

Implementation of a Mobile Device Controlled Multi-behavior Interactive Mobile Robot Over MR Technology

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Abstract—This paper presents a mobile-device controlled multi-behavior interactive mobile robot. The proposed mobile robot is implemented under the technique of mixed reality. The proposed mobile robot has three basic locomotion behaviors that enable the mobile robot moving in a complex environment. The three basic interactive behaviors are: target navigation behavior, face tracking behavior, and obstacles avoidance behavior. The three behaviors are designed by the fuzzy controller, respectively. For people convenience, a hand held mobile device is introduced as a user interface to interactive with the mobile robot. Experiments show that the proposed behaviors are well designed. The proposed robot system and control rules are been conducted in good performance and good reliabilities.

Keywords —*Mobile Robot, Face tracking, Obstacle avoidance, Target Navigation, Mixed Reality, PDA*

I. INTRODUCTION

Robotic technologies have been developing for decades and the relative techniques are introduced to industrial applications, which change human being daily life and let us rely on them. There are many types of robots with different shapes that have been proposed for various demands. Those robots are: industrial application manipulators, mobile robots, quadruped robots, biped robots, and many others. The stability control theories of the robots are still developing, and too far to say a fully functions' human-like robot implementation. It is, nevertheless, that the mobile robot is stable during power off or stopped moving. Since the interactive mobile robot is controllable in the static control mode, it has been enthusiastically developing in the current decade [5-7] and has been introduced to develop the interactive robot. These kind of robots can move easily on a plane environment and can act as an assistant in daily life. An autonomous robot guide is, for example, well suited in places such as enterprise exhibitions, museums, libraries, schools, hospital, etc. The major issues of a mobile robot locomotion are obstacle avoidance, target searching, navigation, location

identification, and interaction with human beings, etc. Actually, the rail-guided autonomous robots have been used in factories or offices area, for example, the semiconductor FAB. It is, however, those environments are clear and organized for the cyclic route autonomous robots. Nowadays, the autonomous robot has been introduced into the society environments; there exists many challenges of the autonomous robot which can smoothly move in crowds or can become an affiliate of the human being society.

The autonomous navigation is the major ability of an intelligent mobile robot. An autonomous robot can avoid obstacles on the path and smoothly move to the target spot. There are many control rule choices. One of the control rules, the fuzzy controller, has been introduced to implement this ability in several previous researches. The fuzzy controller can be used to avoid obstacles; nevertheless, it may not work in an unknown environment, especially in a dynamic environment. There are some patterns of obstacles that may lead the mobile robot to get stuck in a same place; those include dead-ends, moving people, and narrow alleys, etc. These issues can be partially conquered by behavior-based methods; the proposed methods include wall-following, virtual target, potential field, VFH serials, dynamic windows, and many others.

An interactive robot would hold many behaviors that mimic human beings. Those behaviors can be implemented by environments detecting and recognizing algorithms through various sensors. The behaviors include vision contact behavior, voice detection behavior, obstacle avoidance behavior, tactile reflection behavior, object following behavior, etc. There are many proposed papers [1-3] that showed the face tracking techniques have been made many discussions and have been conducted several achievements. In [4], they used a microphone and face tracking skill to give one of the solutions for the interactive robot. Sonar sensors have been introduced to find the obstacles in many researches [8, 9], and it can be integrated with vision information. With the sensor fusion concept, the more various sensors' information combined together the more human-liked of the robot is. Furthermore, the fuzzy controllers have been used in robotic control and have been designed for the mobile robots [10, 11]. In this paper, an interactive robot with face tracking behavior and obstacle avoidance behavior is proposed. The behavior controllers

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have been implemented in a fuzzy control method and the hands-on practice has been implemented by mixed reality technique.

It is, however, that the robot system is not friendly for people. People are used to use the personal digital assistant (PDA) for assisting their daily life. If the mobile robot can be interactive with people through the PDA mobile device, then they would get more confidence to dominate the mobile robot. In this paper, the proposed PDA module offers a user interface that user can draw the moving path for the mobile robot and can also read the experience of the mobile robot moving in the complex environment. Shortly, that the PDA module shows the obstacles in the environment on the screen, and let the user know the environment layout, even in an unknown place.

This paper is organized as follows. In section 2, the system structure is discussed in detail. In section 3, robot's kinematics equations and MR (Mixed Reality) scene mapping equations are shown. In section 4, the behavior controller design for the interactive mobile robot is presented. In section 5, the experimental example is given to show the system demonstration. Finally the conclusions are briefly given in the final section.

