CAUC's Aerial Robot for IARC 2013

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ABSTRACT

To complete the 6th mission of the International Aerial Robotics Competition, a quadrotor aircraft consisting of flight control system and navigation system is designed. The flight control system is composed of a main chip and some sensors, and the traditional PID algorithm is used to control the attitude. The navigation system is composed of a small computer and some sensors, and a navigation method based on finite-state rough set theory is proposed. The whole mission is separated using the finite-state machine model to get the state transition diagram, then rough set theory is used to reduce the properties, and a minimal rule set is achieved. Finally, a program based on the minimal rule set is executed. The vehicle is intended to be Civil Aviation University of China's entry for the 2013 International Aerial Robotics Competition.

I. INTRODUCTION

Quadrotor aerial robots have extensive application prospects because of its small size, stable flight, strong maneuverability and the ability of taking off, hovering, flying and landing in a restricted area. At present, the quadrotor aerial robots have been applied in many fields such as power line patrol, territory exploration, flood relief, forest fire prevention, and have been a hotspot in UAV research[1,2]. Indoor complex environment is an enormous challenge to the autonomous navigation of quadrotor aerial robots, which is mostly solved by global positioning equipments like VICON. The improvement of sensor technology, especially the development of MEMS devices, the improvement of microprocessors and power devices, the application of new material and the increasing of battery life, provide necessary hardware support for the development of quadrotor aerial robots[3]. To complete the 6th mission of the International Aerial Robotics competition, a quadrotor aerial robot is designed, and the technological details are introduced in this paper.

A. Statement of the Problem

The 6th mission of the International Aerial Robotics competition requires the aircraft to enter through a window of 1 square meter from 3 meters away from the starting point. After entering into the window, it should navigate autonomously in an unknown confined indoor environment consisting of identifying the right doorplate and entering the right door and also locating and bringing back a flash drive. The takeoff weight of the aircraft cannot be over 1.5kg and the diameter 1m and the whole process should be limited to 10 minutes. The aircraft should launch its self-destroy

when the mission can't be finished.

B. Conceptual Solution

To accomplish this mission, an aircraft is made all by ourselves firstly. The PID algorithm is used to control the roll, pitch, yaw and height and the results shows the navigation requirement can be perfectly satisfied. The aircraft is equipped with one laser range finder, two cameras and one grabbing/releasing device. The range finder is used to measure the distance between the aircraft and the window or the wall. The front camera is mainly used to identify the status of LED, the right doorplate and the laser trip wire. The bottom camera is mainly used to search the flash disk. The grabbing/releasing device can grab or put down the flash drive according to the instructions of the upper computer. The method of finite state machine and rough set theory is used to navigate in the environment.

C. Yearly Milestones

This is the first time for the CAUC team to participate in IARC. The aircraft is designed to complete the 6th mission and it will have the ability to navigate and explore the whole environment, detect and extract the flash drive. This year we have finished the design of the flight control system and navigation system, some of this mission have been finished, such as flying through the door, flying along the corridor, identifying the doorplate and the flash drive and so on, and in the next year we aim to finish the rest of this mission.

II. Description of Vehicle

A. Aerial Platform

The platform is based on an XAircraft 450Pro quadrotor UAV. Only the basic structure and the propulsion system are adopted. The basic structure of the platform is shown in fig 2.1.

