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Adaptive Guidance for Mobile Robots in Intelligent Infrastructure

Joo-Ho Lee*, Noriaki Ando*, Teruhisa Yakushi**, Katsunori Nakajima**,
Tohru Kagoshima** and Hideki Hashimoto*

*IIS #3, University of Tokyo,
7-22-1, Roppongi, Minato-ku, Tokyo, Japan
{leejooho,n-ando,hideki}@vss.iis.u-tokyo.ac.jp

**Toshiba IT & Control Systems,
2-24-1, Harumi-Cho, Fuchu-Shi, Tokyo, Japan
{teruhisa.yakushi,katsunori.nakajima,toorukagoshima}@glb.toshiba.co.jp

Abstract

In this paper, we propose a method of guiding mobile robots in networked space. To watch human and robots, distributed sensor devices with processors are located around the networked space. In this space, robots as well as human are supported informatively and physically. Distributed sensor devices guide mobile robots in this space and navigation with high adaptability is realized. The simulation and experimental results including deciding camera arrangement and robot guidance with distributed sensor devices are shown.

1 Introduction

Last several years, computer network has proliferated and it became an important part of our daily life. Due to the current situation, not only research on Internet itself, but also Internet related research has been started in various shapes. Well known research in robotics field, such as tele-operation, web-based robotics, etc are some of its examples. Intelligent environment research is also one of its examples. This environment uses computer network for many purposes. Through computer network, user can access the intelligent environment freely from everywhere in the environment.

One of such a environment is the Intelligent Space that is able to watch what is happening in them, build a model of them, communicate with their inhabitants and act based on decisions they make [1]. Especially the capability of the environment to act as a context-sensitive user interface (e.g. to respond to gestures) and react in certain situations (e.g. accidents, intruders) promises a range of application scenarios such as intelligent hospital rooms, office, factory, asylum for the aged, etc.

Normal environment is changed into the Intelligent Space by installing many Distributed Intelligent Networked Devices (DIND) [2]. DIND, a basic element of the Intelligent Space, consists of three parts that are sensor/actuator part, processing part and communication part. DINDs are connected to a network and each DIND watches inside the space to perceive what is happening in it. Furthermore the Intelligent Space supports both human and robots. Especially, robots are able to use resources of DINDs as if their own parts [3]. However it can be also said that such robots are a part of DIND. The core of the Intelligent Space is DIND.

To realize the Intelligent Space as our living environment, we classified existing environment into three classes. In the first class, environment, where the internal equipments can be easily changed and the center is not on the human, is included. Producing line and warehouse in factories is a good example of such environment. Infrastructure is well prepared in such environment and the center is put on others like machines, productivity, efficiency rather than human. Thus, it is easier to build a spatial system in such environment than others.

The second class includes environment where the infrastructure is well constructed but its center is more on the human. Office, hospital can be considered as in this class.

Like our home, obviously the center is on people, who are living in it, that is the third class. Including infrastructure and artificial equipments are very poorly prepared in this class.

We choose the first class as the target of the first step of our Intelligent Space project. Currently most of factories utilize AGV (Autonomous Guiding Vehicle) for unmanned transportation. However, to use AGV, some methods of guiding AGVs should be prepared. The representative method is using special tapes as guide-rail. In this case, it is difficult to cope with frequent structure change of warehouse. All the guide tapes should be re-stuck on the floor every time.

To detect obstacles, mainly human, AGV needs range sensors. If more than one robot is in the same area, some sensors such as ultra sonic sensor, laser range finder, must be used carefully. Since such sensors are easily interfered, some methods to overcome interference are required.

In the Intelligent Space, all such kinds of problems are solved. Because there is no guide-rail in the Intelligent Space, the paths for robots are easily changed according to the change of the warehouse structure as described in Fig 1. Robots do not need sensors for detecting obstacle in the Intelligent Space, which watches what is happening inside it. Obstacles, including human, can be detected and its information is given to the robots by the Intelligent Space. It is a kind of resource saving and sharing.

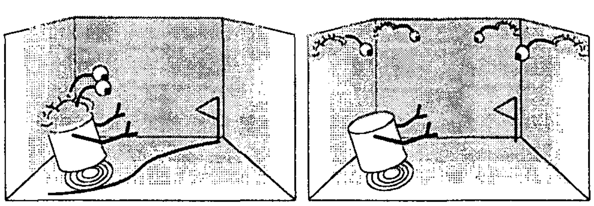
Except these, there are many merits of adopting the Intelligent Space. However, in this paper guiding robot in dynamic environment is focused.

