ZMART Technical Report

The International Aerial Robotics Competition 2012

ZJU's **M**icro-**A**erial **R**obotics **T**eam (**ZMART**) [1]

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Abstract

The Zhejiang University Micro-Aerial Robotics Team (ZMART) has prepared to participate the 2012 International Aerial Robotics Competition (IARC). Our team aims to demonstrate autonomous exploring and operation in an unknown indoor environment. The basic system architecture consists of a quadrotor helicopter platform, control units, different kinds of sensors, communication modules and a base station. The hardware structure, as well as the algorithm structure, will be introduced in this report.

Keywords:
Quadrotor Helicopter, Simultaneous Localization and Mapping, TLD Vision Algorithm, Geometrical Feature Path Planning

1. Introduction

Since Unmanned Aerial Vehicle (UAV) are increasingly applied in military and counter-terrorism fields, the International Aerial Robotics Competition (IARC) maintained its military background in Mission 6. This mission requires the UAV to explore an unknown indoor environment autonomously, building the map, searching a flash drive and bringing it back. Compared with the former missions, the challenges brought by Mission 6 push the requirements on flight control, sensor integration and indoor navigation to a much higher level.

Navigation in the indoor environment is obviously different from that in the outdoor environment. The Global Positioning System (GPS) signal, as the most important localization data source in outdoor navigation, could not be available within the buildings. Alternatively, the UAV relies on Simultaneous Localization and Mapping (SLAM) algorithm to build the map and estimate its position.

Since it is the first time for our team to take part in this type of competition, all work must be done by our groups without any previous experience and hardware setup. Nonetheless, we finished building our own UAV system, implementing the vision searching algorithm, the SLAM algorithm and designing a new indoor navigation method. We anticipate for an attempt in this coming August.

[1] **Team Leaders**: Jiangcheng Zhu (Overall; Motion Planning), Can Cui (SLAM; Vision), Zhongjie Yu (Flight Control) and Wei Qiu (Manipulator; Communication); **Members** (alphabetic order): Yatong An, Weiping Huang, Xinxin Jia, Wen Li, Xin Liu, Wenlong Wang, Lantao Xie; **Supervisors**: Chao Xu, Lei Xie

2. Aerial Vehicle

Concerning the features of the indoor environment and the competition task (picking up a flash drive), one kind of Vertical Take-Off and Landing (VTOL) UAV is desirable as the flight platform. In recent years, much of the attention has been drawn to the quadrotor structure, which excels in dynamic features and stability.

A quadrotor, or quadrotor helicopter, is an aircraft that becomes airborne due to the lift force provided by four rotors usually mounted in cross configuration. It is an entirely different vehicle when compared to a helicopter, mainly in the manner of dynamics and control. Classical helicopters are able to shift the angle of attack of its blades periodically to adjust its flight attitude, while quadrotor helicopter has all the blades fixed to the axles, and achieve flight control via collaboration of the propellers.

We choose quadrotor helicopter as the flight platform of UAV system. A quadrotor helicopter has four propellers, which could provide more lift than a classical helicopter in a similar size. Also, as all the axes of the propellers are parallel and fixed, the physical construction is relatively simple and more robust than many other structures. The space in the four propellers is a suitable place to set onboard electronic system on the geometrical center of the quadrotor helicopter. This installation method reduces the computation complexity of localization and planning.

