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Mobile Robot Localization and Path Planning Using an Omnidirectional Camera and Infrared Sensors

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***Abstract*—In this paper, we propose a self-localization and path-planning method for mobile robot navigation. An omnidirectional camera and infrared sensors are used to extract the landmarks information of the environment. Due to the large field of view of the omnidirectional camera, the mobile robot can capture the rich information of the environment. The landmark features are detected and extracted from the omnidirectional video camera, so the robot is able to navigate in the environment automatically to learn the localization information and avoid obstacles by using infrared sensors. The robot system can then use the localization information to plan a shortest path to visit some particular locations prespecified by the user.**

I. Introduction

Consider the scenario in an exhibition in the future, a mobile robot will show you some paintings and explain the history about the painters. The robot should have some skills like human beings. It has to see and recognize the painting, know the locations of itself and the painting, and construct a map for its movement. It should also be able to plan a navigation path to access a specific painting. This scenario describes an exciting application of mobile robots, which is also the motivation of this work.

The autonomous mobile robots, such as indoor security robots [1], vacuum cleaner robots [2], weeder robots, are getting popular and evolve rapidly in human life recently.

The autonomous mobile robots can be roughly divided to two different types, the foot based and the wheel based. The development of foot based robot focuses on how similar it can be achieved between the robots and human beings, such as running, balance or facial expression. On the other hand, the design objectives of wheel based robots mainly focus on solving the problems related to localization, navigation and path planning. Thus, the foot based robot can be thought as an ultimate goal of autonomous robot systems. The wheel based robot is a convenient mobile platform used to develop some algorithms and applications such as sensor integration, visual computing and communications.

One of the most important problems of autonomous mobile robot research is self-localization. In this work, we attempt to localize the mobile robot itself by using only the omnidirectional vision system. Another critical problem of mobile robots is the path planning. Given a target position in the real scene, it requires that the mobile robot be able to move to the position in a *real-time intelligent mode*. In other word, the intelligent system must estimate a few paths which contain the possible roads. Based on those path, the mobile robot can move from its origin to the target position.

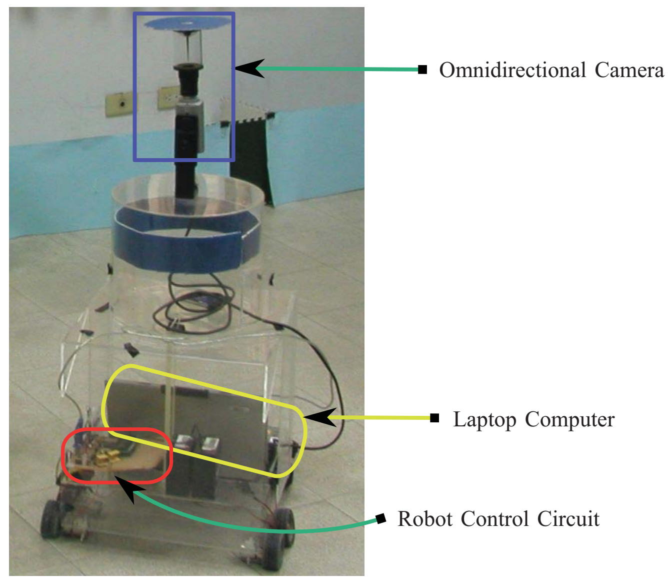

Fig. 1. The mobile robot is developed and used in this work. One omnidirectional camera is mounted on the top to detect the landmarks.

To solve the above problems, the mobile robot must equip with some sensors. There also must be some tasks that the mobile robot might learn and use the information collected from the sensors. In this work, we develop a mobile robot (see Fig. 1), and use omnidirectional vision for self-localization. The robot also uses two infrared sensors to avoid obstacles. The strategy of path planning is to estimate the shortest path that the robot might move from one position to another in a global map.

This paper is organized as follows. The previous and related works are describe in Section II. The mobile robot platform and system overview are shown in Section III. The basic principles of mobile robot localization and path planning are shown in Section IV. Finally, Sections V and VI give our experimental results and conclusions.

