Micro Air Vehicle's Motion Control and Autonomous Navigation Technology in Indoor Environment

Zhijun Bai, Yangfeng Ji, Shenglu Zhou, Dong Liang, Liaoni Wu, Qi Lin*

Xiamen 361005, China

ABSTRACT

This paper presents an autonomous four-rotor aircraft, known as Quad-copter, capable of avoiding obstacle and detecting and replacing the USB flash disk without GPS. Ultrasonic sensor is utilized to fix the flying height, thus the aircraft can fly in a plane. Laser range finder is utilized to create Simultaneous Localization and Mapping (SLAM) and plan route, avoid obstacle according to local map, search and locate door frame or the center of window as temporary target. A visible light camera is mounted on a rotating holder, which has two degrees of freedom rotation, and the holder is located at the base of the vehicle. When the camera is in the horizontal plane it's utilized to detect the target room without searching the whole building. Finally, the aircraft enters the security chief's office, locates the flash disk with the camera down, replaces it and flies back. Test shows that the four-rotor aircraft in this paper can fulfill every single mission.

1. ITRODUCTION

Four-rotor aircraft is a kind of multi-rotor aircraft driven by four motors. The torque and thrust characteristics will change with the change of speed and attack angle of one or more motor, thus the motion control is realized. Four-rotor aircraft has smaller propeller than the traditional one-rotor aircraft, and the thrust generated by the former will achieve better static hover. In recent years, four-rotor aircraft is widely employed as a solution to unmanned vehicle due to its superior features such as smaller size, easier to control, and higher payload. As a result, four-rotor aircraft is widely utilized in both civilian and military field such as aerial photography, advertising, traffic patrol, anti-terrorism and local theater reconnaissance. However, the biggest advantage of four-rotor is indoor flight.

This paper illustrates the technological details of our four-rotor aircraft, including hardware system and conceptual solution, which is designed to be Xiamen University Team's entry for 2013 International Aerial Robotics Competition. Via various sensors mounted on the bottom and the top, the aircraft will implement sort of mission like obstacles and surveillance cameras avoidance, self navigation, target identification and the specific USB flash disk replacement.

1.1 Statement of the problem

The IARC 2013 requires teams to apply completely autonomous aircraft, the takeoff weight of which cannot be over 1.5kg. The aircraft should be 3 meters away from the starting point, passing through an about 1 square meter window to enter the building. When the aircraft searches for the flash disk, besides avoiding obstacles such as walls, pillars and furniture, it also needs to keep away from some visible security systems, including the mobile surveillance cameras installed outside the window.

The whole task must be finished within ten minutes. Once the mission begins, the timer in the MPC starts to work. Mission fails ten minutes later, the self-explosive device will be triggered at that moment.

1.2 Conceptual solution

*Corresponding author: Qi Lin, Department of Aeronautics Xiamen University , Xiamen, China. qilin@xmu.edu.cn

The micro four-rotor aircraft, whose fuselage is made of carbon fiber to lower its weight, is driven by four brushless motors. Integrated flight control system, based on MPC, and classic PID is applied to control flight attitude. Algorithm of intelligent obstacle avoidance and path planning are integrated into the guidance system. The system stabilizes the aircraft with attitude sensor, determines height with ultrasonic ranging, achieves obstacle avoidance with ranging laser range finder, designs planning path through adding of monocular visual aids identification cipher text, and locates the target with monocular 3D stereo vision matching, as shown in Figure 1.