2 System Architecture

To utilize the proposed system in a real warehouse, it requires a high degree of robustness for the components of the intelligent space.

2.1 Hardware Architecture

In this Application, we separate human recognition function and mobile robot tracking/control function in DIND. Area in the warehouse is divided into several parts and each parted area is watched by DIND for mobile robots. Since size of the parted area is decided by capability of DIND, arrangement becomes very important problem. According to the position of DIND, important parameters including size of covering area and tracking precision varies, since we adopt a vision camera as a sensor of DIND for the moment. Influences of height, angle of camera will be discussed in the last part of this paper.



(a) Conventional AGV (b) AGV in Intelligent Space

Figure 1. AGV in environment

Mobile robots in the Intelligent Space need neither sensor to detect obstacle around them nor sensor to estimate pose of them. The robots have passive color bars and a communication device to communicate with DINDs. Due to communication between robots and DINDs, robots are able to use sensors in DIND freely. It is a kind of resource sharing and this feature leads robots to low cost, since expensive sensors, such as gyroscope sensor, laser range finder, etc are not required. Simple PLC board, motors and wireless LAN is only installed in the robot, which we used in this research. Color bars are attached to four corners of a robot. An industrial standard Pentium PC is utilized as a processing device in a DIND.

2.2 Software Architecture

Linux is adopted as operating system in DINDs. All software algorithms are written in C++ and the GUI parts are written in TCL/TK. In this application, required functions of the Intelligent Space are summarized as two. One is to detect human and unknown obstacles, and the other is to handle mobile robots.

Detecting the human is done in two steps. First, the

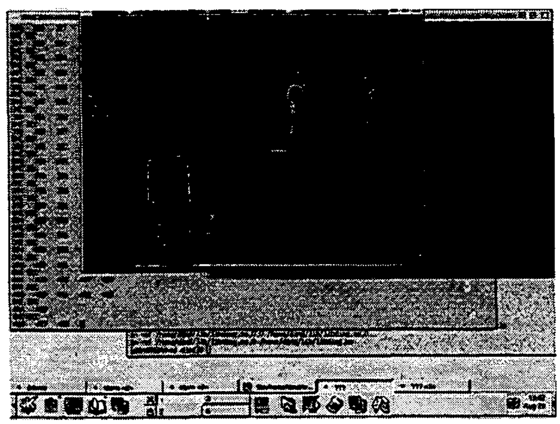


Figure 2. Detecting human and obstacles

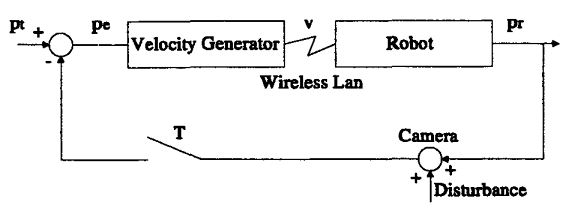


Figure 3. Block diagram of mobile robot closed loop control in the Intelligent Space

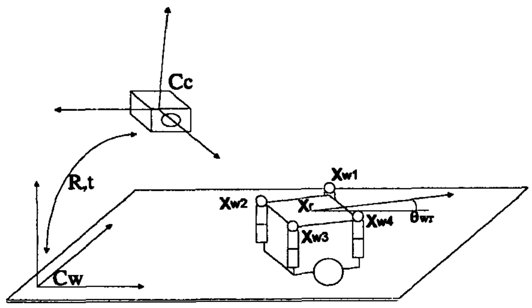


Figure 4. Coordination and parameters

area or shape of a human is separated from the background. Second, the separated image is searched for Skin color. Taking the images from several DINDs, we can then calculate the 3D position of the human [4]. In case of obstacle, whatever it is, background separation is used. Fig. 2 is an example of detecting people and an obstacle.

Unlike the case of detecting human, to handle mobile robots in the Intelligent Space, only one DIND is required. Since DINDs have database of height of color bar and its color codes, one DIND is able to estimate the position of robots. Mobile robots are sensed by vision sensor of DIND and visions server module estimates pose of the mobile robots. According to desired path and estimated pose, control input for the mobile robots are generated and transferred to the mobile robots through wireless LAN. This flow is shown in Fig. 3.