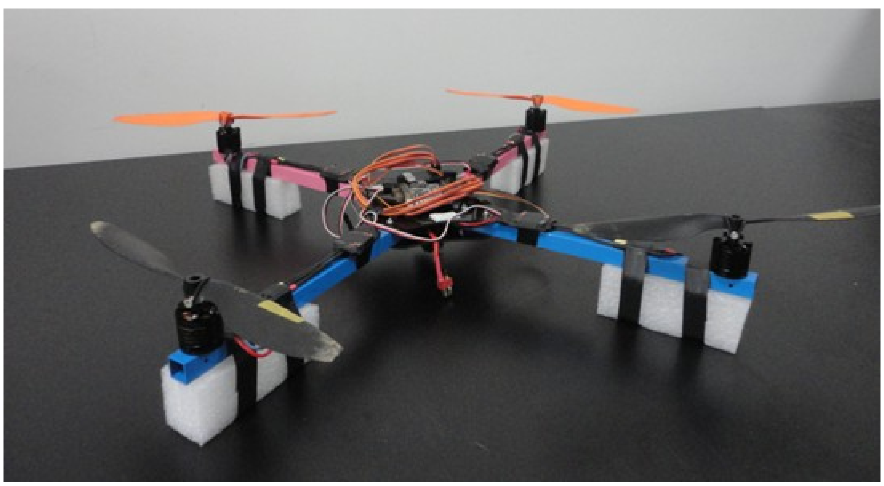

Figure 1: The Quadrotor Platform of the UAV System

2.1. Airframe

The airframe is the mechanical structure of an aircraft that supports all the components. Designing an airframe involves important concepts and knowledge of applied mechanics, aerodynamics, materials engineering and manufacturing technologies to achieve a good performance. Fortunately, since the quadrotor has become one kind of popular aerial vehicles in the aero-modeling field, there are many well-designed airframes available for DIY players.

Concerning the competition background and assigned task, we choose the airframe in Figure 1, which has a raw radius of 550mm. The airframe is made of aluminum alloy and engineering nylon. This kind of airframe compromises weight and mechanical strength quite well. Though other kinds of airframes which are made of glass fibers and carbon fibers perform better on strength and weight, there are fewer accessories for us to make modifications on them.

As there are many electronic boards and sensors, such as laser scanner and camera, needed to be installed on the airframe, we use nylon plastic boards and nylon support shores to extend the installation plates.

2.2. Propulsion System

The motors we applied in this project are electric Direct Current (DC) motors, which are lighter than combustion engines and independent of combustible fuel. Furthermore, brushless DC motors performs more efficiently to be worthy of their cost, when compared to brushed DC motors.

To control the speed of a DC brushless motor, Electronic Speed Controller (ESC) must be used. This hardware receives the power supply from the battery and drives it to the motor in a specific phase consequence according to a Pulse-Width Modulation (PWM) signal that is provided by the controller unit.

The DC Brushless motor, Electronic Speed Controller and EPP-1045 propeller form the propulsion system. This efficient and dependable combination is all based on the experiences from the attempts of many aero-modeling DIY players. With sufficient power support, this propulsion system could provide lift force of about 3kg in maximum. The total weight of the UAV is limited at 1.5kg in this mission.

2.3. Power System

In the aero-modelling market, electric batteries have proven to be a long term cheaper solution to combustion engines. Though combustion engine provide far larger lift force and duration time, it is too heavy to such a quadrotor helicopter. A light and robust power source, Lithiusmion Polymer (LiPo) battery, a newly developed power storage technology, is being called as the best choice of quadrotor UAV system for its high capacity.

A 2200mAh LiPo battery supports all the electric cost of the UAV system. The 4 ESCs obtain 11.1V electric power directly from its polar. Electronic board and sensors get 5V electric power from the ESC. Four motors work in power of 400W, when hovering. Thus, the regular working time of the quadrotor flight platform is about 10 minutes.

3. Hardware Structure

The hardware system includes two parts, the onboard system and the base station. The onboard system consists a Central Control Unit (CCU), an Inertial Measure Unit (IMU), a 2D laser scanner, two cameras and a communication module. The Base station is a laptop computer with a communication module.

Those hardware works in three frequencies according to various demands. The inner control unit and IMU must work in a comparably high frequency because the attitude of the quadrotor platform changes rapidly. The medium control unit, laser scanner and cameras work in a certain frequency enough for controlling the position. The outer and planning level, working on the base station, works in a low frequency.