fig2.1 Basic structure of the platform

There are three major systems: the propulsion system, the flight control system and the navigation system, as shown in fig 2.2.
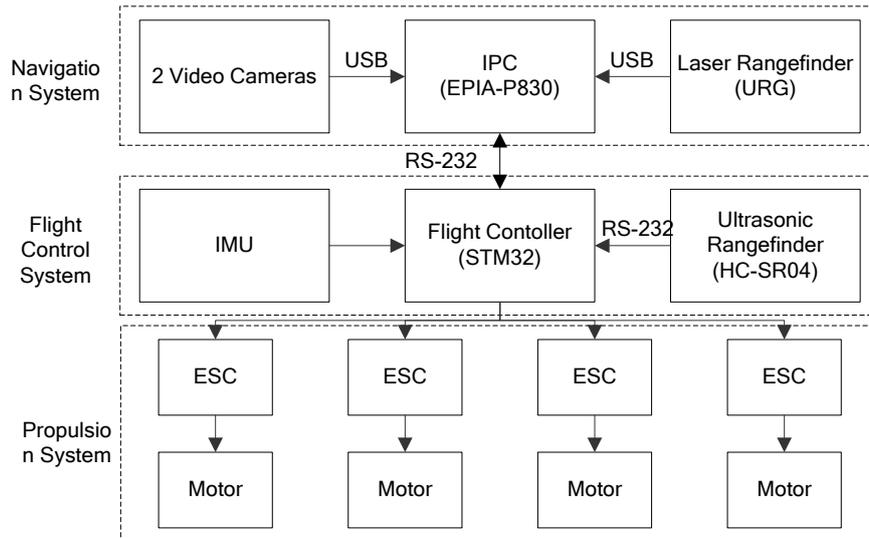
fig2.2 System hardware structure

B. Propulsion and Lift System

The propulsion system provides power for the platform. It consists of four Xaircraft 2215 brushless DC motors (fig 2.3) and matching propellers. Four ESCs (Electronic Speed Controller) are used to control the speed of the motors. The ESCs transform the PWM signal to alternating voltage signal, which controls the speed of the DC motors.

All the electrical power supply is from a rechargeable lithium battery of 4000mAh, which meets the requirement of the task.

fig2.3 Xaircraft 2215 brushless DC motor

C. Flight Control System

Considering the coupling of the system, a double loop PID[4] control method is adopted. The structure of the controller is shown in fig 2.4. The inner loop controls the attitude, i.e. the rotation angle (θ, ϕ, ψ). The outer loop controls the displacement, i.e. the location (x, y, z).
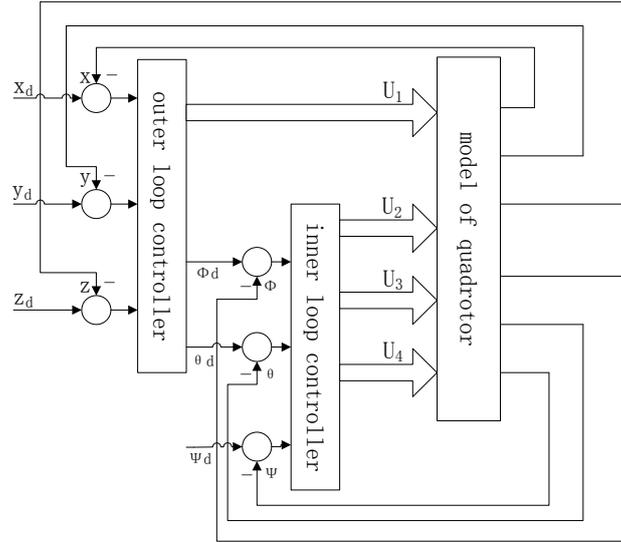
fig2.4 Structure of the double loop PID control system

As shown in fig 2.4, the input of outer loop controller is the error between the desired location and real location, while the outputs are the desired roll angle and pitch angle, as well as the control value U_1. The input of the inner loop is the error between the desired attitude and real attitude, while the outputs are the control values for roll channel, pitch channel and yaw channel named U_2, U_3 and U_4.