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II. Previous Work

The objective of localization is that the robot must determine its position in the environment. A commonly used approach is creating a global map and obtain the information of the environment from various sensors, such as laser range finder [3], ultrasonic [4], infrared [5] and vision, etc.

In the past few decades, many researchers have proposed self-localization techniques using computer vision systems. Lin and Lin [6] adopt a conventional stereo vision system to measure and track 3-D scene points with Harris feature detector [7]. The 3-D features are then used to calculate the location of the mobile robot and record the moving path. Jang et al. [8] localizes the mobile robot using an omnidirectional camera and simple landmarks with different colors. They also embed Extended Kalman Filter (EKF) to update the global map. Kruse and Wahl [9] mount a perspective camera on the ceiling of the indoor environment and use the camera to detect obstacles and feasible path. This captured image can be considered as a global map just like the view from a bird's eye.

Clerentin et al. [10] increase the localization accuracy by combining the omnidirectional camera with the laser range finder, especially in the 3-D architecture estimation. Geraerts et al. [11] and Kavraki et al. [12] represent the global map using "probabilistic road-map". They put a lot of nodes in the navigation space and connect the neighboring nodes if no obstacles among them. The distance is then calculated for each connected path. Finally, the mobile robot navigates via the shortest road from the original position to the target using the "probabilistic road-map".

Lingelbach [13] and Latmobe [14] use "cell decomposition" to construct the global map. The proposed techniques decompose several regions (cells) in the navigation space, and then connect the cells on the road from the original to target position. In other word, the methods convert the "point" locations to a series of cells, and then detect if there is an obstacle in this cell. Hwang et al. [15] and Vadakkepat et al. [16] propose a "potential field" to represent the global map. The field has energy on each position. Suppose the obstacles have the repulse power of the energy, and the target position has the attraction power. Under this configuration, the mobile robot could avoid the obstacles and move to the target position along a designated path.

III. System Overview

In this paper, a mobile robot is constructed and navigates in the known environment using the proposed path planning method. We also deal with the self-localization problem of mobile robotics using and omnidirectional camera and known landmarks.

A. The Mobile Robot Platform

The mobile robot platform shown in Fig. 1 is used in this work. The dimension of the mobile robot is $50 \times 40 \times 105$ cm^3 and the weight is 22 Kg.

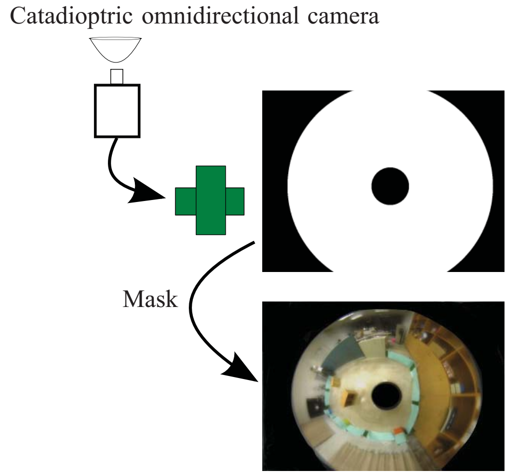

Fig. 2. The redundant region removal.

The robot is equipped with several sensors including a catadioptric omnidirectional vision system, infrared sensors, and a notebook computer, robot control circuit and four motors. The communication between the circuit board and the notebook computer is through the standard serial port. The visual information and behavior decision are processed on the computer, and then the control signals are passed to the robot control circuit through the serial port.

B. Omnidirectional vision system

In order to obtain a more complete view of the environment, the omnidirectional camera is adopted to capture the scene. In this work, the omnidirectional vision system consists of a hyperboloid mirror attached on a digital video camera. A SONY DFW-X710 digital camera is used to capture the images at the frame rate of 15 fps in our system. 3-D points in the scene can be projected to the omnidirectional image plane through the hyperboloid mirror and the lens. This kind of omnidirectional vision system is called the catadioptric camera [17]. The drawbacks along with the omnidirectional viewing capability are the non-linear image distortion and the defocus blur of the image corresponding to the far away region in the 3-D scene.

