Indoor Pictures Monitoring System using a Mobile Robot

Tsutomu TAKESHITA, Akihisa OHYA and Shin'ichi YUTA

Institution: Intelligent Robot Laboratory, University of Tsukuba
Address: 1-1-1 Ten'noudai, Tsukuba, Ibaraki, 305-8573, Japan
E-mail: {benben, ohya, yuta}@roboken.esys.tsukuba.ac.jp

1. Introduction

Security is essential in museums for detecting theft or damage. Nevertheless, because security is often accompanied by hazards, automation must be performed[1)2)3)]. For example, robots are now being used in security applications[4)5)6)7)8)9)]. Security robots have good area coverage with few blind spots and can find intruders autonomously. However, they are not capable of monitoring valuable objects themselves, because their main aim is to find human intruders in a building. So we develop using a mobile robot with a camera to find abnormalities of monitored objects. The defined tasks are patrolling and monitoring exhibits in a museum. The method for monitoring objects and also detecting damage is by comparing images. In addition, the targets are not intruders, instead, we focus on monitoring exhibits in this research.

2. Outline of this system

An outline of this target system is Fig.1. First, the robot with a camera patrols indoor and takes images of normal exhibits beforehand as in Fig.1 (a). These are the standard images. Second, the robot monitors and patrols along the route in Fig.1 (b). The robot moves to the same position where the standard images were taken, then captures new images. These are the test images. Finally, the robot compares a standard image and a test image, and checks for discrepancies as shown in Fig.1 (c). Then, if there are discrepancies, the robot sends a message that the exhibit is abnormal to the monitoring center where a person stays. In addition, the target abnormalities for detection in this research assume replacement, theft and damage.

As previously noted, it is necessary to perform the following three tasks for the system.

1. The robot patrols automatically in the museum.
2. The robot takes test images with minimal error to the taken standard images.
3. Compare the test image and the standard image.

As for above 1, this has already been realized in [4)5)6)7)8)9)]. This research aims to realize above 2 and 3. Particularly 2, the method of taking test images, will be the main focus of this research. A separate section, section 3, will explain this method in detail. Furthermore, this paper will discuss the developed Picture Monitoring System (in section 5).

3. Taking test images

The mobile robot moves to target position estimated using odometry. Odometry is a way to presume the robot's position by measuring its wheel rotation. But because odometry has accumulated errors occurring from slip and other factors, the robot gradually misses the planned route. This may cause possible errors in taking test images, therefore, a special method is necessary for taking images. There must be minimum error between the locations where the standard and test images are taken. This research used the following two procedures.

1. The robot moves to the position as accurately as possible using image processing and odometry (correcting a robot's position).
2. Remove small errors the robot can't modify by transforming the image (modifying an image).

This section will describe the method for realizing the above two modifications and calculating the robot's relative position from each picture which is necessary for the modification.

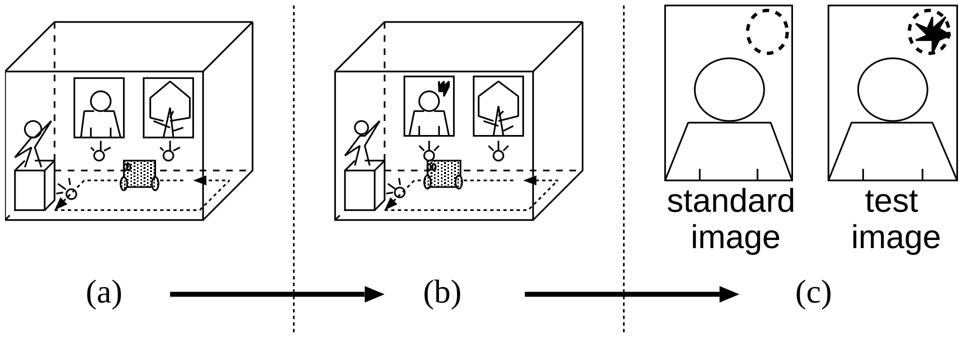


Fig.1 Procedures of the indoor monitoring system ((a): Take standard images, (b): Take test images, (c): Compare images)

3.1 Calculating a robot's position

First, it is necessary to calculate the robot's relative position from each picture for realizing 1 and 2 in section 3. In this section the method of calculation will be presented.