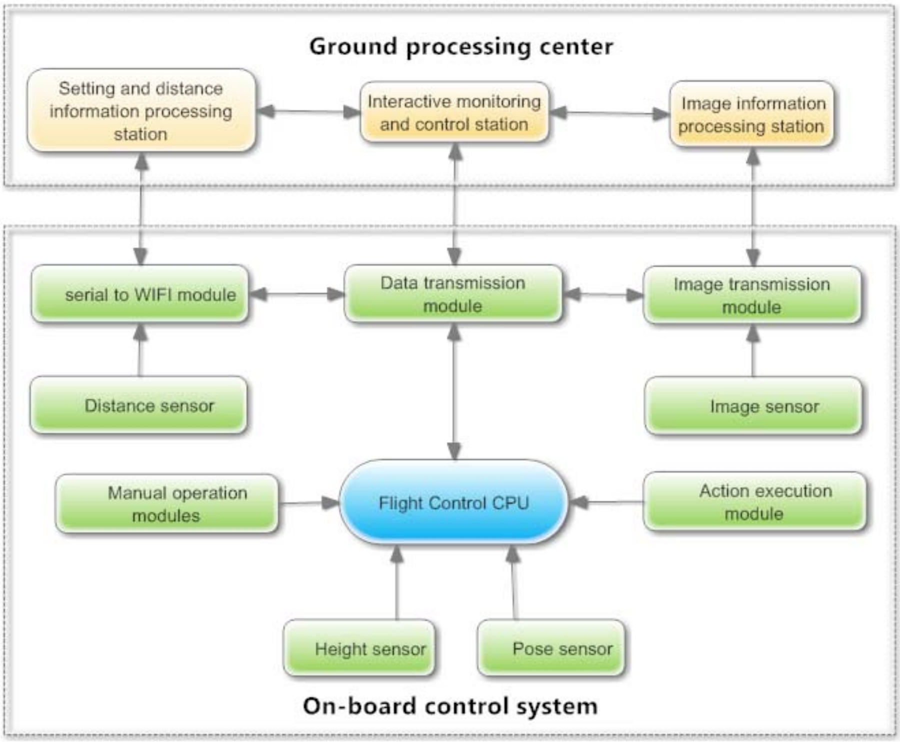

Figure 1. Four-rotor aircraft architecture

2. AIR VEHICLE

2.1 Hardware system

The four-rotor aircraft taking part in this competition uses carbon fiber to make four shaft frames and employs hollow design to lower the aircraft's weight and improve efficient payload. It is driven by four brushless motors, as shown in Figure 2. The four rotor wings, all in the same structure and size, are symmetrically mounted in the front, rear, left and right side and in the same horizontal. Differences between of torque generated by pairs of motors are employed to realize sort of attitude and stability control.

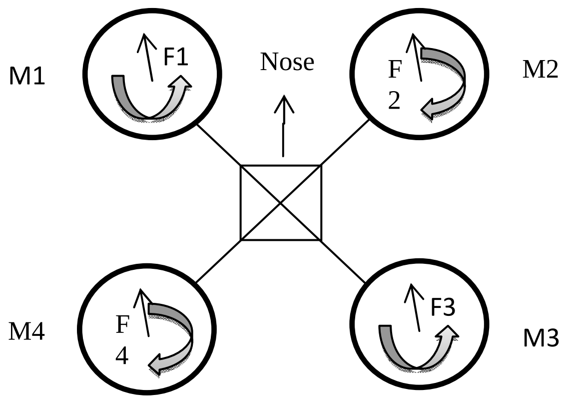

Figure 2. Structure of the four-rotor aircraft

The flight control panels as well as the attitude transducer are installed in the center of aircraft, and the ultrasonic sensors are mounted at the bottom of the aircraft to get the real time height of the aircraft, as shown in Figure 3. 2D laser range finder, installed in the top middle of the body, can capture the distance information within 240 degree, and the measurement plane is above the propeller. The monocular camera, set on the rotating head in front of the base body, contributes to collecting information of the disk. The rotating head can rotate both horizontally and downwardly. Battery installed below the aircraft stabilizes the aircraft and makes the control easier.