Some redundant regions of omnidirectional images are fixed, for example, the center region due to the projection constraint and the non-projected pixels on the surroundings. The redundant regions may cause the errors when performing the landmark detection. We develop a mask image (see Fig. 2) and this can remove the redundant regions.

IV. Mobile Robot Localization and Path Planning

In this section, we focus on the self-localization and path planning problems.

A. Image Based Localization

Self-localization of a mobile robot in a structured environment is an active research topic. We propose a fast self-localization method based on the sine theorem and the image

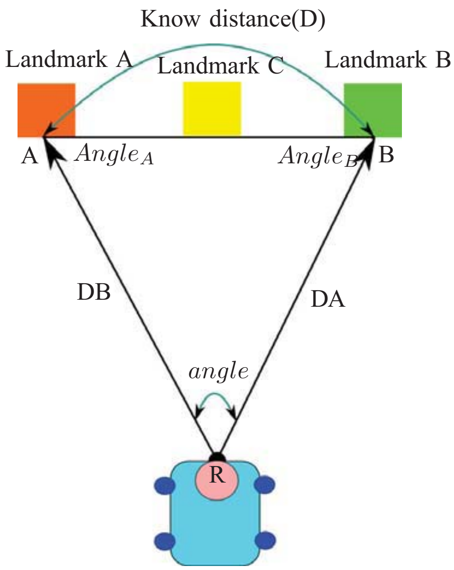

Fig. 3. The sine theorem is used to estimate the distances between the mobile robot and landmarks.

information (see Fig. 3). The law of sines is used since the distance between the landmarks are known and the angles are easier to calculate on the omnidirectional images. Let D be the distance between the landmarks A and B, then

$$\frac{DA}{\sin(Angle_A)} = \frac{DB}{\sin(Angle_B)} = \frac{D}{\sin(angle)} \quad (1)$$

where the angles $Angle_A, Angle_B, angle$ are detected from omnidirectional image. DA, DB are the distances between the mobile robot and the landmarks A, B, respectively. They can be calculated from Eq. (1). Now, the landmark A in Fig.3 is the origin $(0, 0)$ of the global map. The position of the mobile robot in the global map can be calculated as

$$\begin{cases} X = DB \times \cos(Angle_A) \\ Y = DB \times \sin(Angle_A) \end{cases} \quad (2)$$

where (X, Y) is the location of mobile robot on the global map.

B. Obstacles Avoidance

The problem of obstacle avoidance can be divided to three small problems. First, "where are the obstacles?" Secondly, "when does the robot need to avoid the obstacles?" Third, "which direction could the robot avoid the obstacles?" These problems are solved by using the approximate angle and distance between the obstacle and the robot. The obstacle avoidance approach is similar to the work by Chen and Wang [18]. Our system calculates a rotation angle in the robot's local coordinate frame and used to avoid the obstacles. The robot also memorizes the target position in global map and updates the latest direction. Whenever there are no obstacles between the robot and the target position on the global map, the robot moves toward the target.

Infrared sensors are standard light based sensors used in many mobile robot applications. They are usually used to detect the rough distances along fixed directions. Thus, it is an easy and effective way to detect the obstacles using this type of sensors. In this work, there are two infrared sensors mounted in front of our mobile robot and the distance signals are sent to the robot control circuit. The performance of detection range is about $20 - 50$ cm in our system.

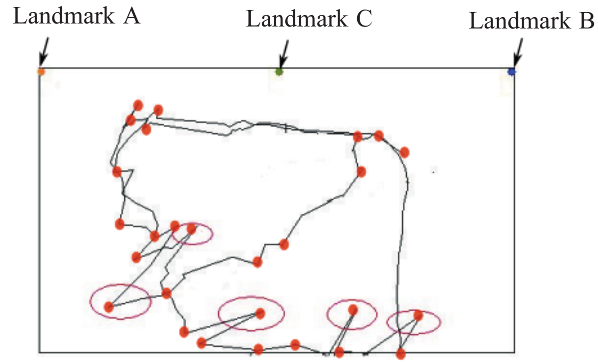

Fig. 4. The exploration global map and nodes. The lines show the feasible paths and red points are the nodes.