First, a coordinate system is set from a picture as Fig.2 (a). Fig.2 shows the state with the robot on (x, y, θ). The camera is set on the center of the robot and it is turned 90° left from the heading direction.

Initially, we calculate a_1 and a_2 in Fig.2. These a_1 and a_2 show the length of perpendicular lines from the camera to the edges of the picture in Fig.2 (a). First, the robot gets coordinates of four corners of the picture in the image by using a method described later, then calculates the (pixel) length of the right and left edges from the image plane. These are h_1 and h_2. In Fig.2 (b), a_1 and a_2 can be calculated using the camera's focal length F, as the following equations shows. Actually, d_1 and d_2 is the real length of the picture's edge, its length is measured beforehand.

$$a_1 = \frac{Fd_1}{h_1}, \qquad a_2 = \frac{Fd_2}{h_2} \tag{1}$$

Next, the method of calculating the robot's position (x, y, θ) is shown. First, the robot calculates b_1 and b_2 by using above a_1 and a_2. In Equation (2) u_1 and u_2 are the lengths from the edges of the picture in the image to the center of the image.

$$b_1 = \frac{a_1 u_1}{F}, \qquad b_2 = \frac{a_2 u_2}{F} \tag{2}$$

By using these, θ can be calculated.

$$\theta = \tan^{-1}\left(\frac{a_1 - a_2}{b_1 + b_2}\right) \tag{3}$$

Then, θ_1 and θ_2 are expressed with equations.

$$\theta_1 = \tan^{-1}\left(\frac{b_1}{a_1}\right), \qquad \theta_2 = \frac{\pi}{2} - (\theta + \theta_1) \tag{4}$$

Finally, x and y can be calculated with the following equations.

$$x = \sqrt{a_1^2 + b_1^2}\cos(\theta_2), \qquad y = -\sqrt{a_1^2 + b_1^2}\sin(\theta_2) \tag{5}$$

By using the above approach, the robot's position can be calculated.

As mentioned above, it is necessary to calculate the length of the right and left edges from the image plane for calculating the robot's position. For that purpose, the robot gets the coordinates of four corners of the picture in the image. The method of determination is by taking the edges of the picture by using Hough transformation. This process is following.

1. Determine the second differential of the image taken by the camera.
2. Perform the Hough transformation on the image, using some threshold level determine the straight lines from the maxima in the Hough space.
3. From the center of the image, determine the longest straight lines. (one to the left, right, top and bottom) (See Fig.3).
4. Find the intersections of the lines, which are the corners of the picture.

As described above the robot is able to determine the coordinates, but it takes a significant amount of time to perform this process. Thus, Hough transformation is done only to establish the coordinates when the robot takes standard images. Template matching is used to determine the coordinates when the robot takes test images while patrolling. Template matching is an operation which searches an image for a pattern with high correlation for a certain template image. The four corners of the standard images are used as template images and utilized to process images while patrolling. The coordinates of the four corners of the pictures are found with the coordinates of the highest correlation to the template.