It is required to keep the mass of any competition vehicle with less than 1.5kg, the amount of payload available for sensing and computation is severely limited compared with the ground vehicles. The total gross weight of the aerial vehicle and the onboard hardware is very close to the limitation. So no backup for any parts of this UAV system is permitted to add onboard. We must test the whole system for many times to guarantee its reliability.

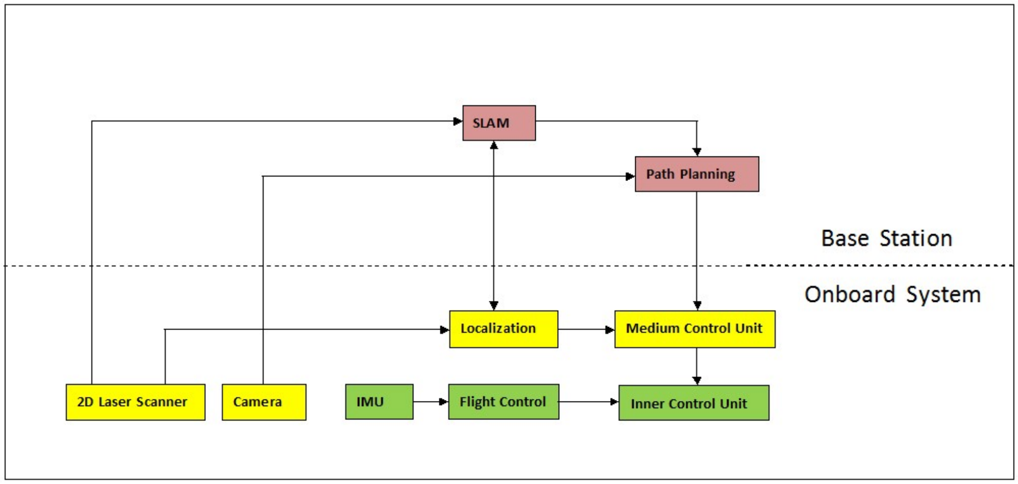

Figure 2: The Hardware Structure Diagram

3.1. Control System

There are three levels of control units for this mission. Each of them works on different electronic board and in different frequencies. The control units, sensors and communication methods of each level will be introduced separately below.

The inner control loop works on a JadeRabbit flight control board. This board integrates control unit and IMU together. Main job of this board is to keep the quadrotor hovering. With the help of an sonar, it can also keep the quadrotor platform fly in a fixed height. It can also control the rotation. Because of the null drift of the IMU, together with the wind disturbance, the inner control loop could not guarantee the quadrotor platform stay in a single point. This task, position keeping, could be accomplished under the cover of the medium control loop.

The medium control loop works on an ARM board. A 2D Laser Scanner, the sensing method in this loop, transmits its data, which includes a distance between the quadrotor platform and the obstacles, in the polar coordinate, to the ARM. Then, the quadrotor could get its relative position against the wall. With this information, the control unit could provide forward, backward, leftward, rightward order to the inner control unit.

Besides the position keeping, the medium control loop also obatins the displacement order from the base station (the upper control loop). It will also send order to the inner loop so that the quadrotor platform could move directly to a certain point under control.

The mapping and planning algorithms work on the base station, which form the upper control loop. Base station collects data from the laser scanner by wireless communication module between ARM and base station. Planning result is sent to the onboard system by the same way.

3.2. Inertial Measurement Unit

An Inertial Measurement Unit (IMU) is an electronic device that measures the velocity, orientation and gravitational forces of the aerial vehicle simultaneously, using a combination of acceleraometers and gyroscopes, sometimes magnetometers. The IMU is the main component of inertial navigation systems used in various aerial vehicles.

The 3-axes accelerator and 3-axes gyro are integrated in the JadeRabbit control board. This IMU is relatively light but lower-quality. With efficient filter algorithm, this attitude data contaminated by external noise could also support the flight control. Another attitude measurement unit is the electronic compass, which is used to provide heading data to the medium control loop.