The above algorithms are implemented in four different software modules of the Intelligent Space. Those are calibration module, vision server module, 3D reconstruction module, and mobile robot control module.

The calibration module is an application module that is interactively launched by an operator. It uses a graphical interface to specify the points of the grid and their coordinates. We adopted Tsai's calibration algorism [5] and made a GUI calibration module.

In this step of Intelligent Space, DIND for human and DIND for mobile robots are separated. Thus, vision server module in DIND for human generates 2D position of human and obstacles. DIND for mobile robots has vision server module for generating 3D pose of mobile robots. The vision server module recognizes color bar codes and pose of mobile robots are generated based on relations of color bars. Fig. 4 shows relations among color bars. Six possible pairs exist in four color bars. Pose of a robot is estimated from geometrical relation, if at least one pair is recognized. Below equations are to estimate position and direction of a robot.

$$x_r = \left(\frac{x_1 + x_4}{2}\right) - \frac{l_2}{2}\cos\theta_r,\ y_r = \left(\frac{y_1 + y_4}{2}\right) - \frac{l_2}{2}\sin\theta_r \tag{1}$$

$$x_r = \left(\frac{x_2 + x_3}{2}\right) + \frac{l_2}{2}\cos\theta_r,\ y_r = \left(\frac{y_2 + y_3}{2}\right) + \frac{l_2}{2}\sin\theta_r \tag{2}$$

$$x_r = \left(\frac{x_1 + x_2}{2}\right) + \frac{l_1}{2}\sin\theta_r,\ y_r = \left(\frac{y_1 + y_2}{2}\right) - \frac{l_1}{2}\cos\theta_r \tag{3}$$

$$x_r = \left(\frac{x_3 + x_4}{2}\right) - \frac{l_1}{2}\sin\theta_r,\ y_r = \left(\frac{y_3 + y_4}{2}\right) + \frac{l_1}{2}\cos\theta_r \tag{4}$$

$$\theta_r = \tan^{-1}\left(\frac{y_1 - y_2}{x_1 - x_2}\right) = \tan^{-1}\left(\frac{y_4 - y_3}{x_4 - x_3}\right) \tag{5}$$

$$\theta_r = \tan^{-1}\left(\frac{y_4 - y_1}{x_4 - x_1}\right) + \frac{\pi}{2} = \tan^{-1}\left(\frac{y_3 - y_2}{x_3 - x_2}\right) + \frac{\pi}{2} \tag{6}$$

Mobile robot control module produces control input for the mobile robots. According to desired path and estimated pose, control input for the mobile robots are generated and transferred to the mobile robots through wireless LAN.

For each pair of cameras of the space, a 3D reconstruction module can be started. It connects two camera servers, and loads its calibration data and offers a stream of reconstructed 3D position of human and obstacles on the network.

DIND is an independent device, and its functions, including localization, control of mobile robots, are performed completely within it. Thus, if a mobile robot is moving in the area, at which one DIND is looking, the robot is guided without any difficulty. We define DIND that has control authority of a robot as dominant DIND for the robot. However, when the robot moves from the area to a different area, dominant DIND for the robot should be changed automatically at the area boundary. We call this handing over of control authority. Dominant DIND has control authority to the robots and only one dominant DIND exists to a robot at once. Thus, the control authority should be handed over to the next DIND at the proper time and location smoothly. To solve this problem, we adopted the concept of reliability rank. This parameter is determined by pre-investigated position error and current recognition rate. In advance, the pre-investigated position error is measured to the locations in the area of DIND. Current recognition rate goes up when DIND succeeds in finding a robot continuously and it goes down when DIND fails. When the reliability rank is under the critical value, current dominant DIND sends the request to adjacent DINDs. If there is DIND, which has bigger reliable rank, control authority is handed to it.

3 System Evaluation

Since the system, which we are proposing in this paper, has obvious target of practical use, its operating characteristics should be looked over thoroughly.