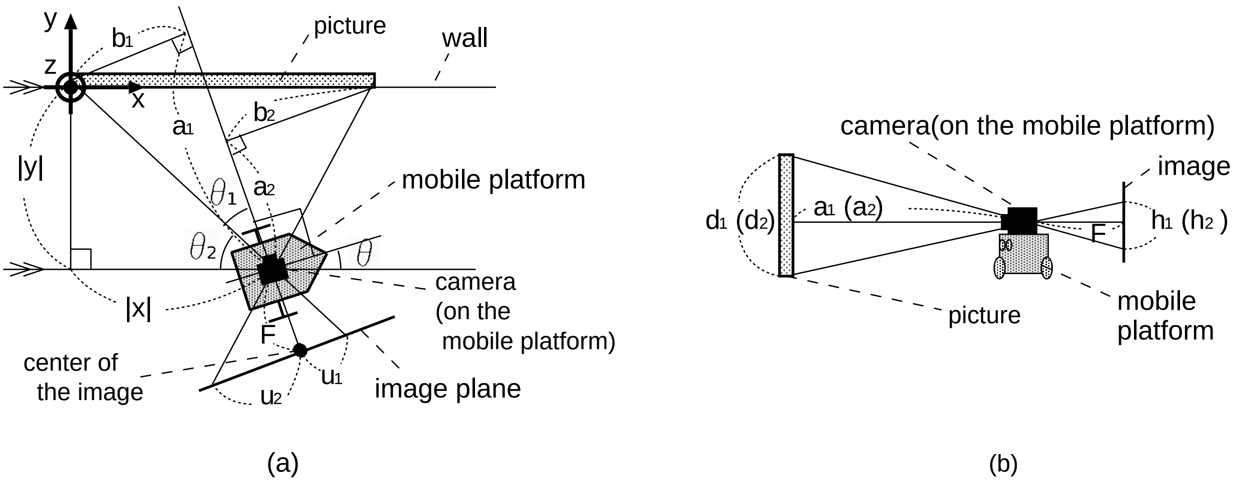


Fig.2 Method of calculating the positional relationship of the picture, the robot and camera ((a): Overhead view, (b): Side view)

Fig.3 Determining the edges of a picture by using Hough transformation

3.2 Correct a robot's position

In order to move to the same position when the standard images were taken as accurately as possible when the robot patrols, the robot does following procedures. First, when the robot takes the standard images, calculates its own position by using the method of section 3.1 and memorizes this (x_s, y_s, θ_s). Next, the robot patrols by using odometry and moves to a position near the general area of the picture, then it calculates its own position (x_c, y_c, θ_c) by using the method of section 3.1. Third, the robot moves to the position (x_s, y_s, θ_s) from the current position (x_c, y_c, θ_c) by using odometry. The robot modifies its own position by repeating this process until it can arrive accurately at the same position when the standard image was taken.

3.3 Modifying an image

It is difficult to ensure that the robot moves to the desired original position perfectly. Therefore, the robot removes the remaining small positional errors by transforming the images themselves. This process is described as follows (See Fig.4).

1. Calculate coordinate (x, y, z) on the real picture corresponding to a pixel (u, v) on the standard image.
2. Calculate the pixel (u', v') on the image taken at the current position corresponding to the coordinate (x, y, z).
3. Calculate the value corresponding to (u', v') from the values of surrounding four pixels by linear interpolation, then put the value on the pixel (u, v).
4. Perform 1. - 3. to all pixels in the image.

Here, the relationship between the pixel (u, v) on the image and the coordinate (x, y, z) on the real picture is shown in Fig.2 and Fig.4. Thus, the pixel (u, v) and the coordinate (x, y, z) can be transformed to each other by using the configuration described in section 3.1.

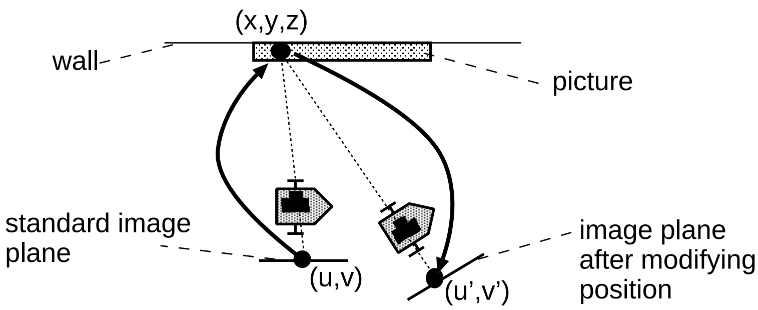


Fig.4 Positional relationship of the robot and a picture used for modifying the image

