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Development of Localization Method of Mobile Robot with RFID Technology and Stereo Vision

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1. Introduction

Many service robotic systems have been developed in order to improve care costs and the quality of the elderly people in the aging population [L. Nagi et al., 2002; Vogl, M.et al., 2005]. Our Human- Assistance Robotic System Project (HARSP) project has been developing a network distributed Human-Assistance Robotic System since 2000 [S. Jia et al., 2002, 2004, 2005]. We developed a hardware base, key technologies and implemented several Common Object Request Broker Architecture (CORBA) application servers to provide some basic services to aid the aged or disabled. Localization and obstacle recognition in indoor environments for mobile robots are main topics in order to navigate a mobile robot to perform a service task at facilities or at home. Many efforts have been made to solve this problem using sensors such as cameras and laser ranger scanners [A. Davision, 2003; W. Shen et al., 2005; H. Surmann et al., 2003]. In our previously developed system, the indoor Global Positioning System (iGPS) has been developed to localize a mobile robot [Y. Hada et al., 2004]. Recently, some research has used radio frequency identification (RFID) technology for indoor mobile robot localization as the information written in ID tags can be easily read out by an RFID reader. Kulyukin et al. used RFID to localize a mobile robot within a coarse position and decided the next movement based on the information written in ID tags [V. Kulyukin et al., 2004]. Kim et al. developed an RFID system including three orthogonal antenna, which determines the direction and distance of a tag by comparing the signal strength in each direction [M. Kim et al., 2004; W. Lin et al., 2004]. In this paper, a novel method is proposed for indoor environmental obstacle recognition and localization of a mobile robot by using an RFID system with a stereo camera as it is inexpensive, flexible and easy to use in the practical environment. As the information (such as type, colour, shape or size of the obstacles) can be written in ID tags in advance, the proposed method enables easy and quick obstacle recognition. The proposed method is also helpful to improve dynamic obstacle recognition (such as a chair or person) and occlusion problems that are very difficult to solve. This is because the communication between the ID reader and ID tags uses RF, and the information written in ID tags can be simultaneously read by an RFID reader. RF is not so stable, so determining the accurate position of obstacle objects is difficult. In order to localize the ID tags accurately, the Bayes rule was introduced to calculate the probability where the ID tag exists after the tag reader detects a tag. Then the stereo camera

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starts to process the Region Of Interest (ROI) determined by the results of the Bayes rule. As the proposed method does not need to process all input images, and some information about environment was obtained from the ID tag, this decreases the image processing computation, and enables us to detect the obstacles easily and quickly. Research on RFID technology integrating stereo vision to localize an indoor mobile robot has also been performed. This paper introduces the architecture of the proposed method and gives some experimental results.

The rest of the paper consists of seven sections. Section 2 describes the structure of the hardware of the developed system. Section 3 presents the localization of ID tags using RFID system. Section 4 introduces the proposed method of obstacle localization and detection, Section 5 details obstacle avoidance with RFID technology and stereo vision. Section 6 explains the principle of the developed indoor mobile robot localization method. The experimental results are given in Section 7. Section 8 concludes the paper.

2. System description

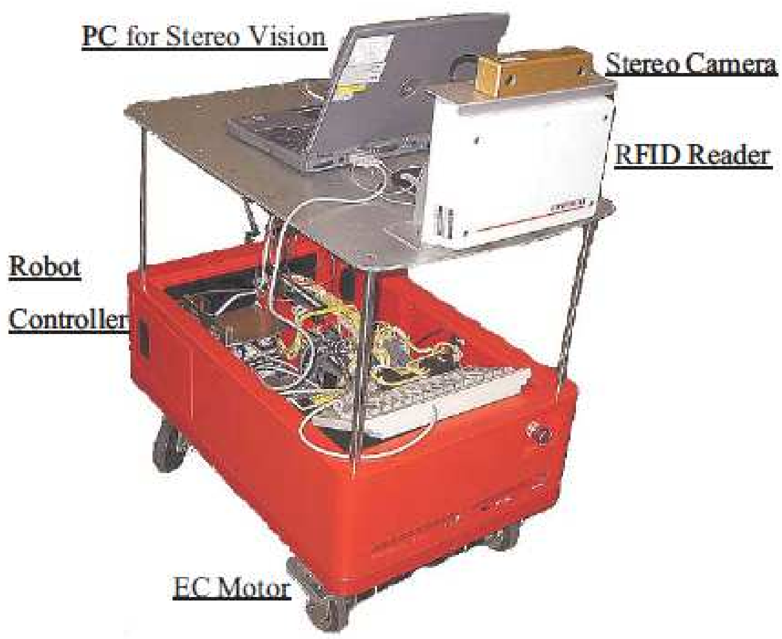

Fig. 1. The structure of developed mobile robot platform.

In the previously developed system, an omnidirectional mobile robot was used to perform service tasks. Owing to the specific structure of its wheel arrangement, it is difficult for a mobile robot to pass over a bump or enter a room where there is a threshold. Another important point is to lower costs and decrease the number of motors so that the battery can supply enough electricity for a mobile robot to run for a longer time. Figure 1 illustrates the developed mobile robot platform. In our new system, we developed a non-holonomic mobile robot that was remodeled from a commercially available manual cart. The structure of the front wheels was changed with a lever balance structure to make the mobile robot move smoothly and the motors were fixed to the two front wheels. It has low cost and can easily pass over a bump or gap between the floor and rooms. We selected the Maxon EC motor and a digital server amplifier 4-Q-EC 50/5 which can be controlled via RS-232C. For

the controller of the mobile robot, a PC104 CPU module (PCM-3350 Geode GX1-300 based) is used, on which RT-Linux is running. For communication between the mobile robot and the mobile robot control server running on the host computer, a wireless LAN (PCMCIA-WLI-L111) is used.
The Kenwood series was used in the developed system. The tag reader S1500/00 communicates with tags via 2.45-GHz radio waves. Figure 2 illustrates the specification of RFID system. Since there is a communication area between the ID tag and tag reader (the communication between the mobile robot controller and tag reader is via RS-232C), if the ID tag comes into the communication area while mobile robot moves to a close to the ID tag, the ID tag can be detected and the information written in it can simultaneously be read by the tag reader mounted on the mobile robot. When the working domain of the mobile robot is changed or extended, what needs to be done is just putting the new ID tags in a new environment and registering these ID tags to the database. It is also helpful to improve dynamic obstacle recognition (such as a chair or person).

Item	Specification
Frequency	2.45GHz
Card Memory size	72byte
The maximum communication distance	4m
Interface	RS-485,RS-232C
Power requirement	DC24(V) 1.0(A)
Weight (reader)	2kg
Dimension (reader)	263x176x53mm (WxLxH)

Fig. 2. The specifications of KENWOOD RFID system.

The Bumblebee (Point Grey Research) stereo camera and MDCS2 (Videre Design) camera are usually used in the robotics field. In our system, we selected the Bumblebee to integrate RFID technology to localize the service mobile robot. The Bumblebee two-camera stereo vision system provides a balance between three dimensional (3-D) data quality, processing speed, size and price. The camera is ideal for applications such as people tracking, mobile robotics and other computer vision applications. It has a resolution of 640 x 480 or 1024 x 768 (640 x 480 at 30 FPS or 1024 x 768 at 15 FPS). The size of the camera is approximately 160 x 40 x 50 mm and the weight is about 375 g. It has features such as: two 1/3-inch progressive scan CCDs to provide significantly better light collection and signal-to-noise ratio; high-speed IEEE-1394 digital communication allowing powering of the camera and camera control through a single cable; and accurate precalibration for lens distortions and camera misalignments and automatic intercamera synchronization, useful for acquiring 3-D data from multiple points of view. A notebook computer (Intel Pentium 3M 1.00 GHz, memory SDRAM 512, Windows XP Professional) was used to process images. Figure 3 illustrates the specifications of Bumblebee stereo camera, and Figure 4 shows the connection of developed robot system. Tag reader communicated with PC 104 robot controller via RS-232C, and Bumblebee stereo camera was connected with a note PC via IEEE1394 bus.

Item	Specification
Baseline	12 cm
Focal Lengths	6mm with 43°
Frame Rates	48 FPS(640x480)
Interfaces	6-pin IEEE-1394a
Power Consumption	2.5W at12V
Dimensions	157 x 36 x 47.4mm
Mass	342 grams
Signal To Noise	Ratio 60dB
Gain	Automatic/Manual

Fig. 3. The specification of Bumblebee stereo camera.