II. SYSTEM DESIGN

The proposed remote autonomous robot can navigate in a complex environment. The hardware of the robot includes a wheeled mobile robot platform, a body with 1 DOF arm, and a head with CCD eyes. The PDA is used to interactive with the mobile robot. The software can be separated into two parts: one is the locomotion controller in the wheeled robot, another is the mixed reality based behavior controller and virtual scene implementation in the remote computer (MR Host). The system architecture is shown in Fig. 1.

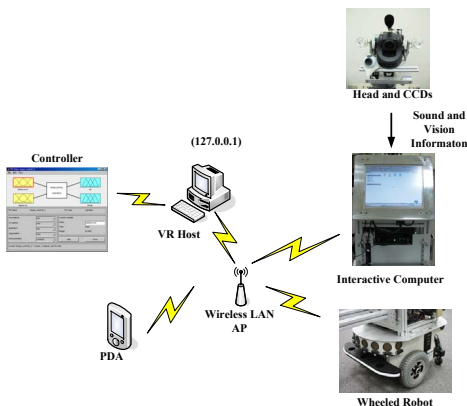


Fig. 1. System Architecture

A. The Hardware Platform

The proposed mobile robot is composed of a wheeled robot, an interactive computer, and a head. The wheeled robot has 8 sonar sensors at the front and rear of the wheeled robot body, respectively. The emergency stop procedure is implemented by the mechanism of the front end bumper sensor and wheels

overload events. This mobile robot is controlled by a DSP+FPGA board, and can communicate with remote commander through a wireless LAN. Inside the body of the robot, an interactive computer is installed. This computer is used to implement the vision and sound detection and processing algorithm. The vision and sound information will be processed in this computer; afterwards, the abstract information is sent to the MR host. The robot's head with two DOF can pan and tilt. The head motors can take the CCDs to face to the designate direction; for example, implementation of face tracking behavior.

The MR host is a high performance computer; both the Virtools engine and Matlab engine are executed on this computer. The Virtools engine is introduced to implement the MR scheme and to develop the navigation behaviors in this study. Through the LAN local host, the Virtools engine communicates with the Matlab engine, and through the wireless LAN it can communicate with the remote robot. The interactive computer is used to implement the vision recognition and voice detection.

B. The Software Platform

The Virtools engine is introduced to construct our laboratory scene in the MR platform. On the other hand, the virtual mobile robot model is created by Maya 3D tool. The major characters in the MR scene are: the virtual mobile robot, the obstacles, and static furniture. It should be mentioned that the obstacles are dynamically placed on the MR floor according to the sonar sensors' feedback. Fuzzy rules are implemented in Matlab engine, and the sensors' inputs and the controller's outputs are queried from and sent to the physical world robot over the TCP/IP protocol, respectively. The vision recognition algorithm is implemented by OpenCV library, which can automatically detect the human face and immediately feedback the human face coordinates. The voice detection rules are used to detect where there is a sound in the local area near the robot. If there is a sound detected then the robot will be woken up; after that, the robot will move its head to search for the human face. The software integration structure include MR engine, Matlab engine, interactive sensors platform, mobile robot controller is shown in Fig. 2. The MR scene and the picture of the experimental environment are shown in Fig 3.

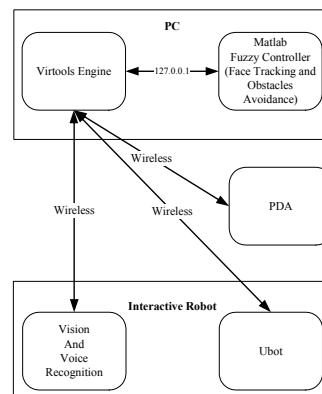


Fig. 2. The Software integration structure

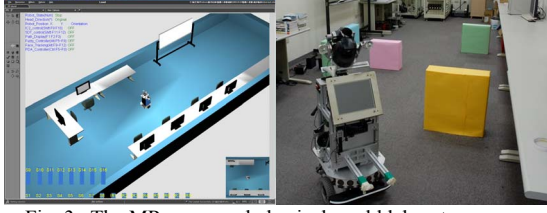


Fig. 3. The MR scene and physical world laboratory scene

III. THE KINEMATICS MODELING

The kinematics modeling of the mobile robot can be shown in the following equations. The center velocity of the mobile robot, V_c , is defined in (1) and the mobile robot rotation speed is defined in (2), respectively.