As a classical control method, PID has many benefits such as simple structure, satisfactory control performance etc, and fits the double loop control. The expression of positional PID is:

$$u(k) = k_p e(k) + k_i \sum_{j=0}^{k} e_j T + k_d \frac{e(k) - e(k-1)}{T}$$

D. Navigation System

The key issues of this mission are the localization and navigation for the UAV. The hardware of the navigation system is based on a VIA EPIA-P830 IPC, which is pico-ITX embedded compact native X86 main board, and a URG laser range finder and two cameras. The IPC is used to process the data from laser and cameras and then transform the results to the flight control system; at the same time, it also monitors the attitude of the aircraft. The navigation system communicates with the flight control system though serial port, by sending the commands in string format.

The laser range finder is used for self-localization, obstacle avoidance and path planning of the aircraft. As the map is mostly given, a grid map is drawn as an indication of indoor environment and then laser is used to acquire environment data. The method of grid map is based on MLE (maximum likelihood estimation)[5] and is used to estimate the most probable position of the aircraft.

After entering into the window, the strategy of flying along the wall is used for going forward. What's more, the shapes of the wall in the environment are classified

into different types corresponding with different strategies. When the aircraft moves, it can detect the type of the wall and follow the corresponding strategy to control the aircraft. The process result of the laser is shown in fig2.5.
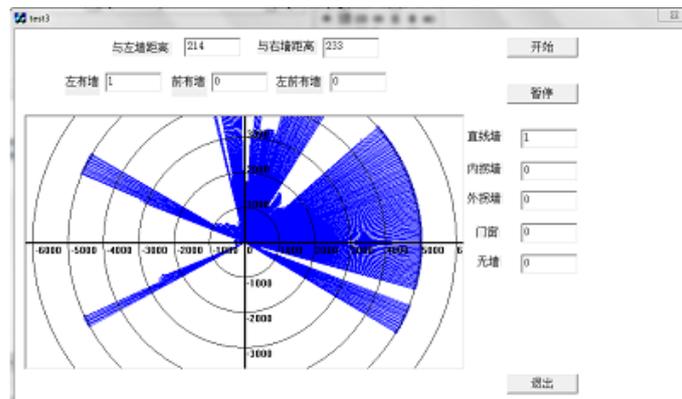

fig2.5 The process result of laser

Two USB cameras are mounted to the vehicle, one is forward-looking as well as rotatable on the horizontal plane, and the other is downward-looking. Image sequence acquired by the forward-looking camera is used for checking the blue LED, detecting the laser gate and recognizing the target Arabic signs. The downward-looking camera takes the images for searching and grabbing the flash drive.

Checking the blue LED over the window is accomplished by identifying of the blue region. If a blue region is detected and its size is beyond a threshold we set, the blue LED light is seen as on, and vice versa.

The flash drive searching is similar with the LED checking. If a black approximately rectangle is detected and its area and perimeter is in a certain range, It is considered as the flash driver.

Detection of the laser gate is done by identifying the triangular symbol. The triangular on the white wall is extracted, then check the whether the polygon contour has three sides.

Recognition of the three Arabic signs is completed by matching the SURF (Speeded Up Robust Features) detector-descriptor of two image. SURF[6-8] is a performant scale- and rotation-invariant interest point detector and descriptor. The algorithm detects the interesting points both of the sample and reference image and matches them at a rate of 6~8 times per seconds.