Figure 3. Image of the four-rotor aircraft

2.2 Indoor navigation system

Instantaneous feedback position information, together with information of distance from the ultrasonic sensors on the bottom, is calculated to obtain the vertical flight level, t hen altitude of the four-rotor aircraft is controlled according to the received data. 2D laser range finder obtains distance information of the surrounding, combines which with real-time attitude information, simultaneously locates the robots and creates map(SLAM[1,2,3]), and creates real-time 2D map by filtering, classification, feature extraction of the former information[4]. The point cloud data can be utilized to realize obstacle avoidance and the local path planning and constantly matching and global maps creation, as shown in Figure 4. The flight control uses the monocular camera to recognize the password information around the door, identifies the visual cipher text type according to the template matching algorithm, decides whether to enter the door or which one is the Flash disk storage room, and then calculates the yaw angle corresponding with the cipher text center point in order to enter the correct door. Once the room with the Flash disk is matched, the aircraft will enter the room and start to search the Flash disk, calculate Flash disk position and orientation relative to the camera with 3D template matching, determine pose of the robot and the Flash disk using hand-eye calibration. Finally, the aircraft returns the starting point according to a global map.

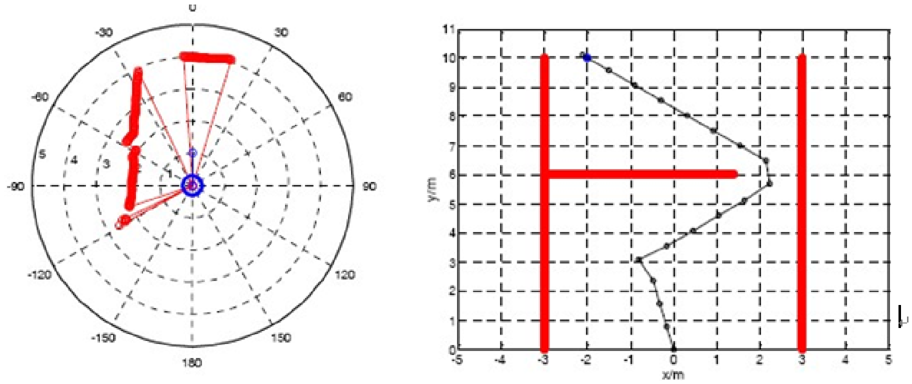

Figure 4. Obstacle avoidance and map display

2.3 Control strategy

Height information, collected by the ultrasonic sensor, together with distance information of indoor surrounding collected by the 2D laser range finder, is utilized to control the relative position of the aircraft indoor environment. The main strategy is to maintain the aircraft, after it takes off vertically, at certain height, the initial value of which is set right to the center of the window. Running the window procedure, calculating coordinates of the center of window according to the data collected by the laser range finder, the aircraft flies to one meter in front of the center of the window in a short time. By judging whether the headlight is open or not, the surveillance cameras could be avoided. While the aircraft flies back to one meter in front of the center of the window again, the corridor procedure starts to run.

3. PAYLOAD

3.1 Sensors

The four-rotor aircraft contains four sensors, a pose sensor, an ultrasonic sensor, a laser range finder and a CCD camera, as shown in Figure 5.

Figure 5.Various sensors

XSENS pose sensor: MT SDK, standard full range-50m/s2, Bias repeatability-0.03 m/s2, as is shown in fig. 5(a). Ultrasonic sensor SRF02: detection range-15cm to 6m, sensitivity-Detect 3cm diameter broom handle at > 2 m. Hokuyo Laser Range Finder: URG-04LX scans a plane around its vertical axis to obtain a set of range data. Its measurement range is from 20mm to 4094 mm and the angular scanning profile, shown in fig. 5(c), is the frontal 240 degrees divided into 682 steps .i.e. its angular resolution is about 0.35 degree.

3.2 Target identification

During flight in the corridor, the laser radar is utilized for real time obstacle avoidance and door frame searching [5,6,7]. The idea of obstacle avoidance is to select data within two meters, and the range within two meters is thought to be feasible. Width of feasible range is calculated to decide whether the aircraft can pass it. If there are more than one feasible range, the one in the front is the first choice, and right direction is always prior to the left if the aircraft can fly to both right and left[8], as shown in Figure 6.