A major disadvantage of using the IMU for navigation is that they typically suffer from accumulated errors. Because of its low quality, we withdrawal the attempt to build an inertial navigation system. Alternatively, the SLAM method based on a 2D Laser Scanner is used for localization.

3.3. 2D Laser Scanner

A laser scanner is a device which uses a laser beam to determine the distance to an object. By sending a narrow-beam laser pulse, the distance to the object could be computed from the time between the sending and returning of that pulse.

SLAM algorithm plays an important role in the localization and mapping. Concerning the scan range and weight, the Hokuyo UTM-30LX 2D Laser Scanner is chosen. URM-30LX is a laser sensor for area scanning. The light source of the sensor is infrared laser of wavelength 785nm with laser class 1 safety. Area can be scanned is the sector with maximum radius of 30m and sight of 270 degree. Its gross weight is 270g, far lighter than the commonly used SICK Laser Scanner on ground robots.

Hokuyo 2D Laser Scanner could get the obstacles' position in polar coordinates. It returns its measurements in an integer array of the size of 1080. From 0 to 270 degree, the beam scans counter-clockwise at a step of 0.25 degree. With this data, the UAV could locate itself in an indoor environment.

3.4. Vision System

In the aero-modelling field, First-Person View (FPV) is a method used to control a RC model vehicle from the pilot's view point. Though our UAV could not be controlled manually, we could use equipments in FPV. The algorithms on the base station will take the place of human pilot to control the UAV.

In this UAV system, two wireless cameras will be installed onboard, one for forward-sight, another for down-sight. This kind of camera has independent power system, which could support about 1 hour work time in regular. Video is transmitted to the base station by the built-in 2.4G communication module. By this way it reduces the requirement of the communication system onboard. The video will be processed by the algorithm in the base station for tracking certain targets.

The wireless camera for forward-sight is used to search and judge the Arabic characters on the doorplate. The one for down-sight is used to search and tracking the flash drive on the table.

3.5. Communication System

A wireless communication module is used to transmit data between ARM and base station. This PC-1212 wireless communication module could guarantee an efficient and dependable data interaction between the onboard system and the base station.

Though that module mentioned above could provide dependable communication, the Wi-Fi communication method is a better choice for its high data transferring speed. In our experiments, sometimes the Wi-Fi module and the camera's 2.4G communication module may disturb each other. It is a pity that the Wi-Fi communication module won't be the first choice unless our team have this problem solved. PC-1212 is used to guarantee the lowest communication requirement.

3.6. Capture Mechanism

Because the total weight of the UAV is limited, the capture mechanism must as light as possible. We used to design a manipulator to pick the flash drive up. But the weight of this manipulator, made of mental, is unacceptable. So we choose another alternative method, that a round baseboard with double faced adhesive tape is installed on the bottom of the quadrotor platform. A box contains the disguised flash drive, driven by a servo, is installed on the upper side of the round baseboard. When needed, the servo will sweep the flash drive off to the desk.

4. Software Structure

Briefly, the software structure of the UAV system could be treated as a 3-level cascade control loop. The inner loop is for stably hovering of the quadrotor platform in desired height and direct. The medium loop aims to make the UAV fly to a certain position. The top loop, which is implemented in the base station, is for the path planning.

Though the whole software structure could be divided into three parts clearly, they do not always been divided in a certain hardware or algorithm. For example, the 2D Laser Scanner provide data for localization and position flight control in the medium loop, also provide data, through wireless communication, to the upper planning level for mapping and path planning.

In this section, different algorithms will not be introduced from the bottom level to the top, but not always be divided according to the level.