$$V_c = \frac{V_R + V_L}{2} \quad (1)$$

$$\dot{\theta} = \frac{V_R - V_L}{d} = \omega \quad (2)$$

The x-axis and y-axis directions' velocity can be found in the following,

$$\dot{x}_c = V_c \cdot \cos \theta, \quad (3)$$

and

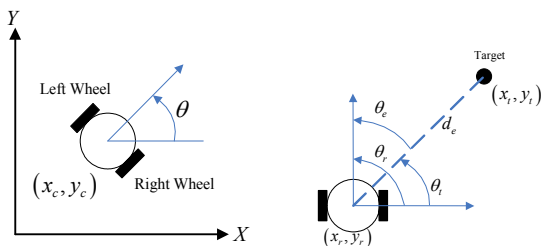
$$\dot{y}_c = V_c \cdot \sin \theta, \quad (4)$$

respectively. In this study, the mobile robot takes the motion commands as a point-to-point motion command. When the sensors platform gets the sensors information and send to the MR system, the MR system switches the motion control behaviors according to different environment events. The motion control behaviors are: face tracking, obstacles avoidance and target navigation. The point-to-point moving command of the mobile robot can be found in Fig. 4(b). The moving orientation command from original point to target point can be concluded to be θ_t . The remaining moving distance can be shown as d_e and the orientation error is θ_e .

$$\theta_t = \tan^{-1} \left(\frac{y_t - y_r}{x_t - x_r} \right) \quad (5)$$

$$d_e = \sqrt{(x_t - x_r)^2 + (y_t - y_r)^2} \quad (6)$$

$$\theta_e = \theta_t - \theta_r \quad (7)$$



(a) Definition of the locomotion model (b) Point to point moving model
Fig. 4 Robot's Kinematics Model

The robot behaviors are implemented in the MR engine; therefore, the behaviors can be recorded in the MR database. The MR scene can be created by the multimedia tools, but the characters performing and route representing between the MR scene and physical world should be transferred. It is, however, the MR engine and physical world coordinate system that can be transferred by the linear transformation. According to the physical world robot's sensors, CCD sensor, odometer and sonar sensors, feedback the characters performing route and obstacles placing position on the MR scene can be calculated by the transfer function. The transfer function is

$$\Delta P_{VR} = T \Delta P_{RW}, \quad (8)$$

where ΔP_{VR} represents the character's coordinate variation in the MR environment and ΔP_{RW} represents the robot's or obstacles' coordinate variation in the physical world environment. The 3x3 diagonal matrix T is a scaling matrix for transferring the physical world coordinate to MR environment coordinate.

IV. THE BEHAVIORS CONTROLLER DESIGN

A. Sensor Feedback Alignment

There are 16 sonar sensors on the mobile robot, the duty zones of the sonar sensors are defined in Fig. 5. Since the sonar sensor may take wrong distance information for the system, the noise has to be removed during the obstacle avoidance behavior process. In this paper, the orientation of the front of the robot has been divided into five duty zones to solve this issue. The adjacent sonar sensors are combined to be one sonar sensor by (9),

$$S = [SF \ SFL \ SFR \ SL \ SR]^T, \quad (9)$$

where $SF = \min \{s_4, s_5\}$, $SFL = \min \{s_6, s_7\}$, $SFR = \min \{s_2, s_3\}$, $SL = \min \{s_{10}, s_{16}\}$ and $SR = \min \{s_8, s_9\}$. The S represents the distance from the mobile robot to the obstacles in the five duty zones.

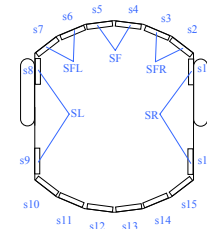


Fig. 5. Sonar sensors' duty zone definition

The CCD sensor with the OpenCV library is used to detect human faces. The image center is defined as the central position that the mobile robot faces human beings. The definition is shown in Fig. 6. When the human face is not on the image center or the robot deviates from the central position, the mobile robot needs to move to get the human

face back to the image center in both cases. It can be found that X-axis bias means the orientation miss taking and Y-axis bias means the distance between the robot and human beings. According to these relationships, the face tracking control factors can be decided as follows,

$$\begin{cases} I_d = -y + O_d \\ I_\theta = -x + O_\theta \end{cases}, \quad (10)$$

where I_d is the distance and I_θ is the orientation bias between robot and human beings. O_d and O_θ represents the offset calibration values of the mechanical structure.