Once the door frame is detected in the hallway, the aircraft will suspend at one meter in front of the center of the frame and check size of the frame. The aircraft won’t enter the frame if it is too small, otherwise it will try to recognize the password near the frame. For Ministry of Torture password, no enter, and for Security Compound password or without password and, enter and continue to search door frame, exit to the hallway if frame is not found. The Flash disk searching procedures will not run until the room of the security officer with cipher text is found.

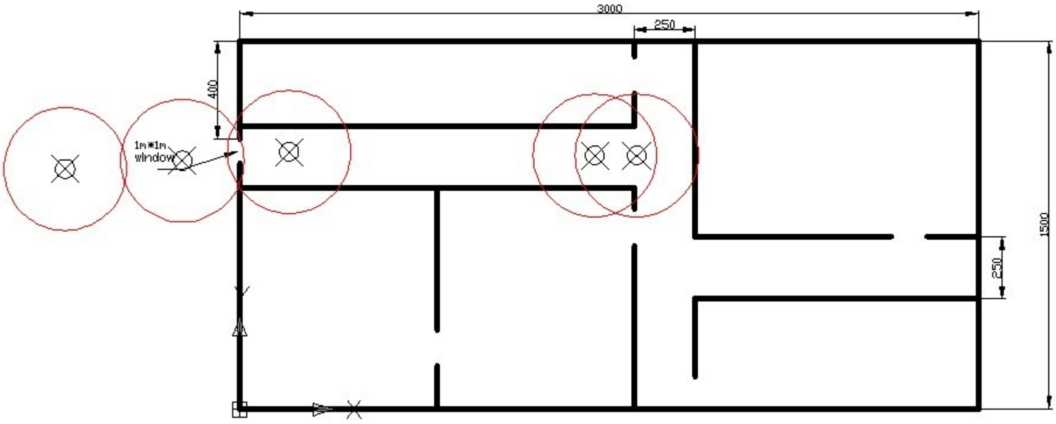

Figure 6. Illustration of obstacle-free in the corridor

When the aircraft enters the room of the flash disk, the information captured by the camera will be utilized to locate objects similar with a desk, then the aircraft flies towards the desk, runs flash disk 3D matching procedure, calculates position and orientation of the flash disk. 3D matching is based on the 3D configuration matching, 3D shape of the Flash disk must be created in advance and the template must be trained.

If the aircraft is over the desktop, the flight control will be canceled, and the aircraft will capture the flash disk accurately and throw the false flash disk on the desk simultaneously. Sticky tape is mounted at the bottom to stick the flash disk. Then the aircraft will fly back to the take-off point as soon as possible.

Once mission begins, the timer in the MPC starts to work. Mission fails ten minutes later, and the self-explosive device will be triggered at that moment.

4. TESTING

In order to test the four-rotor aircraft, the following experiments were done:

4.1 Experiment preparation

Switch flight control to manual remote state, set altitude and the PID parameters, observe stability of the vehicle. In the study of four-rotor unmanned aerial vehicles, the PID algorithm control idea is adopted and respectively applied in the attitude control and position control. Test shows that this algorithm performs well in attitude control and height control.

4.2 Experiment of window-entering

Window-entering procedure mainly contains regional segmentation and feature extraction. Regional segmentation stage mainly completes characteristics of pattern classification and recognition. Features extraction phase mainly fulfills kinds of determination of model parameters and the extraction of feature points.

For each frame distance data, the laser scanning points are divided into different regions. If the distance between two consecutive scanning points is less than a threshold, the two scanning points belong to the same region, else the data will be separated from this place.

There are several important features in the laser radar scanning data: the break point, corner, straight line, arc, as shown in Figure 7.