3.1 Camera Arrangement

When we distribute DIND over environment, precision of 3D detection of robot should be considered. Visible area does not mean serviceable area in DIND. It is natural that precision of estimated position is deeply related to distance

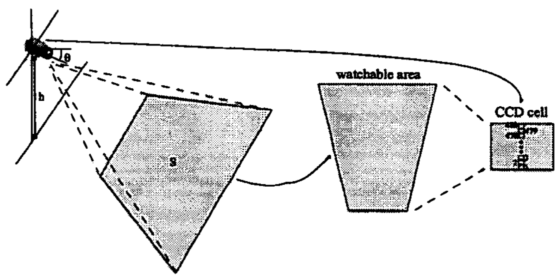


Figure 5. Procedure of computer simulation

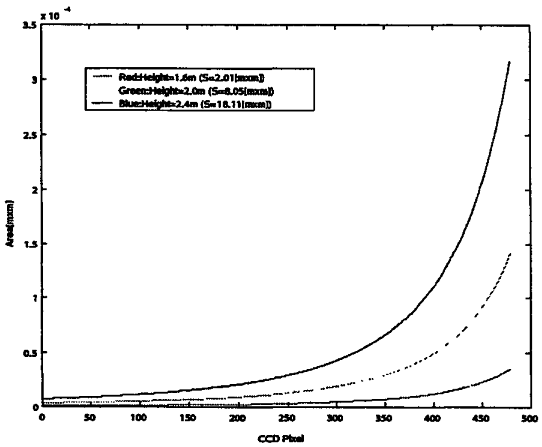


Figure 6. Relation between size of one pixel in world coordination and height of camera

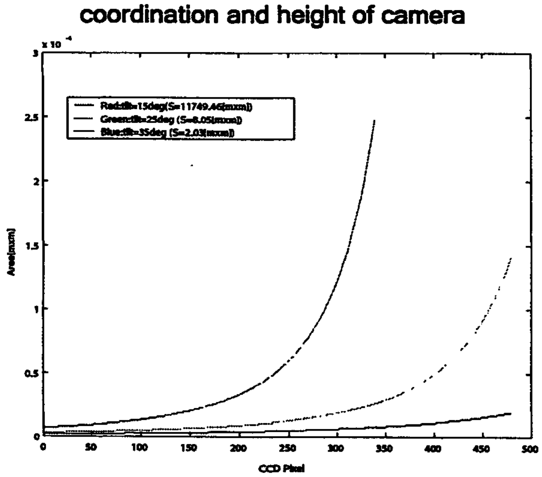


Figure 7. Relation between size of one pixel in world coordination and tilt angle of camera

between robots and DIND. The more a target is far away from DIND, the more the precision become worse. To arrange DINDs in a space, this relation should be considered. In this research, computer simulation software was developed to determine proper tilt angle and height of camera. Since estimation performance is deeply related to control performance of a robot, accurate pose estimation of a robot is required for stable and high-speed control. To guarantee certain accuracy for pose estimation, the color bars on a robot should be watched bigger than a defined image size in whole service area. Fig. 5 shows how the simulation works. According to height of camera and tilt angle, size of service area and the dimension, which corresponds to one pixel of CCD, is computed. Fig. 6 and Fig. 7 is results of simulation. The x-axes in the graphs are position of CCD pixel, shown in Fig. 5. Since we adopted 480-column pixel CCD camera, the simulation was performed based on this. The graphs tell that low height and big tilt angle leads good localization performance to the system. However, size of service area is an important factor to decide DIND arrangement. To find optimal arrangement of a space, a method of using an evaluation function, consist of size of service area and expected error of pose estimation, is being developed currently.

We located two DINDs in our experimental space based on simulation results. Fig. 8 shows the coordination and