C. Environment Exploration and Path Planning

The purpose of the environment exploration is to estimate the localization information and memorize the feasible paths on the global map.

Feasible Path Exploration

In our system development, the mobile robot navigates in the environment. The infrared sensors are used to detect the obstacles at the video-rate.

The omnidirectional vision system is used to detect the landmarks and locate the mobile robot in the global map. During the robot motion, the system puts a node in the global map whenever the omnidirectional images have significant changes. Thus, each recorded position is a feasible position in the global map [19].

After a period of time, the global map is generated with a number of feasible positions and the nodes. We then use the global map for path planning and navigation. Fig. 4 shows an example of feasible path exploration.

Path Planning

The path planning method is based on Dijkstra's algorithm [20]. It is an application of graph and used to search the minimum path from a set of nodes with distances between them.

As shown in Fig. 5, A - E are the nodes and the 1 - 8 are the feasible paths. Assume E is the target position and the mobile robot start at the origin. There are several paths the mobile robot could move from the starting point to the target point (E):

$$\begin{cases} \text{Path}_1 = 1 - A - 2 - E \\ \text{Path}_2 = 5 - B - 6 - E \\ \text{Path}_3 = 7 - D - 8 - E \\ \text{Path}_4 = 3 - C - 4 - E \end{cases} \quad (3)$$

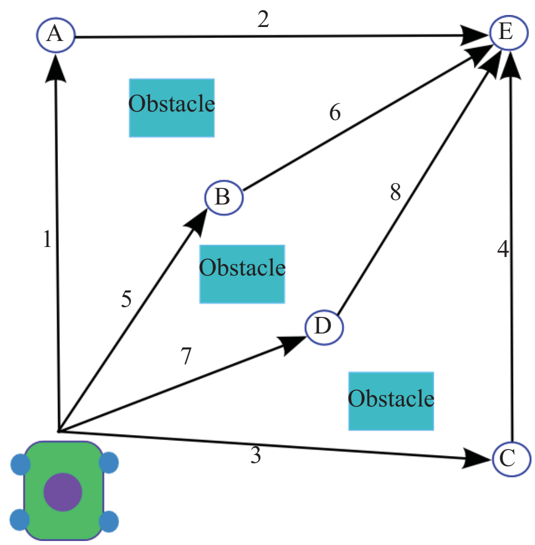

Fig. 5. An example of path planning. A - E are the nodes, 1 - 8 are the feasible paths. There are three obstacles in the map.

The system calculates the distances on each paths and selects a minimum distance to navigate from the origin to the target position.

Procedure of Path Planning

The path planning in our system can be summarized and realized by the following steps:

1) Input the target position on the global map.
2) Derive the path search method on the nodes and decide the action direction.
3) The mobile robot navigates on the path and passes through the nodes.
4) The mobile robot avoids the obstacles automatically using the infrared sensors.
5) Check the target position and the moving direction.
6) Check and update the feasible path if the navigation path is not the same as the original planning path.

The overall procedure states as follows.

Overall Procedure

The overall system architecture about environment and decision making:

1) Given preset landmarks m_a, m_b, m_c.
2) Sense (m_a,m_b) or (m_b,m_c) to reconstruct the global map according to the nearest landmark to the robot.
3) Control the motor by the relative position.

V. Experiments

We have constructed a mobile robot and combined the omnidirectional vision and infrared sensors to explore the unknown environment. The dimension of the environment is about 460×320 cm with 3 known landmarks. Two obstacles are placed at arbitrary locations in the environment.

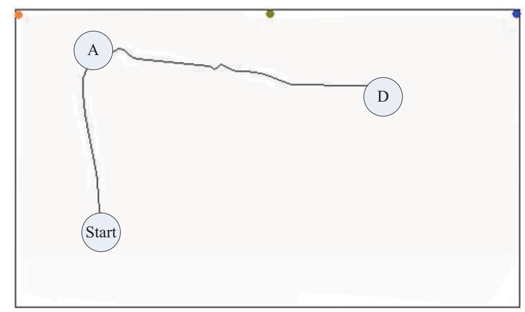

Fig. 6. The first path for localization error analysis. After the robot explores the environment, then the feasible paths and nodes will be recorded in the global map. In the analysis, the robot always navigates on the feasible paths.