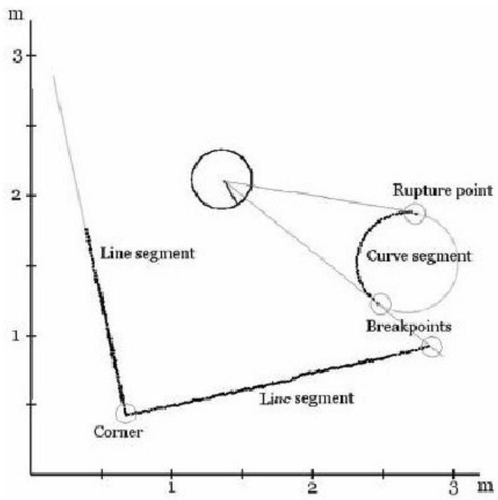

Figure 7. Several important features of data scanned by laser radar

Switch flight control to autonomous state. The vehicle flies at certain altitude, test the window-entering performance according to the window-entering procedure. The data collected by the laser range finder is calculated to get the center position so that the aircraft can fly towards the center of the window, as shown in Figure 8.

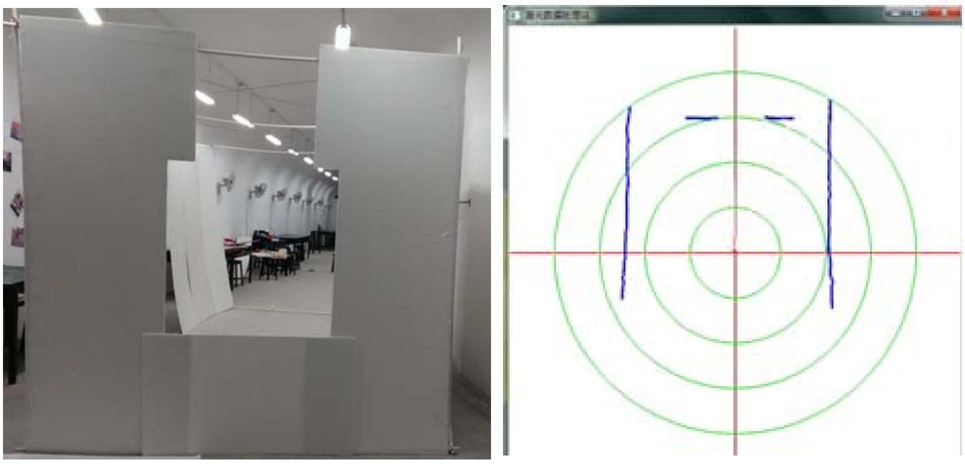

Figure 8. Test site and the corresponding map

4.3 Experiment of searching the door in corridor.

When local map and the position of the robot are unknown in advance, the robot needs to incrementally build environment navigation map, which is utilized to synchronize its position.

In recent years, the mobile robot Simultaneous Localization and Mapping (SLAM) technology is considered as one of the most effective technology to solve autonomous navigation of mobile robot with unknown environment and sensor information under uncertainty. SLAM, based on Iterative Closest Point (ICP) matching, is an algorithm that is used to calculate the rotational and transformation matrix between two scans. Scan matching algorithm is mainly derived from ICP algorithm and its improved algorithm. The results are shown in figure 9.