3.4 Results of taking test images

Fig.5 shows a standard image, an image after patrol, an image after correcting the robot's position and the image after image modification as described above. As shown by Fig.5, errors between the test image and the standard image are removed by these modifications. But, the slight difference between the image after modifying the robot's position and the image after modifying an image is difficult to visualize. This can be viewed from the output of the absolute value of the difference between the standard image and modified test image (based on RGB) and is expressed in Fig.6. As Fig.6 shows, small errors only remain after modifying robot's position. However, these errors can be almost completely removed by modifying the image. As described above, a test image having few errors can be modified to resemble the standard image at normal situations.

4. Comparing images

4.1 Comparison method

A test image with minimal error from the standard image at normal situations can be taken as described in section 3. Comparing images is performed by taking note of these differences. Specifically,

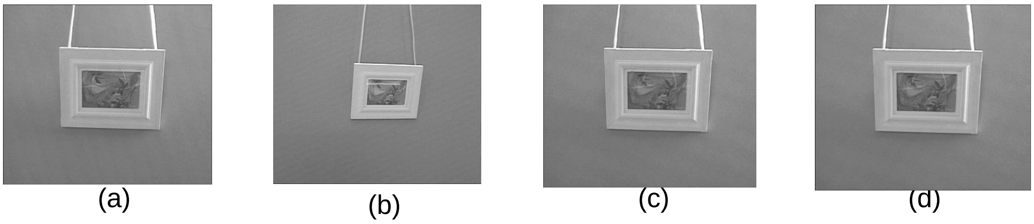


Fig.5 Results of taking test images ((a): A standard image, (b): An image after patrol, (c): An image after correcting the robot's position, (d): The image after modifying the image itself)

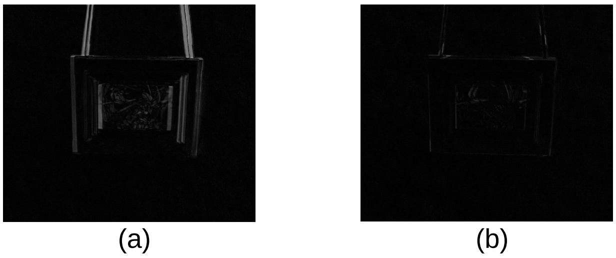


Fig.6 Error between a standard image and a test image ((a): Error between a standard image and a test image after correcting the robot's position, (b): Error between a standard image and a test image after modifying the image itself)

first calculate the sum of absolute values of the differences between a standard image and a test image based on R, G and B colors. Next, recognize an image as abnormal in case the sum exceeds a threshold, and as normal the sum doesn't exceed. And if a picture disappears by theft or is replaced with another one, an error occurring from a template matching in section 3.1 will be also recongnized as abnormal.

4.2 Comparison result

Comparing images is performed by using a standard image, a normal test image and an abnormal test image (pasting a yellow tape about a size of 5mm$\times$30mm) in Fig.7. The size of the real picture is 26cm$\times$21cm and the shooting distance is 80cm. The size of the images are 512$\times$440 pixels, the scale of RGB is 256 levels. Fig.8 (a) is the image output from the absolute values of differences between the standard image and the normal test image. (b) is an image taking by the same process between the standard image and the abnormal test image. As Fig.8 (b) shows, in the case of comparing the abnormal test image, that difference can be detected correctly. Table 1 shows the results of comparing the standard image and the two test images after some trials. Values in the table are the number of pixels where the absolute values of the differences exceed a threshold. Comparing values in the table, this system can recognize the picture as normal or abnormal correctly by setting the threshold properly.