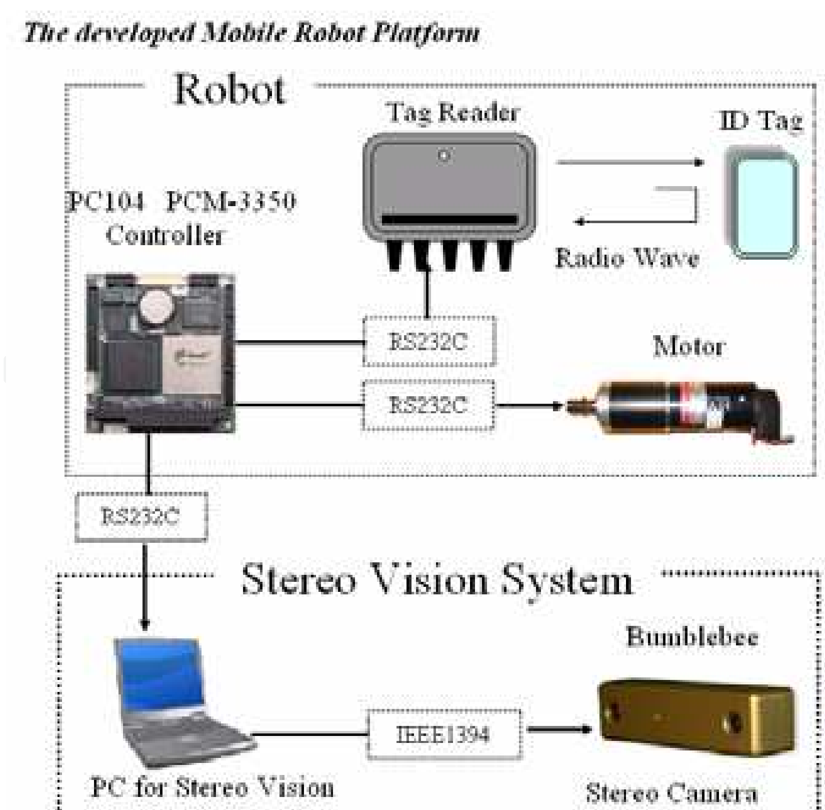

Fig. 4. Connection of the developed mobile robot system.

3. Localization of ID tag using RFID system

3.1 RFID probability model

Obstacle recognition; specially, dynamic obstacle recognition such as chair or human person is a difficult problem. For human being, it is easy to avoid the obstacles such as chairs, tables to perform a task, but for mobile robot, it is very difficult. We proposed the method of indoor environmental obstacle recognition for mobile robot using RFID. Because the information of obstacle such as size, color can be written in ID tags in advance, so the proposed method enables the obstacle recognition easily and quickly. By considering the probabilistic uncertainty of RFID, the proposed method introduces Bayes rule to calculate probability where the obstacle exists when the RFID reader detects a ID tag. In our research, for the obstacle objects like chairs and tables, we attached the ID tags on them, and the system can detect them when the mobile robot moves the place where ID tags enters the communication range of RFID reader. Simultaneously, the data written in the ID tags can also be read out. But localizing accurately the position of obstacle objects is difficult just using RFID because the antenna directivity of RFID system is not so good. We introduce Bayes rule to calculate probability where the ID tag exists after the tag reader detects a tag [E. Shang et al., 2005].
Bayes' theorem relates the conditional and marginal probabilities of two events E and O, where O has a non-vanishing probability.

$$P_t(E|O) \propto P(O|E)P_{t-1}(E)$$

In our method, O is phenomenon of the reception of the signal by the tag reader, E is phenomenon of the existence of the obstacle (ID tag), $P_t(E|O)$ is the conditional probability the tag exists after t times update, $P(O|E)$ is sensor probability model of RFID, and $P_{t-1}(E)$ is the prior or marginal probability after the tag exists t-1 times update. To determine the model for RFID antennas, we attached an RFID tag to a fixed position, and the mobile robot moves in different paths. We repeated this for different distances and counted for every point in a discrete gird the frequency of detections of ID tags. In order to overcome the multipath effect of electric wave, we set ID tags detection buffer for saving latest 10 times detecting results. "1" means the ID tag was detected, "0" means the ID tag was not detected. If the results of 9 times are "1", we think the ID tag can be detected with 0.9 probability. Additionally, we use the recursive Bayesian to calculate probability where the ID tag exists, which can improve multipath effect. According to the experimental results, we can get the data distribution shown in Figure 5. The points means the RFID tag can be detected (0.9 probability). According to this result, we can simplify the RFID sensor model shown in Figure 6. The likelihood of the major detection range for each antenna is 0.9 in this area. The likelihood for the other range is setup as 0.5.
When the user commands a mobile robot to perform a service task, the mobile robot starts to move in the office, or at home. In order to enable a mobile robot to finish a task autonomously, it is necessary for mobile robot to have perfomance to detect the obstacles in indoor environment and avoid them. Many researchers used many sensors to solve this problem. In our system, we proposed the method using RFID and stereo vision to recognize the obstacle. RFID reader system was mounted on the mobile robot platform. When the mobile robot starts to move for performing a task, RFID reader system was started

simultaneously to detect the ID tags arround the mobile robot. There are communication area for different RFID system. The Kenwood series used in the developed system has communication range about 4x1.8m². When the mobile robot moves to place close to ID tags, the ID tag can be detected and the information written in ID tag can also be read out simultaneously. When RFID system detected a obstacle ID tag, a map 4×4m² (cell size 4×4cm², the public precision in the field of robot navigation) will generated. Figure 7 illustrates the initial probability map after the RFID reader detected a obstacle with ID tag. In order to know the obstacle is on the left or on the right of mobile robot, and narrow the area where the obsatcle with ID tag exists, the mobile robot moves along the detection

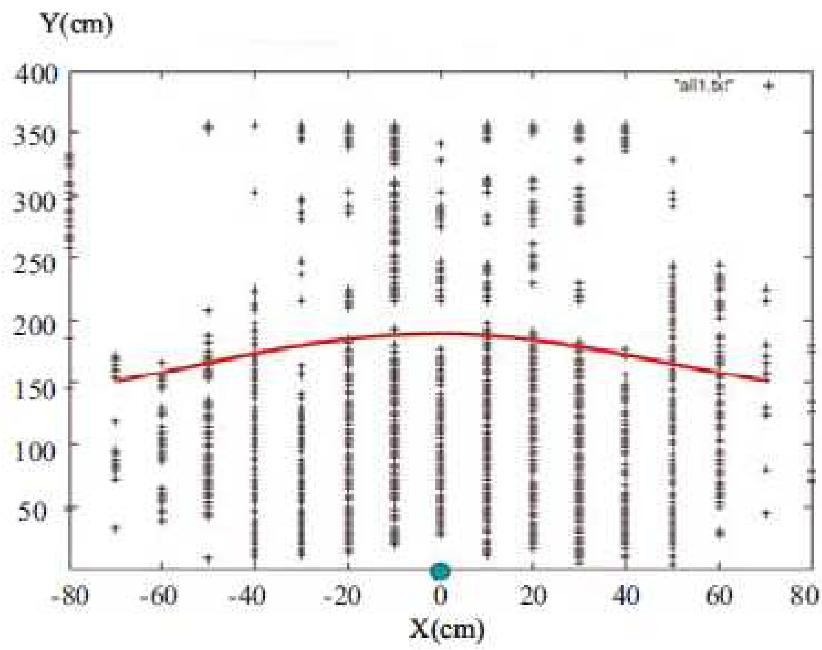

Fig. 5. The data distribution of the RFID.