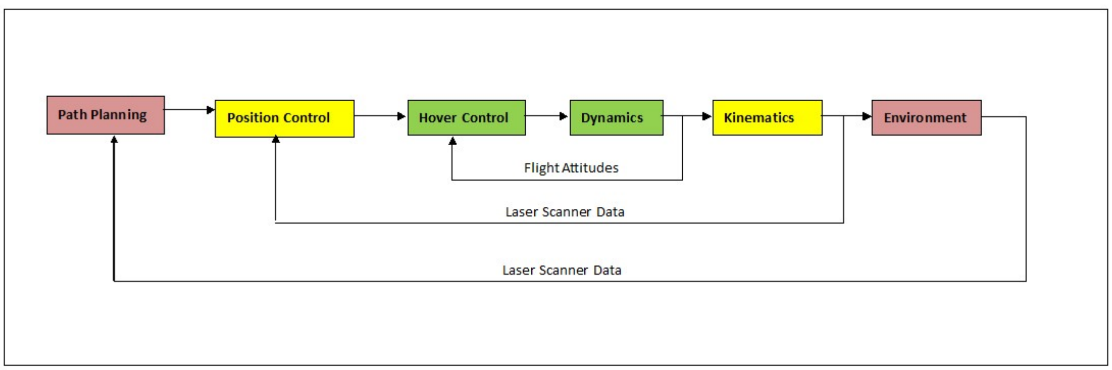

Figure 3: The Software Structure Diagram

4.1. Flight Control

There are many publications focused on the control algorithms of quadrotor platform. Different methodes such as Lypunov Theory, PID control, adaptive control and LQR method have all been discussed. As the PID structure does not require accurate models of controlled objects, it is always been chosen as the control algorithm of quadrotor helicopters [Bre08].

The goal of the quadrotor stabilization is to find those values of the motors' voltage which maintains the quadrotor in a certain position required in the task. To accomplish this task, control results of 4 attitude states (height, roll, pitch, yaw) should be decoupled into the rotation rates of 4 motors. Then, the rotation rates should be transferred to the widths of PWM according to the rotation rate and PWM width relationship.

For hovering, a PID algorithm with decoupler is used to provide motors' voltage. This algorithm is based on the dynamic model of quadrotor helicopter. Because of the specific structure character of quadrotor helicopter, it is possible to use the rotation rates of 4 motors to control 6 attitude states.

4.2. Vision

TLD is a real-time algorithm for tracking of unknown objects in video streams. It is developed by Zdenek Kalal, a Czechish student in University of Surrey. TLD means tracking, learning and detecting. This method simultaneously tracks the object, learns its appearance and detects it whenever it appears in the video. With this method, the computation system could track almost every moving thing in its visual field [K+09].

In the TLD method, Zdenek use an online learning method to get the feature of the target. Even if the camera was rotated or tilted, it could track the target. We will add an offline learning part before the UAV takes off. The UAV will get features about the doorplate and flash drive before they touched the doorplate or flash drive in the competition environment.

By now, we implement this TLD method on the MATLAB environment. We just use its free version to accomplish the mission in this non-profit competition.

Figure 4: Using the TLD Method to Track a Chip

4.3. SLAM

SLAM is a technique used by robots and autonomous vehicles to build up a map within an unknown environment. As GPS localization method could not be used in the indoor environment, SLAM method must be used to get the position, and to rebuild unknown indoor map as well [A+10].

Our SLAM method will be based on the polar coordinator data from the 2D Laser Scanner. Because of the limitation of weight, no more sensors are permitted in the quadrotor platform. We will not use other data sources such as sonar or binocular vision to support an Extended Kalman Filter (EKF). In fact, our experiments show that almost all other measure methods, such as vision odometry or sonar, provide worse distance data than the 2D Laser Scanner. Using an EKF to mix those data always provide a worse result than a single laser scanner.

In our UAV system, an algorithm based on the rotation matrix and featured vector is developed to match scanned data in different places together for a complete map. More details of this method is discussed in the Cui's thesis in detail [Cui12].