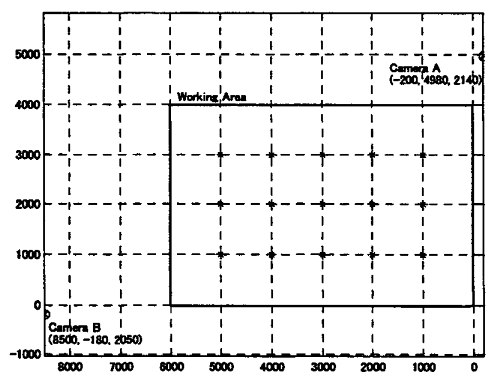


Figure 8. Experimental environment

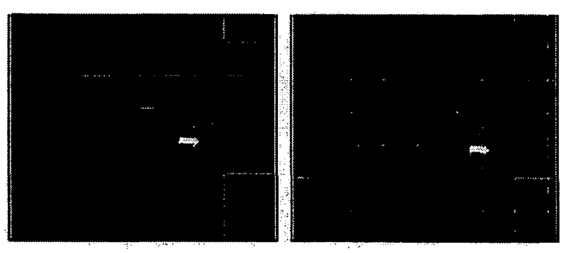


Figure 9. DINDs hand over control authority

locations of DINDs. To find serviceable area for detecting robots, we located a robot at several points in visible area of DIND and measured error between real values and estimated values. A robot was located at 15 different points. DINDs were located at (-200, 4980, 2140) and (8500, -180, 2050). Illumination condition that dependent on time and position, varied from 500 to 1000lux. The serviceable area for detecting robots must be determined by considering the parameters of estimation error, allowed position error of a robot, and speed of robot

3.2 Mobile Robot Control

DIND and a mobile robot make a control loop as shown in Fig. 3. DIND guides mobile robots to reach a goal. However, actually, the goal is not always in the supervisory area of DIND. Work area of warehouse is divided into several supervisory areas of DINDs. To make a robot to reach a goal, which is not in the same supervisory area of DIND, more than one DIND cooperates each other. In this case, DIND guides a mobile robot to reach adjacent supervisory area of other DIND. Fig. 9 shows an example for this. The right side of Fig. 9 is navigation monitor of DIND A and the other is DIND B. The length of path in Fig. 9 is about 8000mm. Approximately serviceable area of DIND A and DIND B is right side and left side of the space respectively. Detailed method of handing over is explained in [7]. Red dot is a goal and yellow dots are sub-goal, which the mobile robot should pass through. Green circle and arrow mean the mobile robot and its direction. Ladder shape is expected progressing area of the mobile robot. The DIND generated control input for the mobile robot based on current pose of it and sub-goals (TP). Maximum speed of mobile robot is set to 30cm/sec that is the maximum speed of AGV, prescribed by Japanese standard association [8]. Green line expresses the mobile robot trajectory, perceived by DIND. The cycle of the control loop is 300msec. It is possible to decrease the cycle faster than this. However, currently, since real-time OS is not used, surplus time is required to keep regular interval of control cycle. Fig. 10 shows that two robots are controlled by one DIND. While two robots moved on a square path continuously, they kept fixed distant interval.

DINDs are watching what is happening in the environment continuously. Thus they are able to detect dynamic changes such as moving obstacles. Fig. 11 shows how the DINDs guide a robot in dynamic environment. A path was generated to guide a robot. An obstacle was detected and the path was designed to avoid it. However, when the obstacle was removed, DINDs re-generate a new path, which passes shortest way, for the robot. Fig. 12 shows how the DINDs re-generate a path.

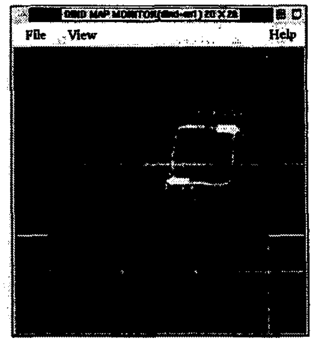


Figure 10. Two robots are controlled by DIND

4 Conclusion

In this paper, arrangement method of DINDs and how the DINDs guide robots in a dynamic environment is explained. We showed features of proposed system by showing some experimental results. It is known from the results that the Intelligent Space is able to guide robots adaptively in varying situation.