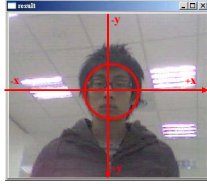


Fig. 6. The definition of the mobile robot central position

B. The Behaviors Arbitrator Design

There are three behaviors have been implemented in the proposed interactive mobile robot. The first behavior is target navigation, which can lead the mobile robot to the target spot under fuzzy control rules. Under the different fuzzy knowledge base design, the fuzzy control rules are also conducted on another two behaviors. The second behavior is obstacle avoidance behavior, which can take the mobile robot through the obstacles on the way to target spots. The third behavior is face tracking, which may ask the mobile robot to follow the human beings and keep a comfortable distance from human beings. Even just a mobile robot, it has the most important mission that must be executed at every moment. Therefore, the priority of the robot choosing behavior can refer to human beings behavior. The obstacle avoidance behavior takes the highest priority, and the face tracking behavior takes the second priority, and the target navigation has the lowest priority. Then the fuzzy controller switch can be designed by the following rule,

$$P_o > P_f > P_T \quad (11)$$

where P_o is the priority of the obstacle avoidance behavior, P_f is the priority of the face tracking behavior, and P_T is the priority of the target navigation behavior. The system behavior control block diagram is shown in Fig. 7.

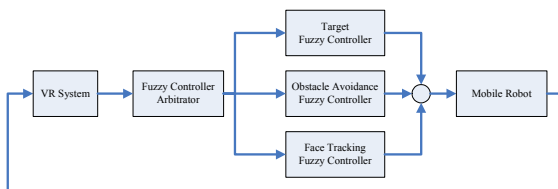


Fig. 7. System behavior control block diagram.

In Fig. 8, the software message flow chart is shown. The mobile robot sends the sonar sensors feedback and odometer

record to MR system through the wireless LAN. The interactive computer, on the tank of the mobile robot, sends the face coordinate and voice event feedbacks to the MR system through the wireless LAN, too. The MR system then makes its decisions to choose the robot's behavior. Afterward, the MR system passes those feedbacks to the behavior fuzzy controllers and gets the fuzzy controller's commands for the interactive mobile robot.

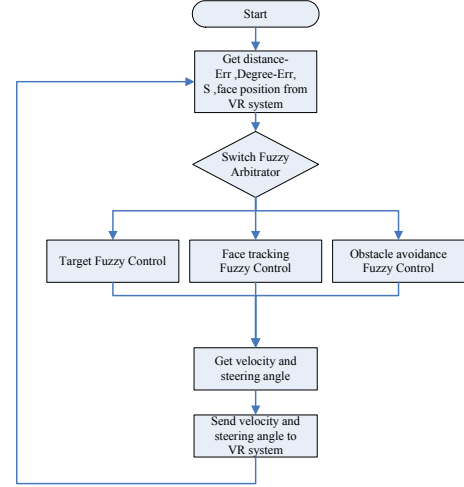


Fig. 8. Software message flow chart

V. THE EXPERIMENTAL EXAMPLES

The hands-on implementation is on a mobile robot, which is designed by ITRI. The mechanical architecture of the mobile robot is based on the UBot mobile robot, which is a wheeled robot. We integrated the UBot mobile robot with the body tank and head. In this study, we use sonar sensors and CCD sensor to detect the environment information. The front sonar sensors are used to get the obstacles' distance between the mobile robot and the obstacles. The side sonar sensors are used to follow the edge of the obstacle when the robot turns its orientation. The rear sonar sensors are used to detect if there is enough room for the mobile robot to back off. The back off behavior is executed when the mobile robot meets an impasse situation. In the impasse case, the mobile robot moves back off from the alley and set a virtual point to lead the robot escape away from the predicament. The microphone here is used to detect the voice around the mobile robot. When there is nothing to do, the mobile robot will lower its head; when it hears a voice then it will be woken up and rotates its head to search for a human face. This function, however, is to present that the mobile robot may play like human beings.

There are two experiment examples were shown here. In the first example, the mobile robot got a navigation mission and tried to move to the target spot. At beginning, the mobile robot was asked to move to the target spot 1. In the way to the target spot 1, the student ran into the environment and intentionally let the mobile robot to detect him. The mobile robot started interacting with the student. The interaction is that the mobile robot will follow the student and make it's possible to face the student. The student guided the mobile

robot to move to the obstacle area. As soon as the mobile robot found the obstacle, its behavior will be switched to be the obstacle avoidance behavior. This time, the mobile robot still had one mission to accomplish reaching the target spot 1. If there was no human begins' face detected again, then it will use the target navigation behavior and obstacle avoidance behavior to arrive at the target spot 1. Eventually, the mobile robot arrived at the final target. The experiment result is shown in Fig. 9.