fig2.6 A sign recognized using SURF

The theory of finite state machine is used to navigate in the environment based on the navigation hardware. Firstly, the whole mission is departed into finite states according to the information from the sensors. Secondly, the transform relationship between the states is determined and some rules are obtained, fig2.7 shows the state transition diagram of the whole process. Finally, the rough set theory[9] is used to reduce the properties and a minimal rule set is achieved.
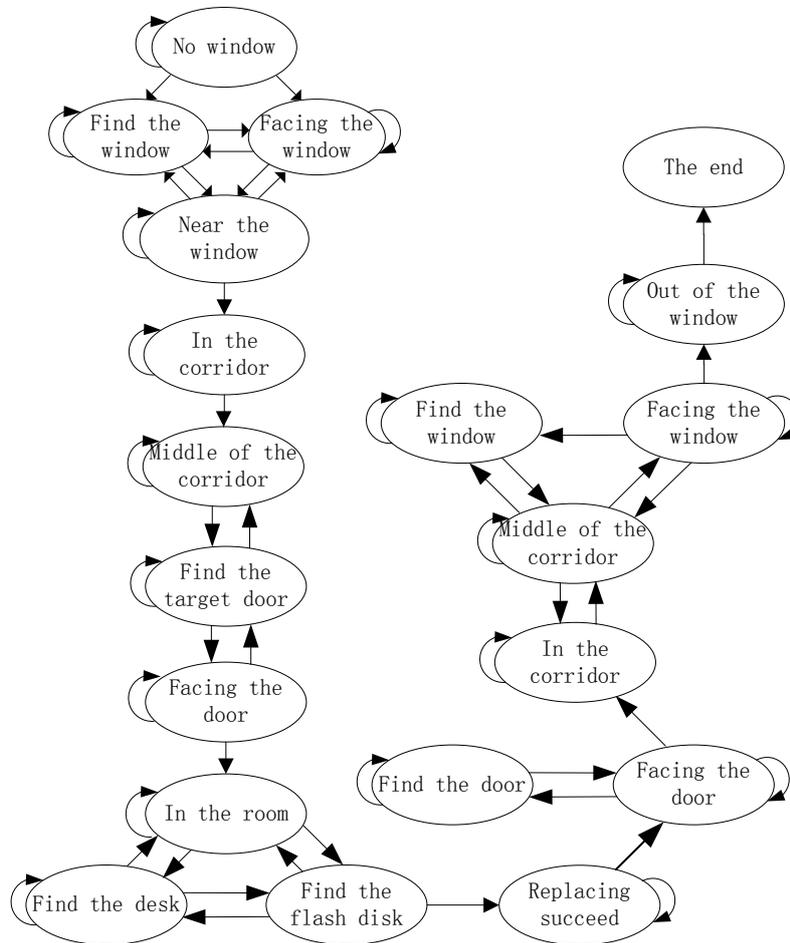

fig2.7 The state transition diagram of the mission

E. Flight Termination System

An IARC common kill switch is necessary for safety. It provides a simple and effective means of killing power to the motors through the use of a separate radio control receiver. When quadrotor loses control, the operator can take over the flying quadrotor through RC or just press the kill button.

III. Payload

A. Sensors

A laser range finder and two cameras are mainly used to offer the navigation information. The laser range finder used is the Hokuyo URG-04LX-UG01. It is capable of measuring distances up to 4m and has a maximum detection area of 240 degrees, with a resolution of 1mm and 0.31 degrees respectively. The JR-T99 is a

compact camera with high-resolution (640×480) CMOS image sensor and high-speed USB2.0 interface. Its frame rate is 29fps and field view is 60 °.

B. Communications

The onboard IPC and the STM32 flight controller communicate via RS-232 interface. The IPC also has a wireless LAN through which it can communicate with a ground station computer, on which the status of the vehicle can be monitored.

IV. Operations

A. Flight Preparations

A pre-flight checklist has been developed in order to ensure the security of the pilot and potential bystanders.
1) Setup the Ground Control Station, make sure all devices work properly.
2) Check Wi-Fi transceiver connection.
3) Turn on the transmitter and make sure all buttons are set to the right position.
4) Program the UAV with the latest stable code.
5) Do a small test to check if the quadrotor is ready to fly.
6) Check the IPC and run the necessary software.

B. Man/Machine Interface(MMI)

This MMI system is composed of Remote Controller for manual mode and Control Station in Navigation System for autonomous system.

The WFT07 Remote Controller produced by the company of WFLY is used to let the aircraft fly manually and then change into the autonomous mode. When an emergency happens, it can also be used to stop the aircraft.