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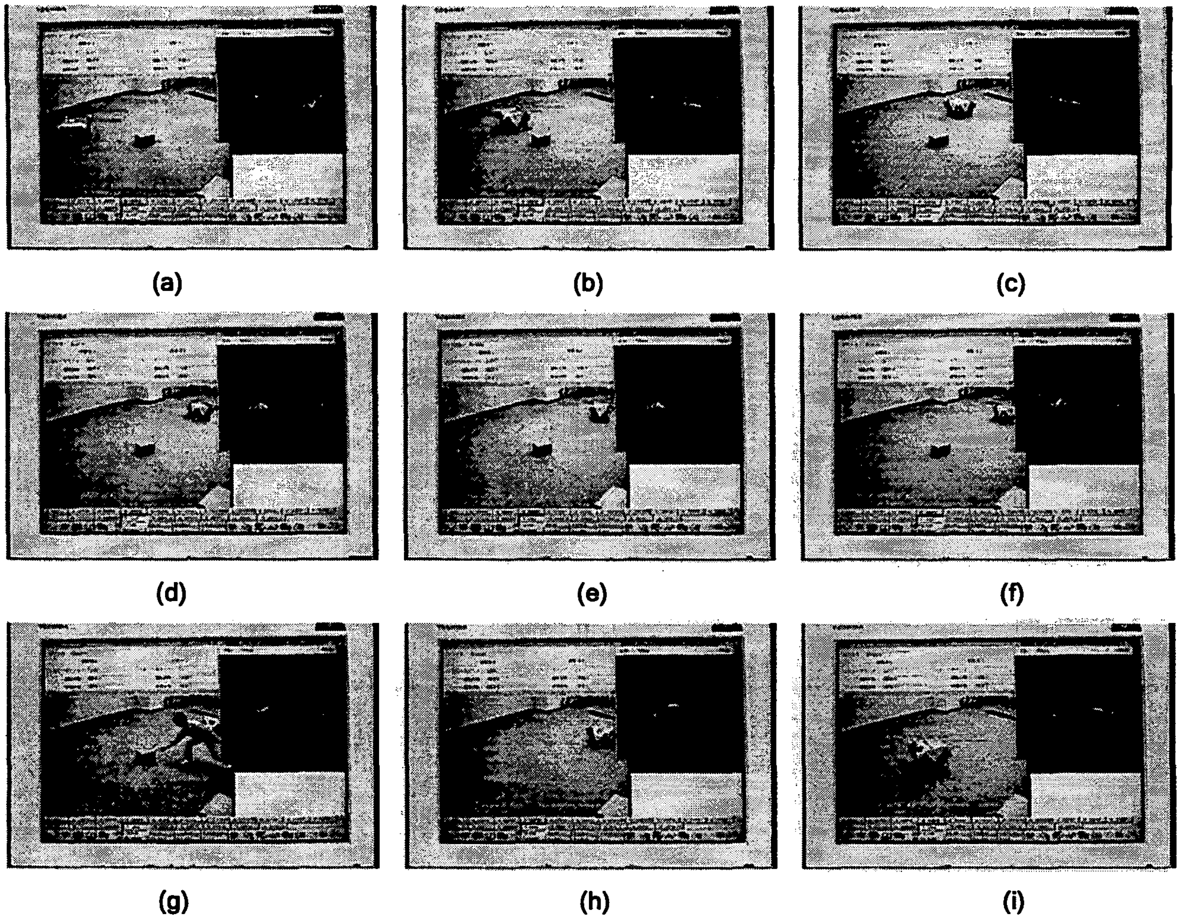

Figure 11. Active path planning for dynamic environment

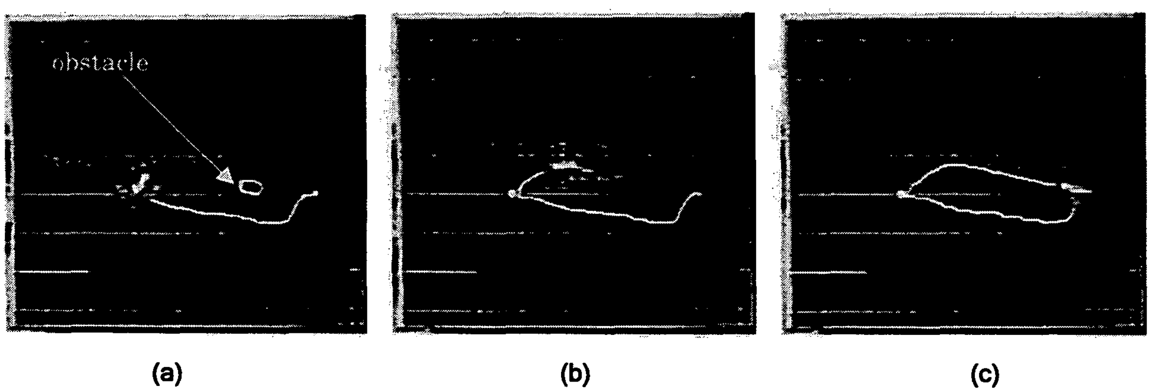

Figure 12. Active path planning for mobile robot