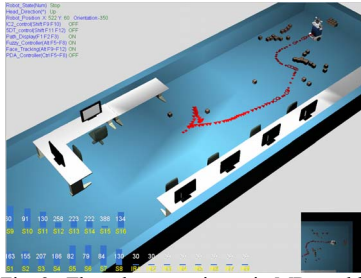


Fig. 9. The robot experience in MR world.

The triangle legends show that the mobile robot was led by the student's face, on Fig. 10. The circle legends show that the mobile robot was experiencing the obstacle avoidance behavior. The position error curve and orientation of target navigation error curve are shown in Fig. 11. The second experiment photo is shown in Fig. 14.

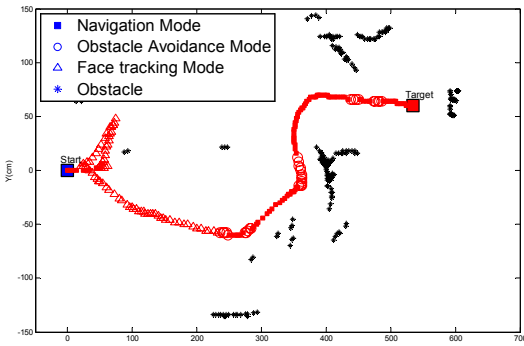


Fig. 10. Robot orientation, x-axis bias, and obstacle events curves

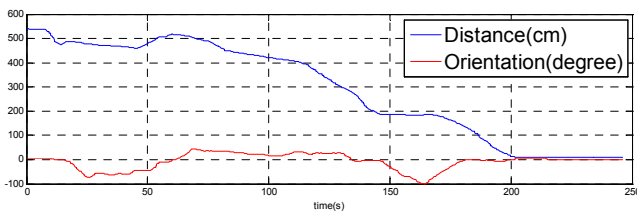


Fig. 11. The position error and the orientation error of target navigation

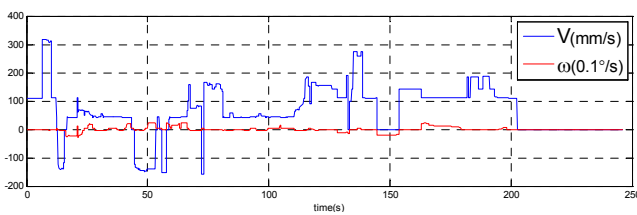


Fig. 12. Robot orientation, x-axis bias, and obstacle events curves

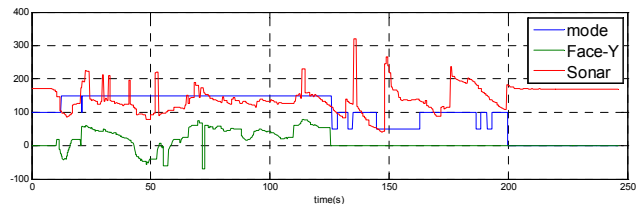


Fig. 13. Robot orientation, x-axis bias, and obstacle events curves



Fig. 14. Experiment photos

The second experiment shows the mobile robot is controlled by a PDA. The main-machine interface (MMI) of the PDA is shown in Fig. 15. One can select the path drawing mode to give a locomotion trajectory for the mobile robot. Once the trajectory was sent through the internet; the mobile robot started tracking the trajectory path and moving to the end point. The red line indicates the trajectory command, and the green line shows the trajectory tracking result, shown in Fig. 17 and Fig. 18. In Fig. 18, the upper figure in the right side, the blue line indicates the position tracking error, and the read line is the orientation of the mobile robot.