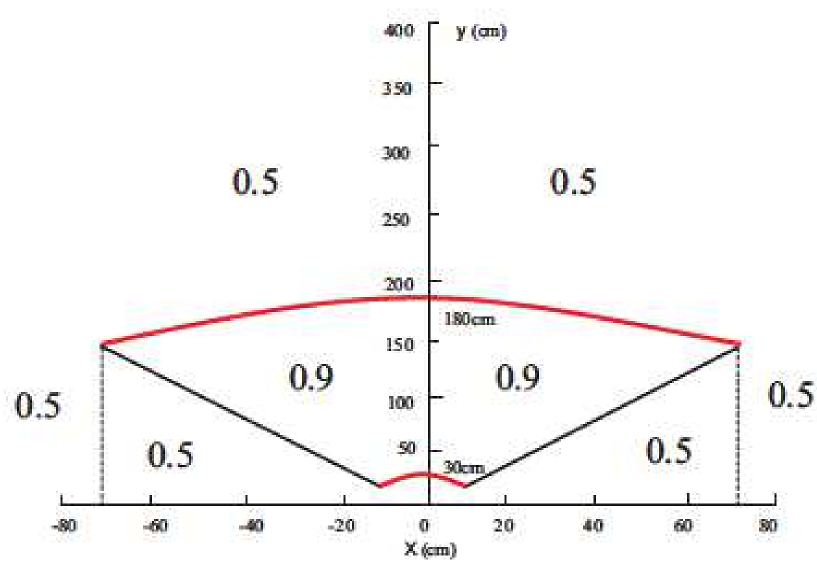

Fig. 6. Simplified sensor model for antenna.

trajectory. Because the relative offset between ID tag and antenna affects on the P(O|E), the posterior $P_t(E|O)$ is different when the robot changes its relative position. Whenever the reader mounted on the robot detects a ID tag after robot was changing its relative position, the posterior $P_t(E|O)$ of each cell of map is updated according to recursive Bayesian equation and using sensor model (Figure 6), and a new probability map was generated. The cell center position of the maximum probability in the latest map after mobile robot finishes its detection trajectory is considered as the position of obstacle with ID tags. Figure 8 illustrates the detection trajectory when the RFID detects a obstacle with ID tag. We have done some experimental results for different angle of curve of detection trajectory, and α = 30° was best.

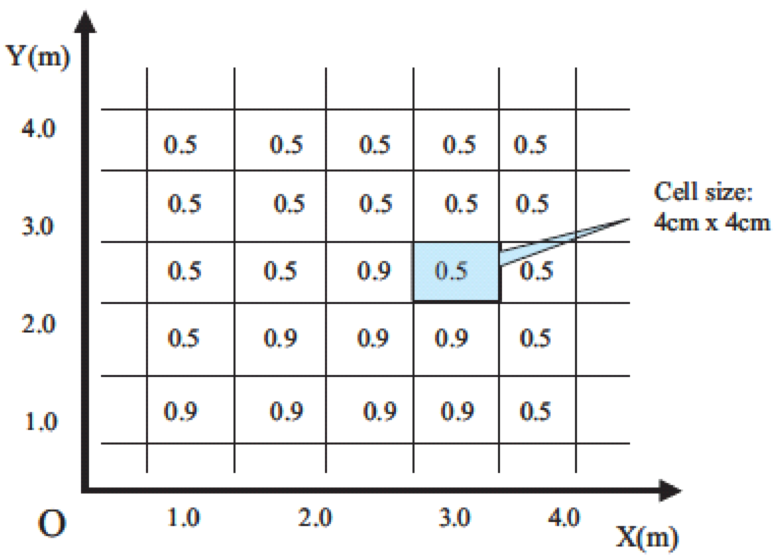

Fig. 7. Probability map of mobile robot.

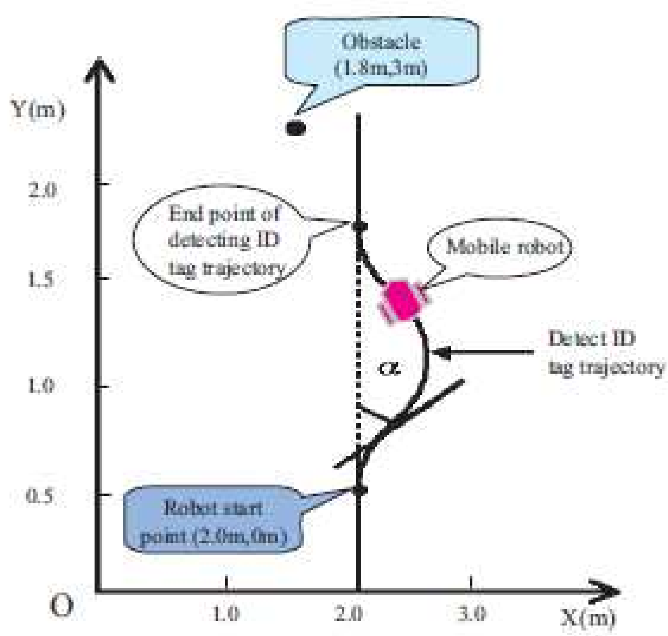

Fig. 8. Detection trajectory for localizing ID tag.

3.2 Simulation and experimental results of obstacle detection using RFID

When the ID tag reader detects a obstacle ID tag, system will generate a 4×4m² map, and do cell splitting. The cell size is 4×4cm², which is regarded as the accepted precision in navigation research fields. Mobile robot moves alone a trajectory and updates the probability of each cell at a constant time stamp, then we can calculate the cell which has maximum probability. Figure 9 shows some simulation results and Figure 10 shows some experimental results. According to the results shown in Figure 9 and Figure 10, we can localize the RFID tag within the area about 0.1m² for simulation results, for experimental results, it is about 0.26m². So, the error of experiment results of localization of mobile robot is bigger than the results of simulation. This is because that the communication between ID Reader and ID Tags uses Radio Frequency, Radio Frequency is not so stable, and the sensor model is not so accurate. In order to improve the accuracy of localization of obstacles just using RFID tag, we will use stereo camera to recognize the obstacle objects further according to the information of obstacle written in ID tags.

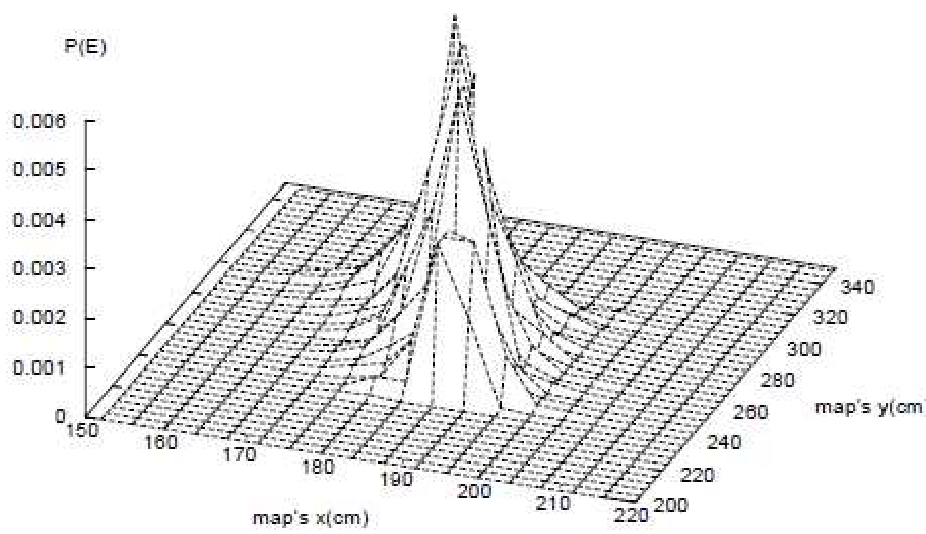

Fig. 9. Simulation results of localizing ID tag using Bayes rule.

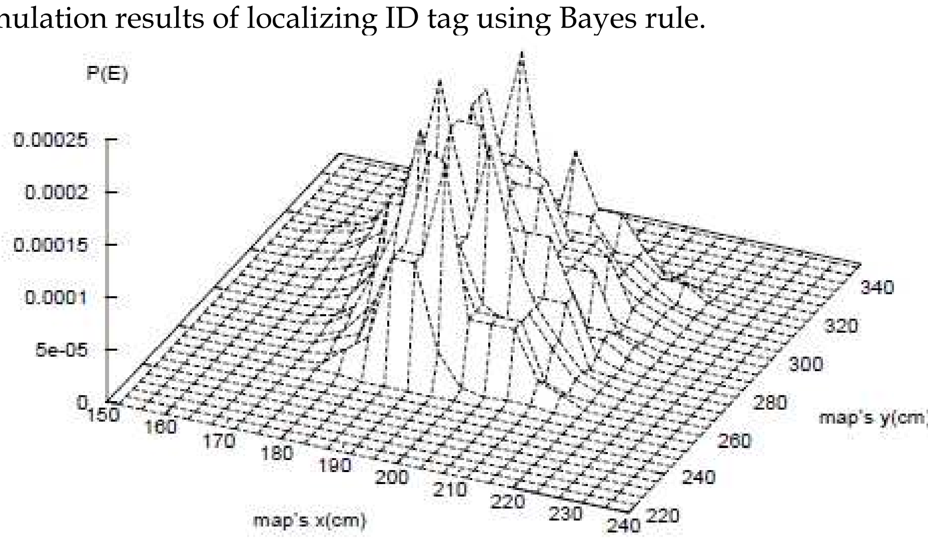

Fig. 10. Experimental results of localizing ID tag using Bayes rule.