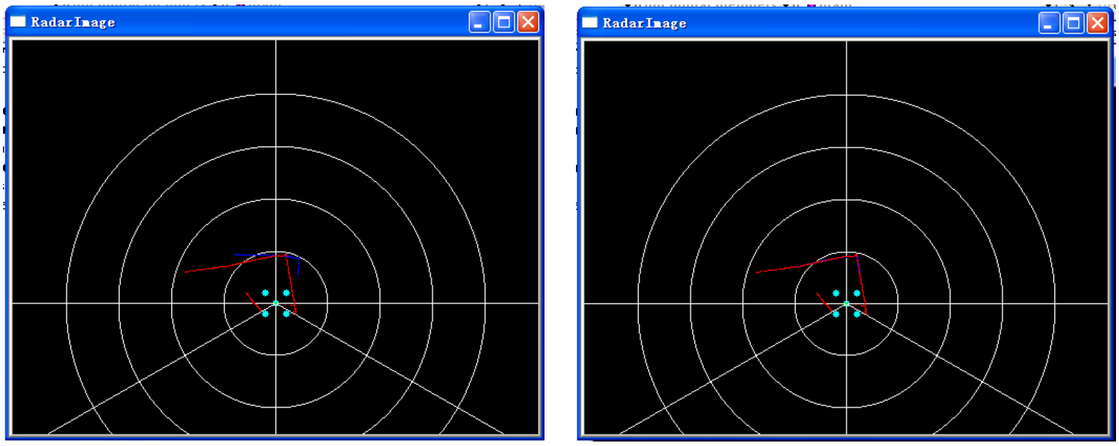

Figure 9. Two scanning and the results ICP matching

However, the algorithm assumes that the robot's initial position and deviation between the real-position of robot is small enough to achieve the global optimal matching, as shown in Figure 10. The pink points represent the location of robot.

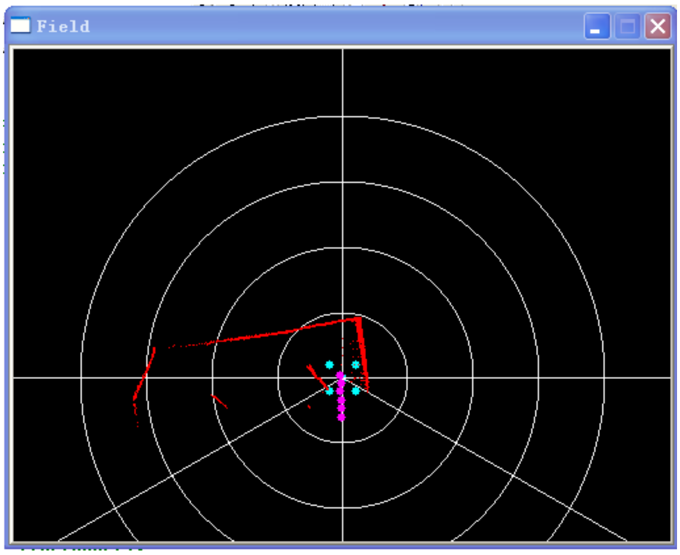

Figure 10. The global map

4.4 Experiment of searching and matching the password.

In general, for 2D template matching there are three kinds of matching methods, Component-based, Gray-Value-based and Shape-based. Due to the shape of the cipher text known in advance, the method based on shape matching is adopted in this competition. To create a matching model, a region of interest that covers the template in the training image must be specified.

According to the shape of the cipher text, an outline of the cipher is extracted to create the template. The layers of pyramid are set up to reduce the search time. The number of pyramid is set to 3, as is shown in figure 11. Then the affine transformation matrix is executed on the template to search a cipher in the image. Finally, with the calibration camera， the angles of cipher text, relative to the camera, are returned, as shown in figure 11. If one or multiple objects are found, their poses (rotation, and scaling) or 2D projective transformation matrices together with a score are returned, thus the poses of cipher text can be used to find door frame close to the cipher.

Figure 11. Password identification

4.5 Experiment of searching and matching the flash disk.

3D matching method is utilized to search and match the flash disk. The aim of 3D matching is to find a specific 3D object and determine its pose, i.e., the position and orientation of the object in space. There are two kinds of 3D matching method, shape-based 3D matching and surface-based 3D matching, and the former is utilized in this paper.