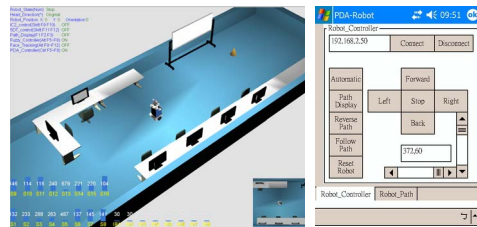


Fig. 15. PDA MMI

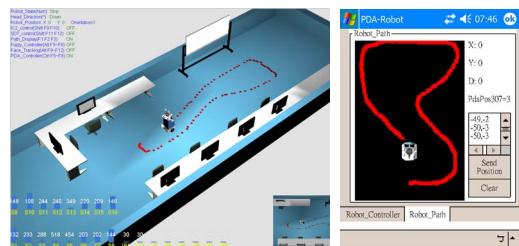


Fig. 16. A path trajectory is planned by PDA

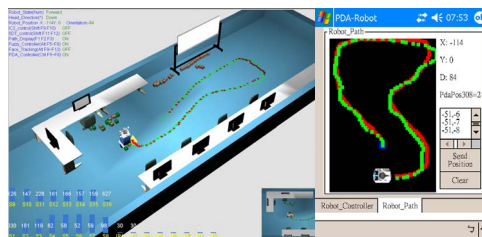


Fig. 17. Trajectory tracking result

VI. CONCLUSION

This paper proposed a remote controlled interactive mobile robot. The proposed mobile robot processes three basic behaviors that mimic from human beings. It is fair to say, the mobile robot is an intelligent robot, but it can change the three behaviors and use them to finish the missions. The PDA is introduced to this study for evaluating the possibility of implementing a remote control mobile robot. In this study, the system shows that the PDA may be used to be a user interface for interacting with the human beings. On the other hand, the mixed reality offers a great platform, which can play the motion simulation and behavior algorithms off line. It would not damage the physical mobile robot even we practice thousand times for finding the intelligent algorithms. Since this interactive mobile robot is developed on the mixed reality technique, the system may keep the study continuously. The future works are of implementing more behaviors to let the interactive mobile robot can be a helper in the world. Since the MR system can afford the multi-robots to play on it at same time, the research of the multi-robots society in it will be continued.

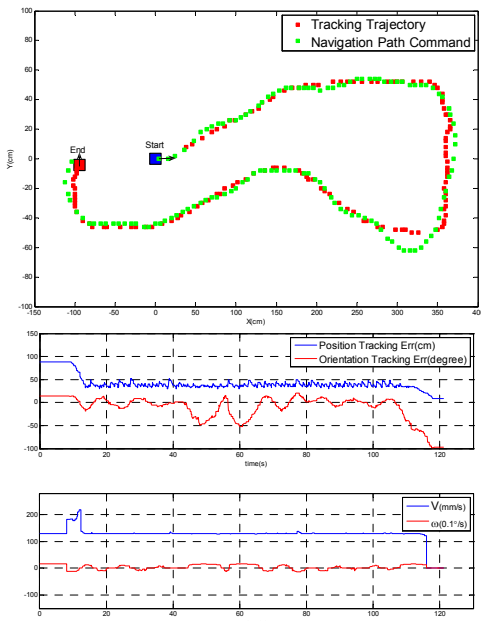


Fig. 18. Trajectory tracking data in detail

For the unknown environment testing, the user asked the mobile robot move to the front target. It is, however, there are two obstacles on the way to the target. The experiment showed that the mobile robot feedback the environment situation and the PDA system marked the obstacles on the screen immediately for the remote user. The experiment result can be found in Fig. 19 to Fig. 21.

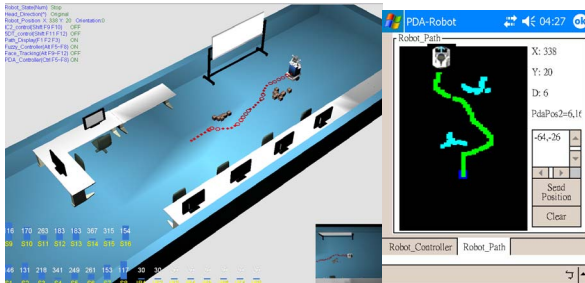


Fig. 19. The unknown environment locomotion experiment

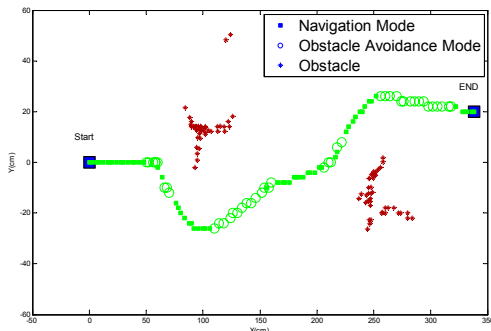


Fig. 20. Experiment data shown by the Matlab



Fig. 21. Experiment photos of the experiment two

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