4. Obstacle localization using RFID and stereo camera

Bayes rule was introduced to calculate the maximum probability where the obstacle exists, but the precision is not enough for navigating a mobile robot. Thus, we use the results of the Bayes rule to determine the ROI that stereo vision needs to process in order to get the posture of the obstacles much more precisely. For obstacles such as chairs, we developed the processing algorithm as follows:

- Open the stereo camera to grab images.
- Set up the configuration of the camera.
- Preprocess the images taken by the stereo camera.
- Do RGB–HSV conversion, morphologic operation and labeling processing according to the information about the obstacle written in the ID tag for the ROI of the input image obtained by the Bayes rule.
- Calculate the position (x, y) and orientation (θ) of the obstacle according to the results of the imaging process
- Get the depth of the obstacle by the information of the depth image obtained from stereo vision.

Human detection is indispensable when the mobile robot performs a service task in an indoor environment (office, facilities or at home). Detection of the human body is more complicated than for objects as the human body is highly articulated. Many methods for human detection have been developed. Papageorgiou and Poggio [C. Papageorgiou et al., 2000] use Haar-based representation combined with a polynomial support vector machine. The other leading method uses a parts-based approach [P. Felzenszwalb et al., 2005]. Our approach first uses the Bayes rule to calculate the probability where the human exists when the RFID reader detects a human with the ID tag, then the stereo camera starts to perform image processing for the ROI determined by Bayes rule results. The depth information of the ROI from the depth image can be obtained from stereo vision and the histogram of pixels taken for the same distance of the obstacles was built:

$$P_{\text{obstacle}}(m) = \sum_{i=0}^{w} \sum_{j=0}^{h} f_m[i,j]$$

Here, $P_{obstacle}$ is the number of pixels for the m obstacle having the same depth in the image. *W* is the width variable of object, *h* is the height variable of the object. For each $P_{obstacle}$, the values of pixel aspect ratio are calculated by image processing, and then the most fitting value to the human model was selected as candidate of human body. Because the human part from shoulder to face is easy to be recognized and is insensitive to the variations in environment or illumination, we make the second order model of human. We calculate the vertical direction projection histogram and horizontal direction projection histogram. The top point of vertical direction projection histogram can be thought the top of head. The maximum point in vertical axis around the top of head was thought as the width of head. According to the human body morphology, the 2.5 to 3 times height of the width of head can be thought the height of human from face to shoulder. Figure 11, 12, 13 shows one sample of second order model of human.

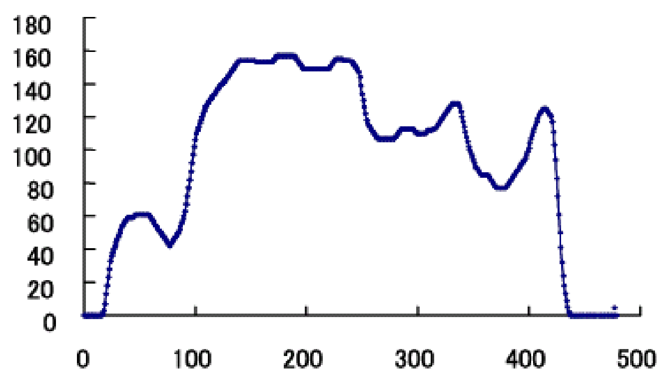

Fig. 11. Vertical direction projection histogram.

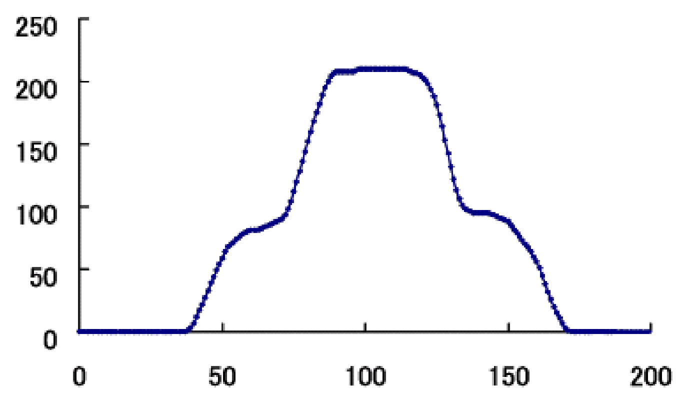

Fig. 12. Horizontal direction projection histogram.

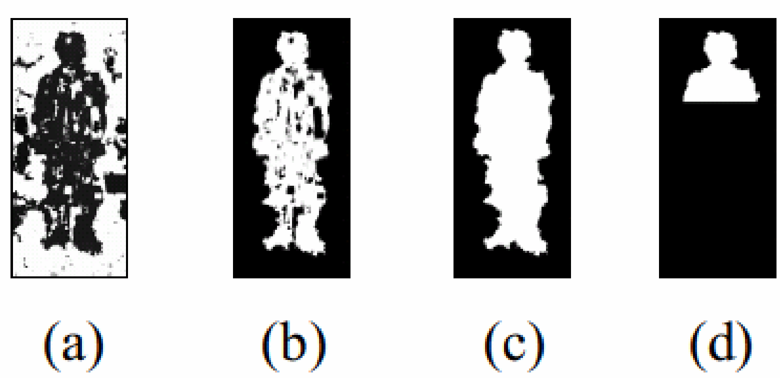

Fig. 13. The second order model of human.

For the obstacle having the same aspect ratio with human body, we introduce Hu moments invariants as feature parameters to recognize second order human body model further. Hu moment invariants are recognition method of visual patterns and characters independent of position, size and orientation. Hu moment defined the two-dimensional (p+q)th order moments in discrete can be defined as following equation.

$$m_{pq} = \sum_{i=0}^{N} \sum_{j=0}^{K} i^p j^q f(i,j)$$

Here, p, q=0, 1, 2....
The central moments $m\mu_{pq}$ are defined as

$$mu_{pq} = \sum_{i=0}^{N} \sum_{j=0}^{K} (i - \bar{x})^p (j - \bar{y})^q f(i, j)$$

Here, $\bar{x} = m_{10}/m_{00}$, $\bar{y} = m_{01}/m_{00}$.
It is well known that under the translation of coordinates, the central moments do not change. The (p+q)th order central moments for image f(i, j) can be express as:

$$\eta = \mu_{pq} / \mu_{00}^{r}$$

Here, r= (p+q+2)/2, p+q>2. For the second and third order moments, we can induce six absolute orthogonal invariants and one skew orthogonal invariant. Using these seven invariants moments can accomplish pattern identification not only independently of position, size and orientation but also independently parallel projection. Using this method first learned a number of patterns for human and chair, then calculated the seven invariants moments. According to the results, the seven invariants moments of human are almost the same in spite of the position of human in image changing, and the seven invariants moments of chair is different from that of human (Figure 14). The average value of seven invariants moments of a number of patterns for human was used as character parameters for human recognition. For the new input ROI image, first calculate the seven invariants moments of the obstacle, then get the Euclid distance by the equation

$$d_i = \sqrt{\sum_{i=0}^{6} (X_o{}^r - X_i^h)}$$

Here, X_i^h is the seven invariants moments of human calculated in advance, and X_o^i is the seven invariants moments of the obstacle. If $d_i < L_i$ is satisfied, the obstacle is recognized as human.

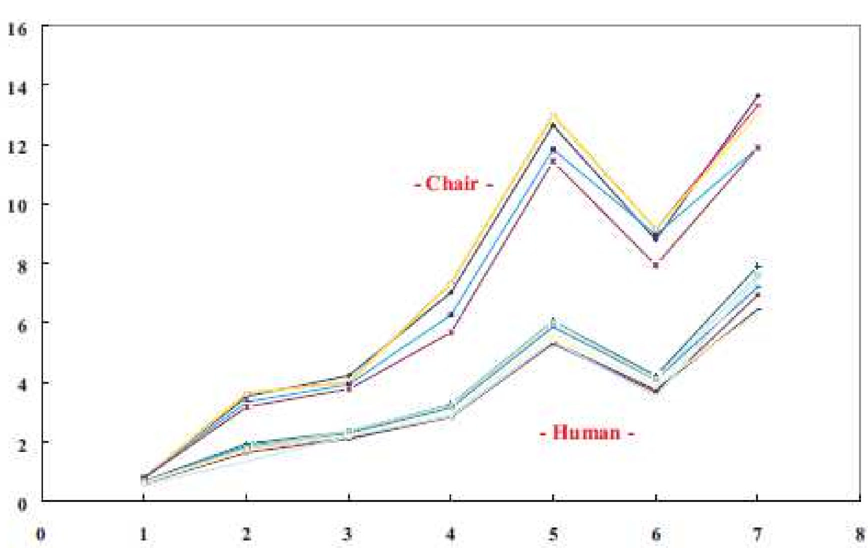

Fig. 14. Hu seven invariants moments of human.

