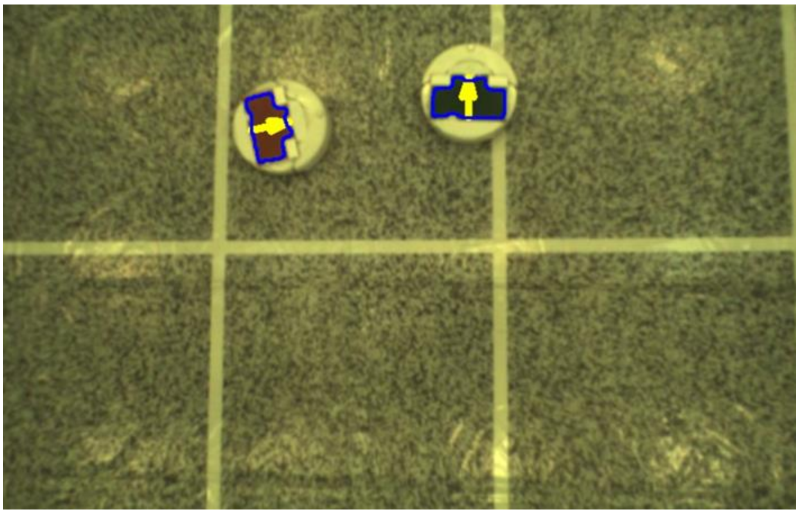

Figure 10: A snap of iRobot detection from down-sight camera

Camera B is also used to detect boundary of competition area. Since the color is always blue and white inside the competition area and always green outside area which is obvious and stable in the vision of down-sight camera, it is fast and robust to detect boundary by using color feature, so we just using a method with a threshold in RGB space to distinguish inside area and outside area on images which returns a binary image with black means inside area and white means outside area.

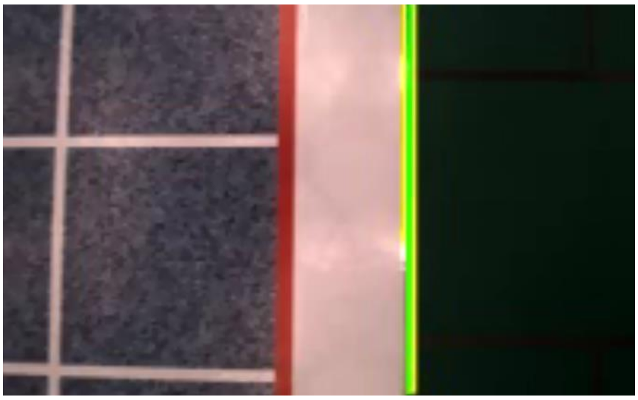

Figure 11: Boundary detection from down-sight camera (boundary is labeled by green line)

4.3 Obstacle Avoidance

There are already many methods proposed for obstacle avoidance. Artificial potential field approach is a real-time robot path planning method, and is widely used for autonomous mobile robot obstacle avoidance due to its elegant mathematical analysis and simplicity. Combined with the detection data from laser scanner, artificial potential field approach can determine admissible and reachable place for its path planning.

Compared with method like dynamic window approach, potential field method is more effective and simple for our task due to there are just 4 robots with tall cylinders obstruct the aerial robot.

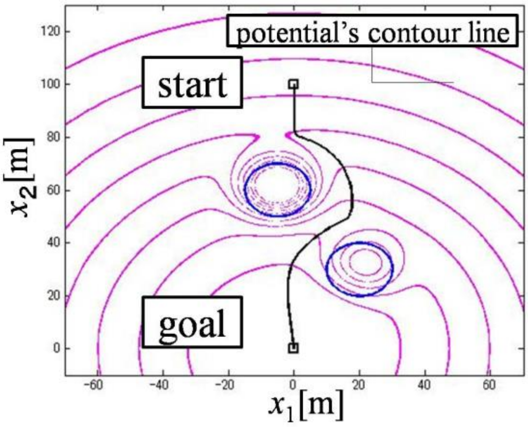

Figure 12: Artificial potential field approach

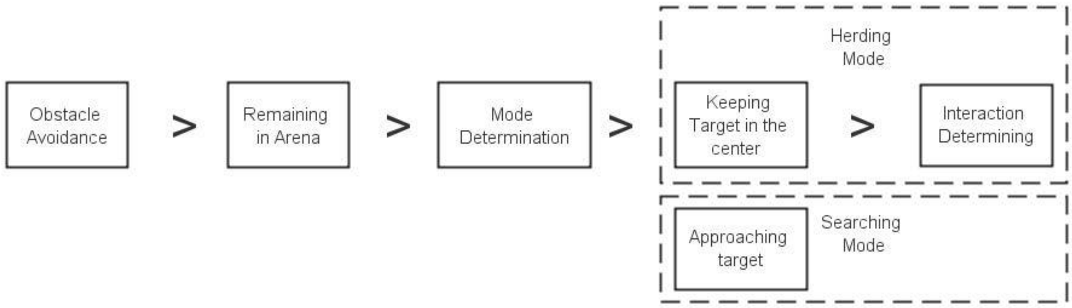

Figure 13: Priority of events

5. Conclusions

In this work, we develop an UAV system, based on a quadrotor platform, for the IARC Mission 7. Four main modules, localization, obstacle avoidance, height control and object tracking are implemented in both hardware and software. Although this system is somewhat aggressive, the system can be highly improved after some modification. Additional test is still needed before the UAV system become robust enough.

Acknowledgement

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