The Control Station has the ability of monitoring, communication setting, PID control parameters regulation and so on. The monitoring interface is capable of displaying the real-time state of the quadrotor including attitude, heading, altitude and location. The whole flight can be easily monitored from the pre-taking-off phase to the final landing. The communication setting can be also finished in this interface including serial communication port and baud rate setting. What's more, the control parameters can be regulated real-time by entering applicable numbers into edit boxes in this interface. This function saves time of regulating parameters, thereby strengthening the durability of vehicle.

V. Risk Reduction

A. Vehicle Status Monitoring

The ground station computer communicates with the IPC via wireless network, on which we can easily monitor the status of the vehicle by radmin 3.2 software. Radmin is a product of Famatech International Corp. It is remote control software for Microsoft Windows which uses the Mirror Driver (Video Hook Driver) to remotely control another computer.

All mouse movements and keyboard signals are transferred from the local computer (ground station computer) directly to the remote computer (IPC) over the network (via LAN or Internet), relaying the graphical screen updates back in the other direction. Radmin Server uses the Mirror Driver (also known as Video Hook Driver) to read the remote screen bypassing Video Display Controller. Mirror Driver allows to read only changing parts of the screen. This software allows us to monitor and control the navigation system synchronously.

B. Safety to Bystanders

The protecting frame shown in fig 5.1 helps protect the vehicle as well as the bystanders, facilities and equipments around. It is made by carbon fiber, which is strong enough to protect the vehicle and people without adding too much weight to the platform.
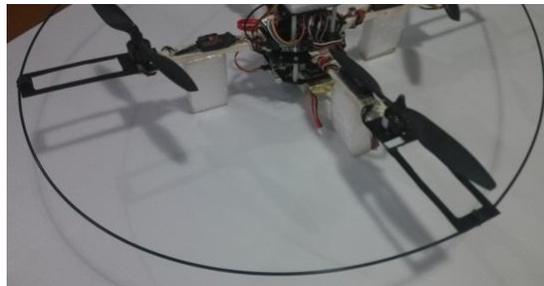

fig5.1 protecting frame

C. Modeling and Simulation

(1) Modeling

The model of the vehicle is established to study its dynamics. The structure of the vehicle is shown in fig 5.2.
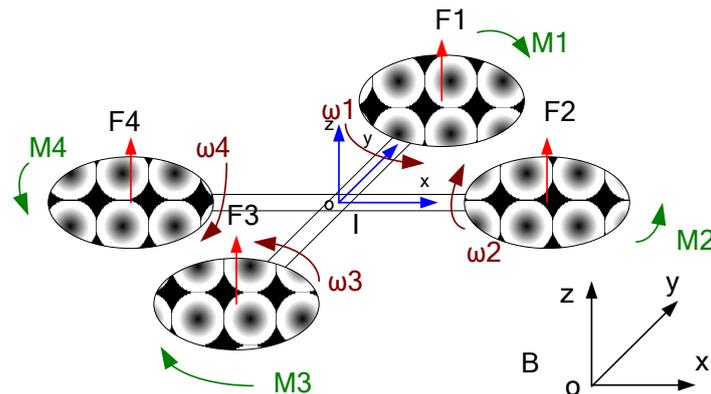

fig 5.2 structure of the vehicle

The quadrotor UAV is an under actuated system with 6 DOF and 4 inputs. The inputs are the speed of the 4 propellers. The propellers generate 4 thrust named F_1, F_2, F_3 and F_4, and 4 torques named M_1, M_2, M_3 and M_4. Based on the literatures[10-12], the linearized model of the system is given by:

$$
\begin{cases}
\ddot{\phi} = \dfrac{1}{I_x}\left\{\dot{\theta}\dot{\psi}\left(I_y - I_z\right) + dU_2\right\} \\[2mm]
\ddot{\theta} = \dfrac{1}{I_y}\left\{\dot{\phi}\dot{\psi}\left(I_z - I_x\right) + dU_3\right\} \\[2mm]
\ddot{\psi} = \dfrac{1}{I_z}\left\{\dot{\theta}\dot{\phi}\left(I_x - I_y\right) + U_4\right\} \\[2mm]
\ddot{x} = \dfrac{1}{m}\left\{\left(\cos\phi\sin\theta\cos\psi + \sin\phi\sin\psi\right)U_1\right\} \\[2mm]
\ddot{y} = \dfrac{1}{m}\left\{\left(\cos\phi\sin\theta\sin\psi - \sin\phi\cos\psi\right)U_1\right\} \\[2mm]
\ddot{z} = \dfrac{1}{m}\left(\cos\phi\cos\theta\right)U_1 - g
\end{cases}
\tag{5.1}
$$

where U_1, U_2, U_3 and U_4 are the control value for height, roll, pitch and yaw channels. They are linear combinations of the 4 thrusts generated by 4 propellers:

$$
\begin{bmatrix} U_1 \\ U_2 \\ U_3 \\ U_4 \end{bmatrix}
=
\begin{bmatrix} F_1 + F_2 + F_3 + F_4 \\ F_4 - F_2 \\ F_3 - F_1 \\ F_2 + F_4 - F_3 - F_1 \end{bmatrix}
=
\begin{bmatrix} k_p \displaystyle\sum_{i=1}^{4} \omega_i^2 \\ k_p(\omega_4^2 - \omega_2^2) \\ k_p(\omega_3^2 - \omega_1^2) \\ k_d(\omega_1^2 - \omega_2^2 + \omega_3^2 - \omega_4^2) \end{bmatrix}
\tag{5.2}
$$

Where k_p and k_d are the lift coefficient and torque coefficient respectively.

(2) Simulation

To reduce the risk, we simulated the flight controller by simulink before actual tests. The results of height channel and roll channel are shown in fig 5.3 & 5.4, where the initial status is: $x_0 = 0$, $y_0 = 0$, $z_0 = 0$, $\phi_0 = 0$, $\theta_0 = 0$, and $\psi_0 = 0$, and the desired status is: $x_0 = 0$, $y_0 = 0$, $z_0 = 1$, $\phi_0 = 0$, $\theta_0 = 0$, and $\psi_0 = 0$.
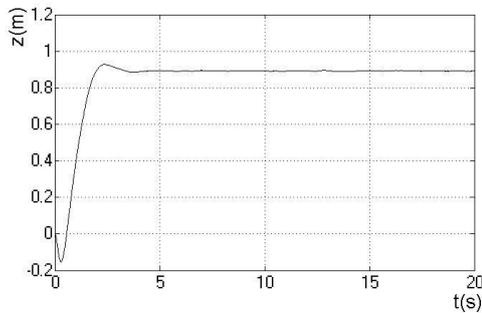

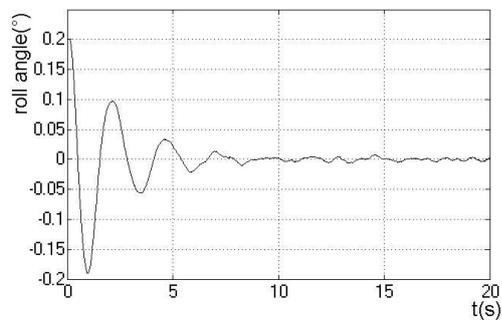fig 5.3 simulation result for height channel   fig 5.4 simulation result for roll channel