5. Obstacle avoidance

The Obstacle Avoidance Module calculates the avoidance area and route for the mobile robot to avoid the obstacle after the obstacle has been detected. After the tag reader detects the ID tag and localizes the obstacle using the Bayes rule, the mobile robot will determine how to avoid this obstacle. Figure 15(a) shows the flowchart of obstacle avoidance algorithm. Figure 15(b) shows the real obstacle-avoiding route that was calculated. First, the mobile robot will determine the avoidance area (R) to judge if the mobile robot can directly pass obstacle. The avoidance route will be generated for the mobile robot by the Obstacle Avoidance Module if the mobile robot cannot pass directly:

$$R = r + r_{err}$$

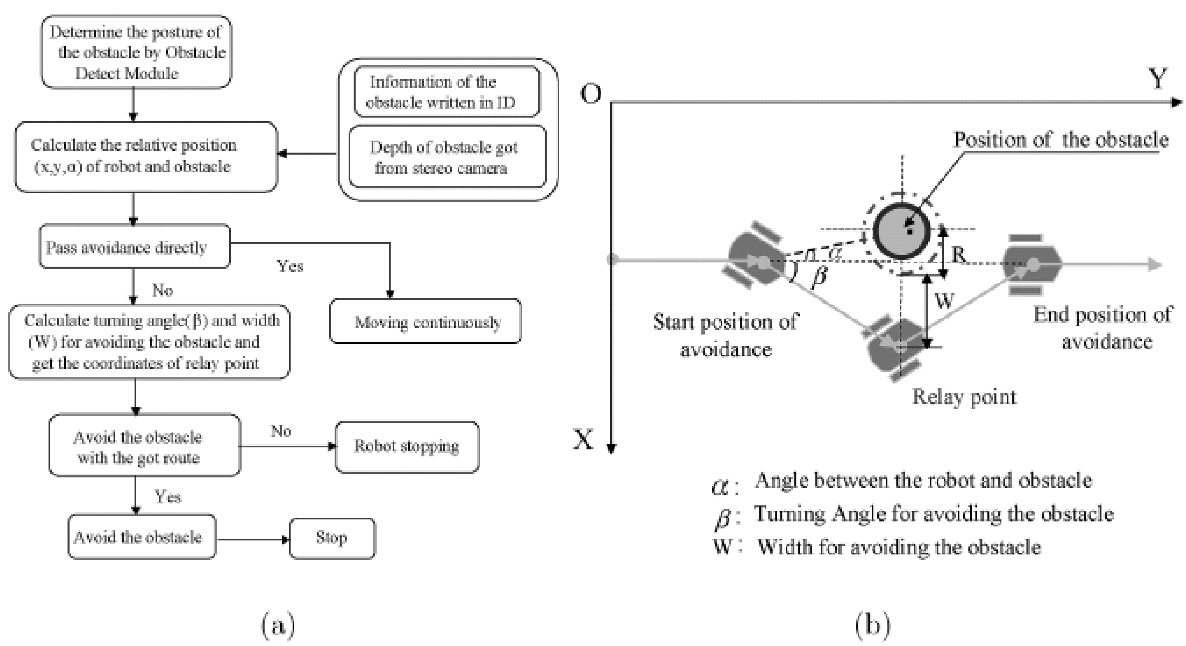

Fig. 15. Flowchart and route of obstacle avoidance.

where r is the radius of the circumscribed circle of the obstacle and r_{err} is the error of the position of the detected obstacle.

6. Robot localization using RFID and stereo camera

The Robot Localization Module localizes the mobile robot when the tag reader detects the ID tags of localization. We propose the localization method for an indoor mobile robot using RFID technology combining stereo vision. First, the RFID reader detects the ID tags and judges whether they are localization tags or not. If ID tags for localization are detected, then the system starts the stereo camera system to recognize the ID tags, and calculates the pose of the mobile robot according to the information written in the tags and the results of image processing. The Bumblebee camera was used and was connected with a notebook computer, and the image processing calculation was run on a notebook computer. The results of information about the position and orientation of the mobile robot were sent to the mobile robot controller and the mobile robot controller sends the commands to adjust the pose of the mobile robot to return its desired position to finish a task.

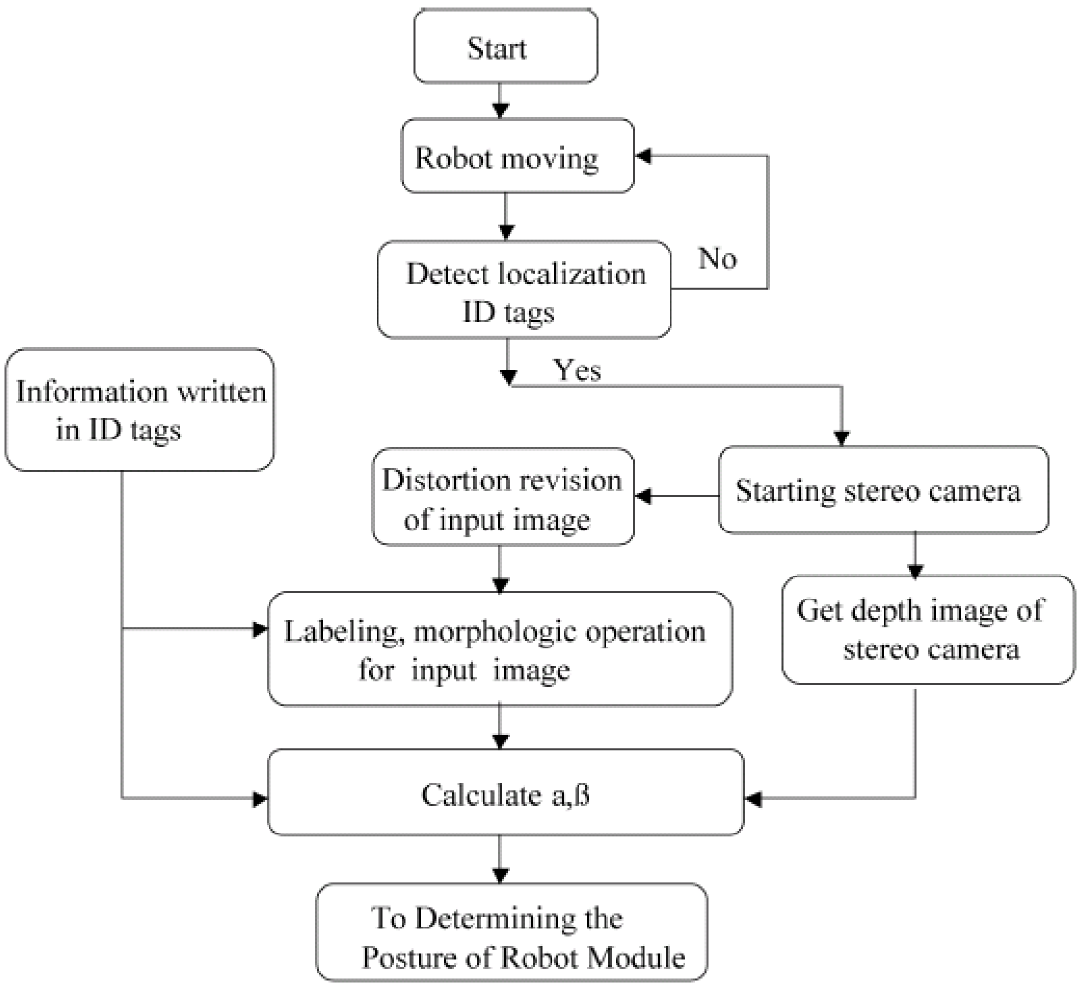

Fig. 16. Flowchart of localization of the mobile robot.