TABLE I
Localization Error Analysis on First Path. The Three Nodes Are Set and Measured as the Locations Ground Truth.

Global / Nodes	Start	Node A	Node D
Real position X	$90-120$	$60-90$	$360-390$
Real position Y	$210-240$	$30-60$	$60-90$
Robot position X	90	79	365
Robot position Y	218	50	90
RMS error	$21cm$	$4cm$	$21cm$

The laptop computer is equipped with a 1.8 GHz CPU and 1 GB RAM. The real-time navigation and path planning results are shown in Fig. 8. Fig. 8(d) shows 3 nodes on the corner positions in the global map.

The analysis of localization error is tabulated in Tables I - III with three different paths shown in Figs. 6 - 8. We select three target positions and the localization error is calculated with three different paths. The estimated paths are not smooth as a consequence of the time delay which start from vision system to the control circuit. The error analysis illustrates that our system is robust with one omnidirectional camera and known landmarks in indoor environment.

VI. Conclusion and Future Work

In this work, we develop a mobile robot and propose a method for localization and path planning by combining the omnidirectional vision and infrared sensors. Given a target position in the environment, the mobile robot fisrt localizes itself and constructs the global map and nodes. It is then moves to the target position on the minimum path. Currently, there are some drawbacks of the system:

1) If the environment is large, the exploration time is long.
2) The noise of the landmark image generally affects the localization result.
3) The vision based localization is sensitive to illumination change.

In the future, the dynamic feature detection, such as SIFT [21] and tracking [19], will be used for self-localization.

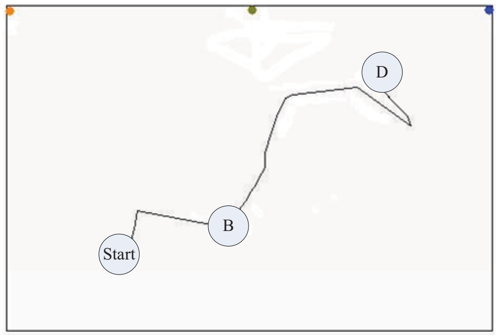

Fig. 7. The second path for localization error analysis.

TABLE II
LOCALIZATION ERROR ANALYSIS ON SECOND PATH.

Global / Nodes	Start	Node B	Node D
Real position X	$90-120$	$210-240$	$360-390$
Real position Y	$210-240$	$150-180$	$60-90$
Robot position X	107	232	361
Robot position Y	232	172	64
RMS error	$7.6cm$	$9.8cm$	$11.4cm$

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REFERENCES

[1] K. H. H. H. T. A. Y. S. F. K. A. K. Y. Shimosasa, J. Kanemoto and S. Yuta, "Security service system using autonomous mobile robot," in *IEEE Proceedings of the SMC'99 Conference on Systems, Man, and Cybernetics*, vol. 4, 1999, pp. 825–829.

[2] "http://store.irobot.com/corp/index.jsp."

[3] I. J. Cox, "Blanche-an experiment in guidance and navigation of an autonomous robot vehicle," in *IEEE Transactions on Robotics and Automation*, vol. 7, 2003, pp. 193–204.

[4] A. Elfes, "Sonar-based real-world mapping and navigation," in *IEEE Journal of Robotics and Automation*, vol. 3, 1987, pp. 249–265.

[5] V. F. R. Want, A. Hopper and J. Gibbons, "The active badge location system," in *ACM Transactions on Information Systems*, vol. 10, 1992, pp. 91–102.

[6] H. Y. Lin and J. H. Lin, "A visual positioning system for vehicle or mobile robot navigation," in *IEICE Transactions on Information and Systems*, vol. E89-D, 2006, pp. 2109–2116.