VI. Testing

The environment same as the real environment of the mission is built and the aircraft is tested in it. Attitude control and position control have been finished and the data is obtained during the tests and are shown in fig6.1. Furthermore, more other tests such as entering into the window as shown in fig6.2.
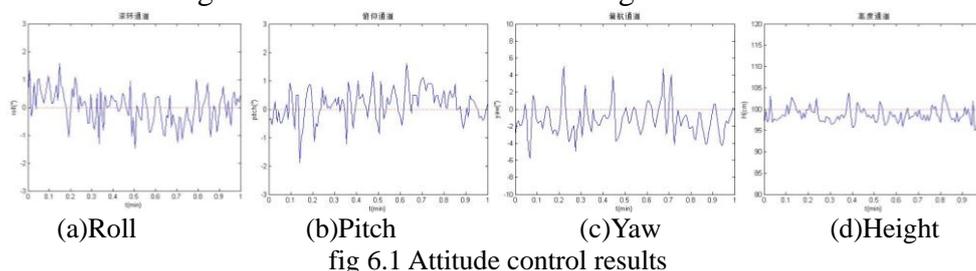

| (a)Roll | (b)Pitch | (c)Yaw | (d)Height |

fig 6.1 Attitude control results

fig6.2 enter into the window

VII. Conclusion

In this paper, the technical details of a quadrotor system are presented, and it can explore unstructured indoor areas, detect and replace a specific USB flash disk, without rely on any external navigation aids. The quadrotor platform with three subsystems is developed. The information from the laser range finder and ultrasonic range finder is used to perceive the environment. Two video cameras are mounted on the vehicle, which are used to detect specific targets. The frontward one is used to detect the target door, while the downward one is responsible for USB disk identification. A simple manipulator is designed to replace the USB flash disk. An FSM based decision algorithm is introduced to guide the vehicle complete the task.

So far, FSM and control architecture development hace been finished, corresponding test and simulation are currently in progress. The CAUC Aerial Robotic Team intends to compete in the 2013 IARC with this vehicle.

Acknowledgments

References

[1] ZHAN Lei, HE Renqing, XIE Yang, LONG Yan. Intelligent navigation system based on four-rotor micro UAV[J]. Electronic Measurement Technology.

2011,34(6):1-3.

[2] WANG Xu. The key technologies of the four-rotor aerial vehicle in the transmission line inspection[D]. Baoding: School of Electrical & Electronic Engineering, 2011.03.

[3] YANG Yungao, XIAN Bin, YIN Qiang, LI Haotao, ZENG Wei. Current Research Situation of Frameworks and Control of Quadrotor Unmanned Aerial Vehicles[C]. Proceedings of the 30th Chinese Control Conference. July 22-24, 2011, Yantai, China.

[4] Samir Bouabdallah, Andre Noth, Roland Siegwart. PID vs LQ control techniques applied to an indoor micro quadrotor[C]. Proc of the 2005 IEEE International Conf on Robotics and Automation. Barcelona, Spain:ICAR'05.2005.

[5] Yu J X, Cai Z X, Duan Z H. Fuzzy likelihood estimation based map matching for mobile robot self-localization[C]. Lecture Notes in Artifical Intelligence (ICNC06-FSKD06). Xian, China, 2006:846-855.

[6] H. Bay, T. Tuytelaars, and L. Van Gool. Surf: Speeded up robust features[C]. European Conference on Computer Vision, 1:404-417, 2006.

[7] M. Brown and D.G. Lowe. Invariant features from interest point groups[C]. British Machine Vision Conference, Cardiff, Wales, pages 656-665, 2002.

[8] D. G. Lowe. Distinctive image features from scale-invariant keypoints[J]. International Journal of Computer Vision, 60(2):91-110, 2004.

[9] Pawlak Z. Rough classification[J]. Int J Man Machine Studies, 1984, 20(5): 469-483.

[10] LI Hang. Study on real-time control system for quadrotors[D]. Dalian: Dalian University of Technology, 2010.12.

[11] Erginer Bora, Altug Erdinc. Modeling and PD control of a quadrotor VTOL vehicle[C]. Proc of the 2007 IEEE Intelligent Vehicles Symposium. Istanbul, Turkey:IEEE,2007:894-899.

[12] Ly Dat Minh. Modeling and control of quadrotor MAV using vision based measurement[J]. IEEE Trans. Circuits Syst, 2010, 33(4): 70-77.