6.1 Landmark recognition

Landmark Recognition Module is used to take the images of the environment when the ID tags for localization are detected, perform image processing and localize the ID tags. Landmark recognition [K. E. Bekris., 2004] for localization of a mobile robot is a popular method. The image processing computation of the usual landmark recognition methods is enormous because the vision system needs to recognize all kinds of landmarks in real-time while the mobile robot moves. As the system can get tag information of the environment such as their world coordinates when the RFID detects a tag, the proposed method of the localization method of a mobile robot just does image processing after the RFID system detects ID tags for localization. It is helpful to decrease the image processing computation and to improve dynamic obstacle recognition (e.g., a person or chair). Figure 16 illustrates the flowchart of localization of the mobile robot. The image processing of recognizing the ID tags for localization includes:

- Open the stereo camera to grab images.
- Set up the configuration of the camera.

- Preprocess the images taken by the stereo camera.
- Perform RGB binary processing, exclude noise, perform template matching with threshold.
- Get the coordinates of the ID localization tags of the left and right images.
- Perform stereo processing to get the world coordinates of the ID tags.
- Calculate α and β (see Fig. 17) in order to determine the position and orientation of the mobile robot.

6.2 Determining the posture of the robot

Determining the Posture of the Robot Module is used to calculate the position and orientation of the mobile robot using the information of the Landmark Recognition Module and the information written in the ID tags. Figure 17 illustrates the principle of the proposed method of localization of the mobile robot. Four ID localization tags are used as one set and

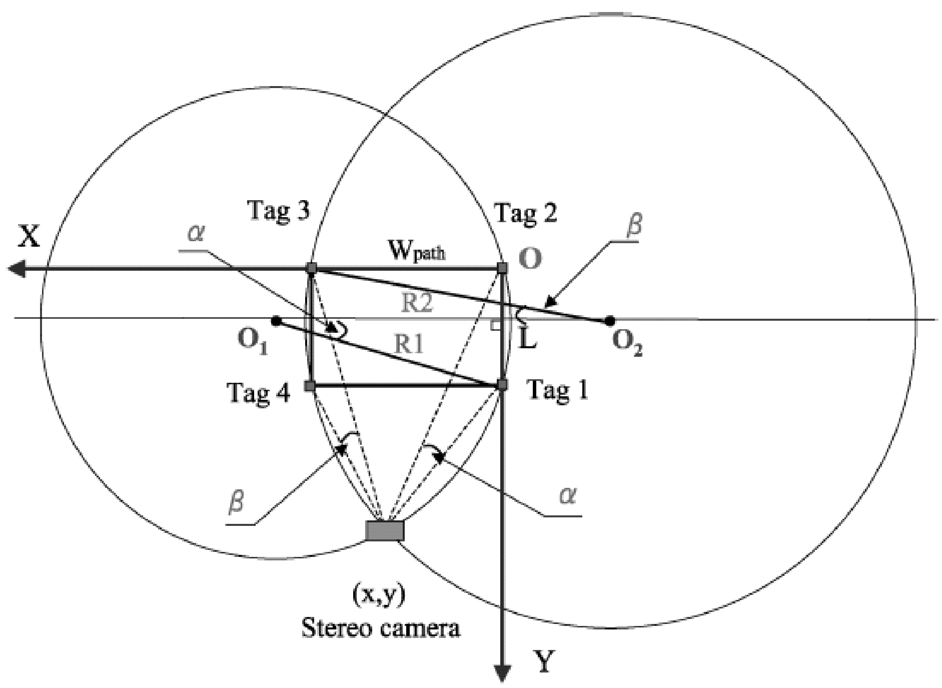

Fig. 17. Principle of localization of the mobile robot.

are affixed in the environment. Since the ID tag's absolute coordinates are written in them in advance, the RFID reader can read out their information simultaneously when it detects tags. α and β can be determined by the Landmarks Recognition Module, the position (x, y) and orientation (ε) of the mobile robot can be calculated by

$$x = \frac{(W_{\text{path}} - R_2 \cos\beta)^2 + R_1^2 \sin\alpha^2 - R_2^2}{2(W_{\text{path}} - R_2 \cos\beta - R_1 \cos\alpha)}$$

$$y = \frac{L}{2} + \sqrt{R_1^2 - (x - R_1 \cos\alpha)^2}$$

$$\epsilon = \arctan\frac{x}{(y - L)} - \delta,$$

where W_{path} is the width of the passage, L is the distance between tag 1 and tag 2 or tag 3 and tag 4, R_1 is the radius of circle 1 and R_2 is the radius of circle 2. α is the angle between the center of the camera to tag 1 and the center of the camera to tag 2. β is the angle between the center of the camera to tag 3 and the center of the camera to tag 4. δ is the angle between the orientation of the camera and the centerof the camera to tag 1.

6.3 Path planning

A Path Planning is necessary and improtant issue for calculating the optimal route for the mobile robot to move in order to perform a service task autonomously in indoor environment. Many reseachers give their effrot on path planning for mobile robot to finish a task costly and efficiently. In our research, we also proposed method of path planning for our mobile robot system. As we know, each ID localization tag has a unique ID, so each ID localization node (consisting of four ID localization tags; the center of the four ID localization tags is defined as the position of the ID localization node) can indicate an absolute position in the environment. All the nodes make up a topologic map of the indoor environment in which the mobile robot moves. For example, if the mobile robot moves from START point A to GOAL point F, the moving path can be described with the node tree shown in Fig. 18. The system searched the shortest path between the START and GOAL node (e.g., the shortest path between A and F is A→B→ C→D→F) by tracing the branches between them.

In order to navigate a mobile robot in an indoor environment, building a map is a big problem. Generally, there are two kinds of map, one is geometric approaches, and the second is topological map which can be thought of as robot-centric, or representations in sensor space. In our system, the topological map based on RFID and vision for the mobile robot was developed. For building a topological map, we use a 6-bit decimal numbe to represent the connectivity of ID localization nodes and the relative direction angles between every two adjacent ID nodes.

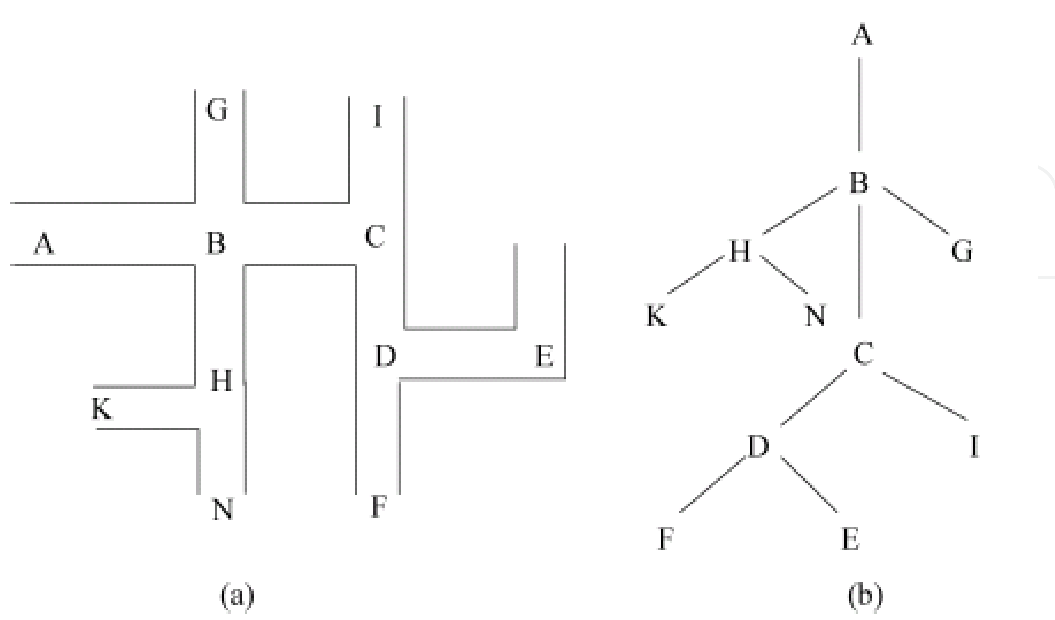

Fig. 18. Movement path and its description with nodes.