[7] C. Harris and M. Stephens, "A combined corner and edge detector," in *Alvey Conference*, 1988, pp. 147–152.

[8] J. K. G. Jang, S. Kim and I. Kweon, "Metric localization using a single artificial landmark for indoor mobile robots," in *IEEE/RSJ International Conference on Intelligent Robots and Systems*, 2005, pp. 2857–2862.

TABLE III
LOCALIZATION ERROR ANALYSIS ON THIRD PATH. THE PATH AND PARTIAL IMAGE ARE SHOWN IN FIG. 8.

Global / Nodes	Start	Node C	Node D
Real position X	$90-120$	$360-390$	$360-390$
Real position Y	$210-240$	$240-270$	$60-90$
Robot position X	110	363	365
Robot position Y	240	265	90
RMS error	$15cm$	$15.6cm$	$21.2cm$

[9] E. Kruse and F. M. Wahl, "Camera-based observation of obstacle motions to derive statistical data for mobile robot motion planning," in *Proceedings IEEE International Conference on Robotics and Automation*, 1998, pp. 662–667.

[10] L. D. A. Clerentin and E. Brassart, "Cooperation between two omnidirectional perception systems for mobile robot localization," in *Proceedings of the 2000 IEEE/RSJ International Conference on Intelligent Robots and Systems*, 2000, pp. 1499–1504.

[11] R. Geraerts and M. Ovmnars, "A comparative study of probabilistic roadmap planners," in *In Proceedings of Workshop on Algorithmic Foundations of Robotics*, 2002, pp. 43–57.

[12] L. Kavraki and P. Svestka, "Probabilistic roadmaps for path planning in high-dimensional configuration spaces," in *IEEE Transactions on Robotics and Automation*, 1996, pp. 566–580.

[13] F. Lingelbach, "Path planning using probabilistic cell decomposition," in *Proceedings IEEE International Conference on Robotics and Automation*, 2004, pp. 467–472.

[14] J. C. Latmobe, "Robot motion planning," in *Kluwer Acdeemic Publishers*, 1991.

[15] Y. K. Hwang and N. Ahuja, "A potential field approach to path planning," in *IEEE Transactions on Robotics and Automation*, vol. 8, 2004, pp. 23–32.

[16] K. T. P. Vadakkepat and W. Liang, "Evolutionary artificial potential fields and their application in real time robot path planning," in *IEEE Evolutionary Computation*, vol. 1, 2000, pp. 256–263.

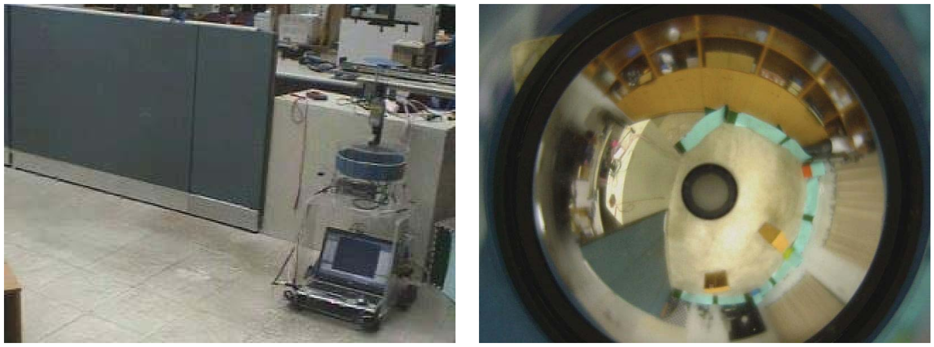
[17] P. W. L. Hong and Z. Hongbin, "Motion detection for multiple moving targets by using an omnidirectional camera," in *Proceedings of IEEE International Conference on Robotics*, vol. 1, 2003, pp. 422–426.

[18] Y.-T. W. Yu-Cheng Chen, "Obstacle avoidance and role assignment algorithms for robot formation control," in *International Conference on Intelligent robots and systems*, 2007.