A 3D shape model is generated from a 3D computer aided design (CAD) model, which must be available in DXF, OFF, or PLY format. The 3D shape model consists of 2D projections of the 3D object seen from different views, as shows in Figure 12. Having access to the 3D object model, the approach-specific 3D model can be created, which prepares the 3D object model for the specific 3D matching approach. A 3D shape model is generated by computing different views of the 3D object model within a user-specified pose range. The views are obtained by placing virtual cameras around the object model and projecting the 3D object model into the image plane of each camera position.

Before search, several parameters can be set to control the search process. The procedure returns the pose of the matched model and a score that describes the quality of the match, as shown in Figure 12.

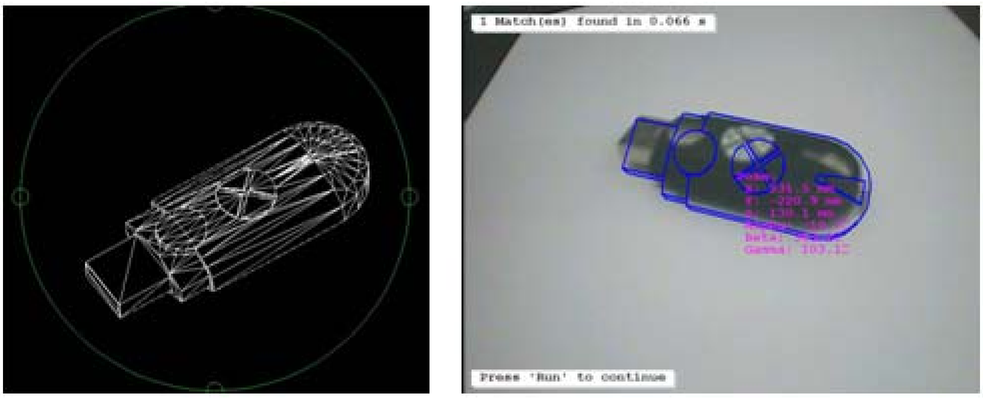

Figure 12. 3D model of the flash disk and the pose matching result

5. CONCLUSION

A solution of MAV autonomous navigation in unknown indoor environment without GPS is presented. Various on-board sensors ensure the aircraft to implement obstacle avoidance, create real-time map, identify the password, locate the flash disk and replace it. The experiment results show that so far our four-rotor aircraft can fulfill every single mission. Two problems, data transmission occasional delay and instability of the aircraft, will be solved before the competition.

REFERENCE

[1] Dissanayake G, NewmanP, Clark S.A.Solution to the simultaneous localization and maP building (SLAM) Problem [J].IEEE Trans on Roboties and Automation, 2001:229-241.

[2] Guivant J E, Nebot E M.Optimization of the simultaneous localization and maP-building algorithm for real-time imPlementation.IEEE Trans.Robotics and Automation [J].2001, 17(3):242-257.

[3] Huang S,Wang Z.Time oPtimal robot motion control in simultaneous localization and maP building(SLAM) Problem[C].Proceedings of the IEEE/RSJ International Conference on Intelligent Robots and Systems,2004:3110一3115.

[4] H Choset,K Nagatani.ToPological Simultaneous Loealization and MaPPing (SLAM) Toward Exact Localization without ExPlicit Localization[J].IEEE Transaetions on Robotics and Automation,2001:125-137.

[5] J. Borenstein, and Y. Koren, Obstacle avoidance with ultrasonic sensors, IEEE Journal of Robotics and Automation,4(2): 213-218, 1988.

[6] J. Borenstein, and Y. Koren, Real-time obstacle avoidance for fast mobile robots, IEEE Trans. Syst. Man Cybern.,19(5): 1179-1187, 1989.

[7] P. Veelaert, and W. Bogaerts. Ultrasonic potential field sensor for obstacle avoidance, IEEE Transactions on Robotics and Automation, 35(4): 774-779, 1999.

[8] A. Elfes, Sonar-based real-world mapping and navigation,IEEE Transactions on Robotics and Automation, RA-3(3):249-265, 1987.