7. Experimental results

The experiment of obstacle detection was performed by the proposed method using RFID technology and stereo vision. ID tags were affixed to the obstacles of the environment. When the mobile robot mounted on the RFID reader moves close to the chair, the tag reader can detect the ID tags. When the mobile robot detected an obstacle using the RFID system, the area of the obstacle existing in high possibility was determined using Bayes rule together with the information about the obstacle written in the ID tag. Then the ROI value of the image to be processed can also be determined. Figure 19(a) shows one sample of the distortion revision of the input image from stereo camera. Figure 19(b) shows the depth image for the input image from the stereo camera. Figure 19 illustrates one sample of image processing for a ROI image to recognize the obstacle (chair). We have done some experiments for comparison of the processing image time using the proposed method. The experiments were done by image processing from taking raw images (640×480), doing HSV conversion, morphologic operation, and labelling processing. For the common method, the average processing image time was about 295ms, and that of the proposed method was about 125ms.

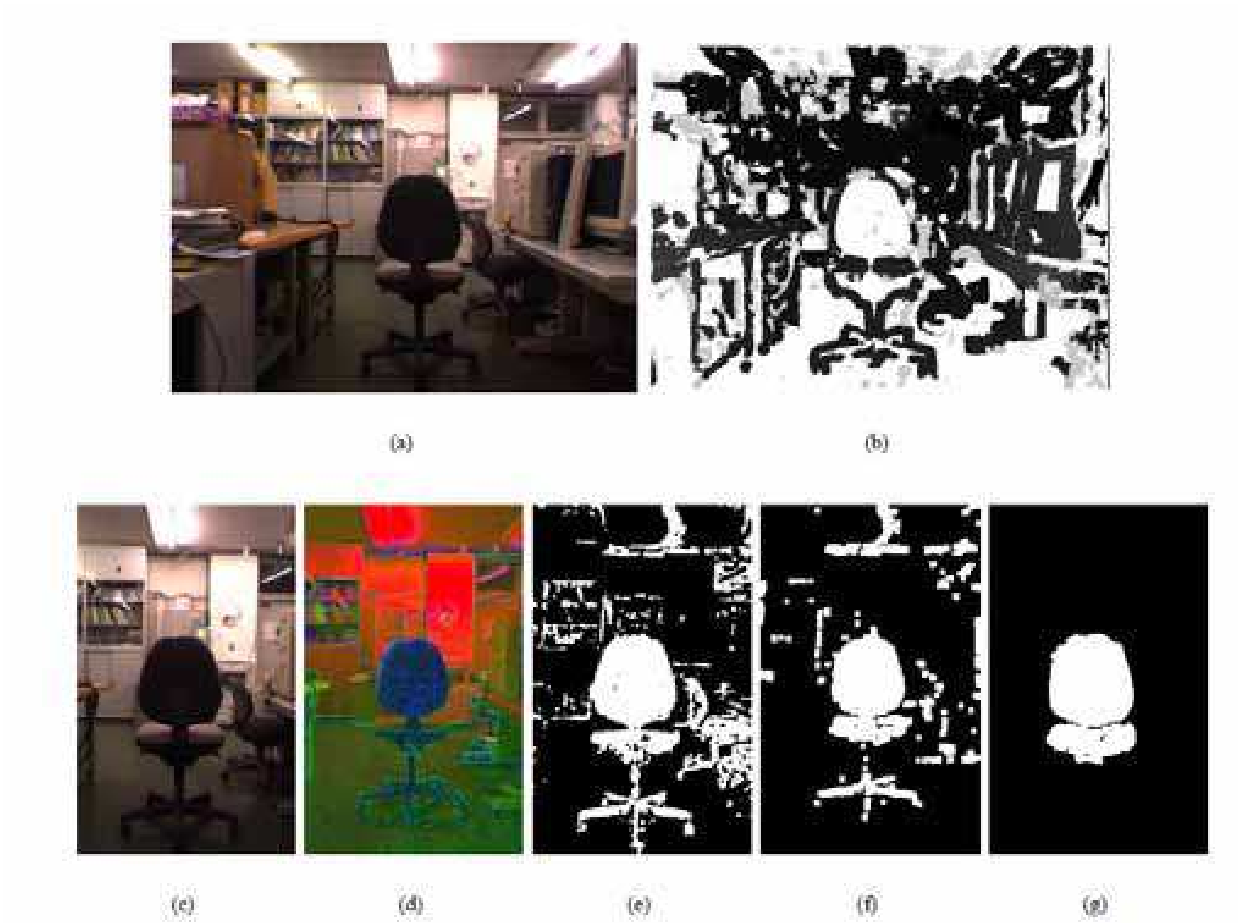

Fig. 19. Obstacle recognition experimental results using the proposed system.

Human detection experiments were also performed in our laboratory. Figure 20 illustrates the results of detecting a human body using the proposed algorithm. Figure 20(a) is the input image with distortion revision from the stereo camera and Figure 20(b) is the depth image. We used the Bayes rule to calculate the probability to narrow the human location and then determined the ROI value (Figure 20(c)). Figure 20(d) is the histogram built according to the depth image. Comparing the human pixel aspect ratio in the image, we can successfully detect the centre of gravity of the human as shown in Fig. 20(g).

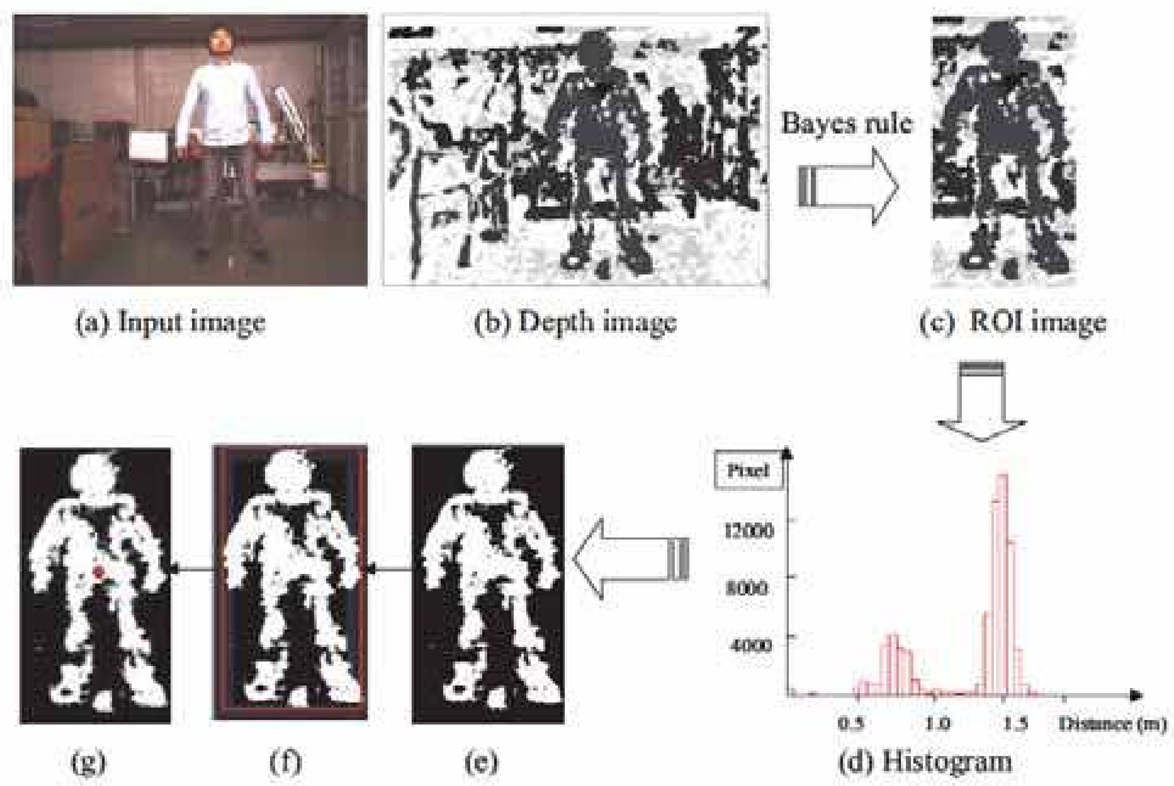

Fig. 20. Human detection experiment: (a) input image, (b) depth image, (c) ROI image after narrowing the human using Bayes rule, (d) histogram, (e) binary image, (f) image with human pixel aspect ratio detected and (g) resulting image with the centroid detected.