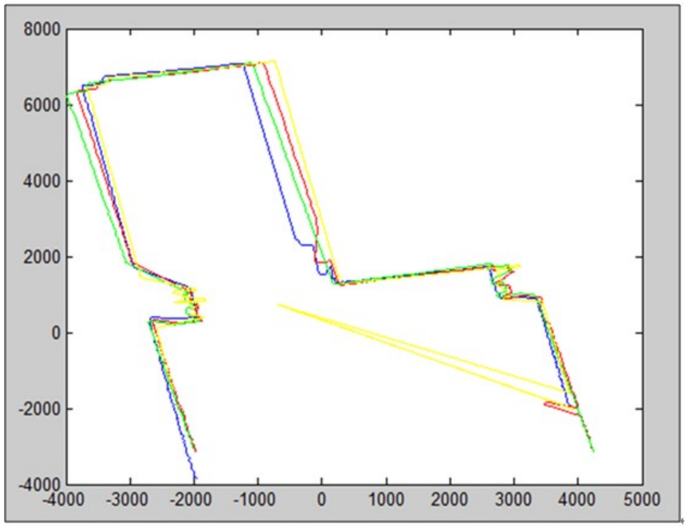

Figure 5: Using the SLAM Method to Build a Map

4.4. Path Planning

There are already many publications on path planning methods in unknown environments. They always incorporate the predicted uncertainty of future position estimates into the planning process to acquire a better performance. However, planning in the space of probabilistic position estimates, or belief space, can incur substantial computational cost [PR10].

Different from existing planning algorithms based on map information and probability. We develop a path planning method based on the geometry feature of the competition environment. This method is operated step by step. In each step, the quadrotor platform stops and hovers to get the laser scanning data. Then, the planning algorithm analyzes the laser scanner data to get geometrical feature points and judges the branch corridor or room entry. The planning result will be sent to the onboard system. Geometrical method is used in each step to keep the quadrotor platform out of wall in a safe distance [Zhu12].

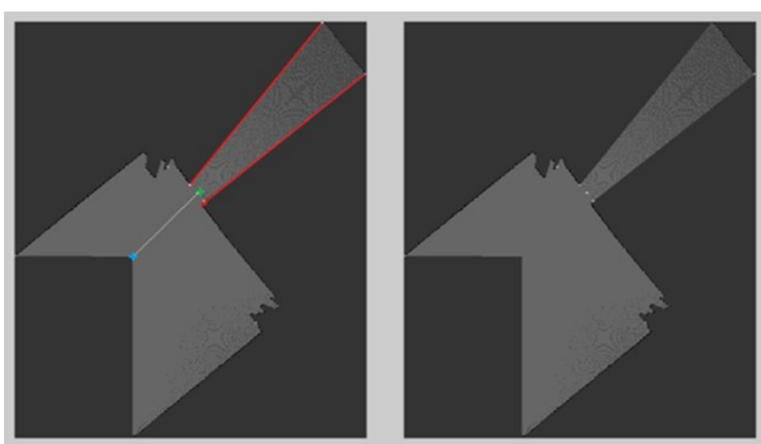

Figure 6: The Path Planning Result in a Corridor Environment

Because this planning method do not rely on the map information generated from the SLAM algorithm, those two programs could be processed in a parallel style for computation, which could accelerate the computing speed.

After the UAV captured the flash drive, map from the starting point to the end has been built, then it is not necessary for an online dynamic planning any more. Offline planning will provide a general path from the flash drive to the starting point based on the map generated by the SLAM module.

5. Conclusion

In this work, we develop an UAV system, based on a quadrotor platform, for the IARC Mission 6. A 3-level control loop, both in hardware and software, is developed to accomplish hovering, localization, mapping, indoor exploring and searching. New methods of mapping and planning are developed according to the features of the payload limitation and competition environment. Additional test is still needed before the UAV system become robust enough.

Acknowledgement

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