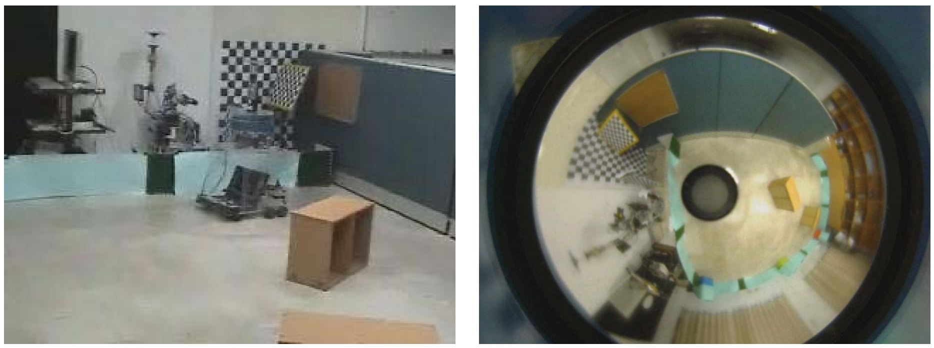
[19] M. L. W. H. Y. Lin and C. C. Huang, "A robust visual surveillance system based on an omnidirectional vision sensor," in *Journal of Computers*, vol. 19, 2008.

[20] E. Dijkstra, "A note on two problems in connection with graphs," in *Numerical Mathematics*, vol. 1, 1956, pp. 269–271.

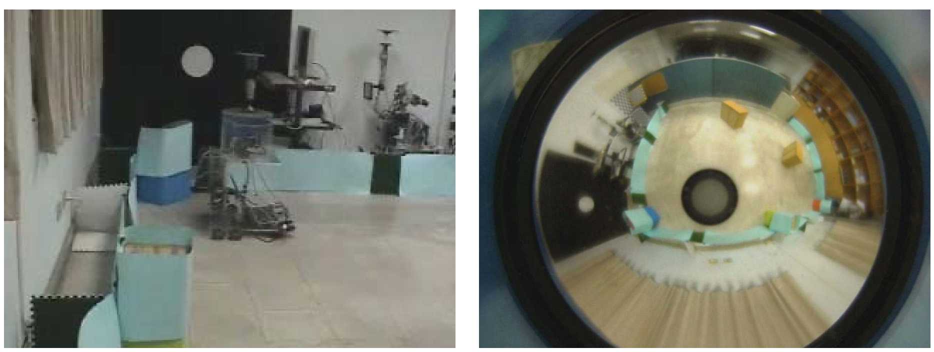
[21] D. Lowe, "Local feature view clustering for 3d object recognition," *Computer Vision and Pattern Recognition, 2001. CVPR 2001. Proceedings of the 2001 IEEE Computer Society Conference on*, vol. 1, pp. I–682–I–688 vol.1, 2001.



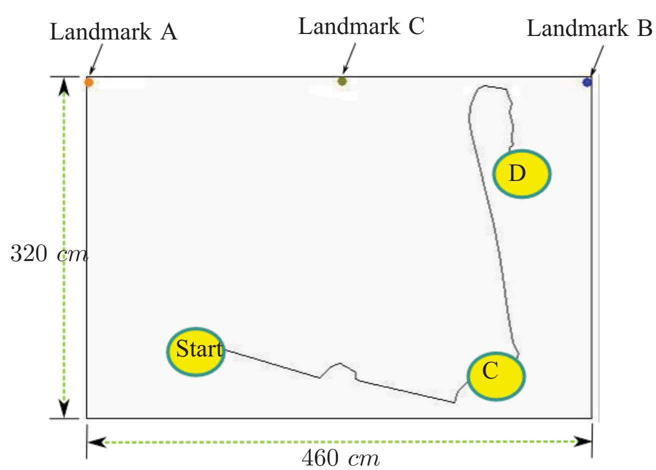
(a) The mobile robot at the position “Start” in the global map and the omnidirectional image.



(b) The mobile robot at the position “C” in the global map and the omnidirectional image.



(c) The mobile robot at the position “D” in the global map and the omnidirectional image.



(d) The global map and the navigation path.

Fig. 8. The global map and path. This path is also the third path for localization error analysis.