The obstacle avoidance experiments have been performed in an indoor environment. When the position of the obstacle was localized, the avoidance area and route were determined for the mobile robot to avoid it. Figure 21 shows the experimental results of the mobile robot avoiding the obstacle (chair) using the proposed method of integrating RFID and stereo vision. Figure 21(a–e) shows the obstacle on the right of the mobile robot and Figure 21(k–o) shows the obstacle on the left of the mobile robot. Figure 21(f–j) shows that the mobile robot was not disturbed by the obstacle and the mobile robot did not need to change its movement route. According to the experimental results of Figure 21, we know that the proposed method can detect an obstacle and enable an indoor mobile robot to avoid the obstacle (chair) successfully in different cases.
We proposed a localization method of an indoor mobile robot using RFID combining stereo vision to decrease the image processing computation and improve dynamic obstacle recognition (such as a person or chair). When the RFID system detects ID tags for localization of a mobile robot, the stereo camera will start to recognize the ID localization tags as landmarks. Then the position and orientation of the mobile robot can be calculated according to the information written in the ID tags. This experiment of localization of mobile robot was performed in a passage (width: 233 cm) in our corridor of our lab, and the tags

were fixed on the wall at 117 cm intervals. The mobile robot moved from a random position and orientation and, after localization, it can move back to the centreline of the passage. The average error of localization of the mobile robot is about 8.5 cm. Figure 22 illustrates some experimental results of localization of an indoor mobile robot. According to the experimental results, we know the proposed method of localization for mobile robot using RFID and stereo vision was effective.

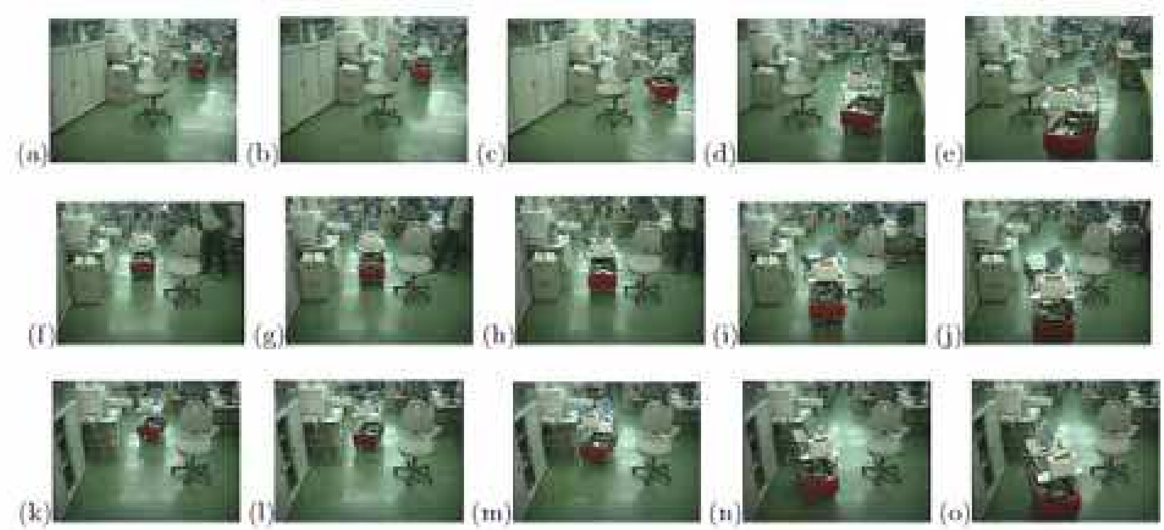

Fig. 21. Obstacle avoidance experimental results using the proposed system.

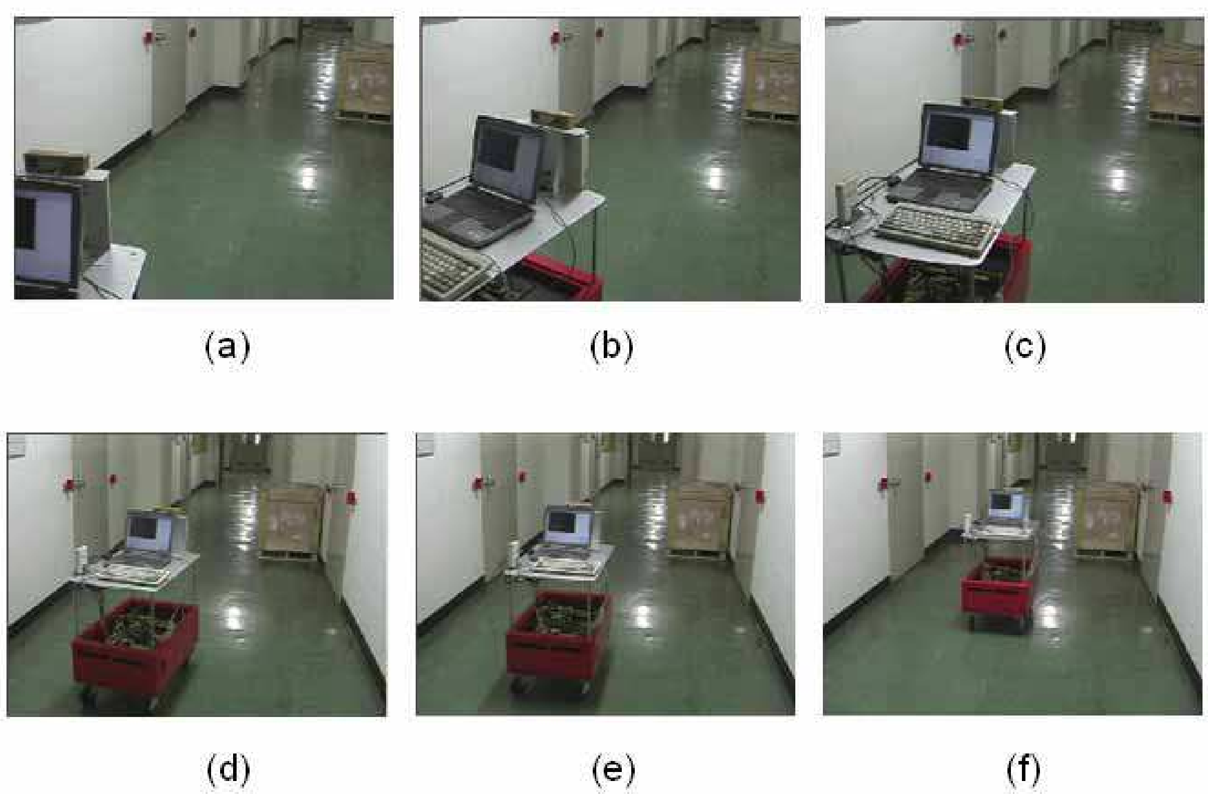

Fig. 22. Experiments of localization of a mobile robot.

8. Conclusion

This paper presents the proposed method of obstacle recognition and localization of a mobile robot with RFID technology and stereo vision. We developed hardware and software such as the Obstacle Detecting Module, Obstacle Avoidance Module, Robot Localization Module, Landmark Recognition Module, Determine the Posture of Robot Module, Path Planning Module and Communication Module. In order to improve the accuracy of localizing the ID tags, Bayes rule was introduced to calculate the probability where the ID tag exists after the tag reader detects a tag. Experiments with RFID technology integrating stereo vision for obstacle detection and localization of an indoor mobile robot have been performed. As the system can obtain tag information of the environment such as obstacle and the world coordinates when the RFID detects a tag, the proposed method is helpful to decrease the image processing computation, and improve dynamic obstacles recognition (such as a person or chair) and occlusion problem. The experimental results verified that the proposed method was effective. The main topic for future work will be performing home service tasks by using the proposed method to aid the aged or disabled.

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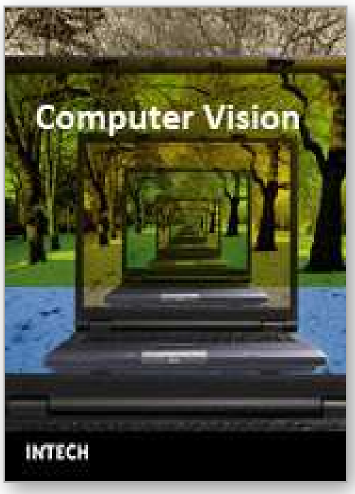

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This book presents research trends on computer vision, especially on application of robotics, and on advanced approachs for computer vision (such as omnidirectional vision). Among them, research on RFID technology integrating stereo vision to localize an indoor mobile robot is included in this book. Besides, this book includes many research on omnidirectional vision, and the combination of omnidirectional vision with robotics. This book features representative work on the computer vision, and it puts more focus on robotics vision and omnidirectioal vision. The intended audience is anyone who wishes to become familiar with the latest research work on computer vision, especially its applications on robots. The contents of this book allow the reader to know more technical aspects and applications of computer vision. Researchers and instructors will benefit from this book.

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