Table 1 Comparison of the standard images and test images (The number of pixels with differences more than 100)

Trials	(1)	(2)	(3)	(4)
The number of pixels (Comparing with normal images)	2	0	15	0
The number of pixels (Comparing with abnormal images)	211	182	260	163

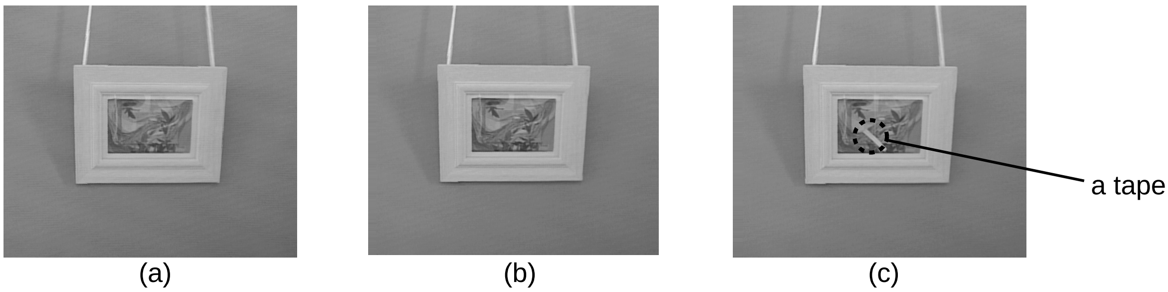


Fig.7 Images for comparing ((a): A standard image, (b): A normal test image , (c): An abnormal test image)

Fig.8 Differential images showing results of comparing images ((a): Difference between the standard image and the normal test image, (b): Difference between the standard image and the abnormal test image)

5. Picture monitoring system

The monitoring system for pictures is constructed using the methodology described above. The system is composed of the robot system and monitoring center as shown in Fig.9. The robot system is built on a mobile platform with a camera, an image processing unit and a notePC. The monitoring center receives the monitoring information and latest test image from the robot system and displays the monitoring status.

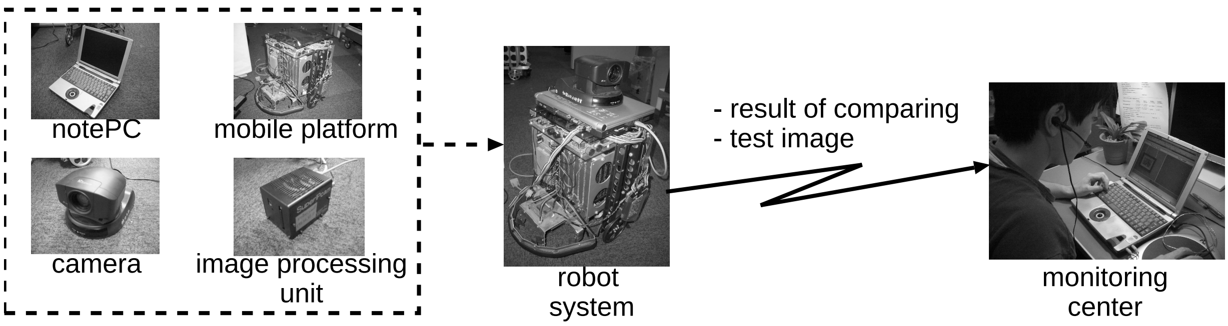


Fig.9 Structure of the robot system

5.1 Monitoring procedures

The monitoring procedures are described in Fig.10. A patrolling route appropriate to the pictures' positions is set in advance. First, the robot takes a picture and memorizes its own position as in Fig.10 (a). The robot performs this process for all pictures in (b). During the process the robot moves by odometry, which is preparation for the patrolling steps. Next, it moves to the patrol position, then takes an image and calculates its position again as in (c). The robot corrects its position by moving to the position (a) from the current position. The process in (c) is repeated until it is able to achieve accuracy within 5 millimeters and 1 degrees from the position (a). Then, the robot gets a test image by modifying the image after correcting its position as in section 3.3. Next, it compares the standard image and the test image in (d) and sends the result to a monitoring center in (e). A decision of the compared result is done by a procedure described in Fig.11. If the robot finds abnormal, it checks again so that it can judge normal or abnormal more precisely. And, the robot system monitors and patrols by repeating (c)-(e) along the route of (b) for all pictures.

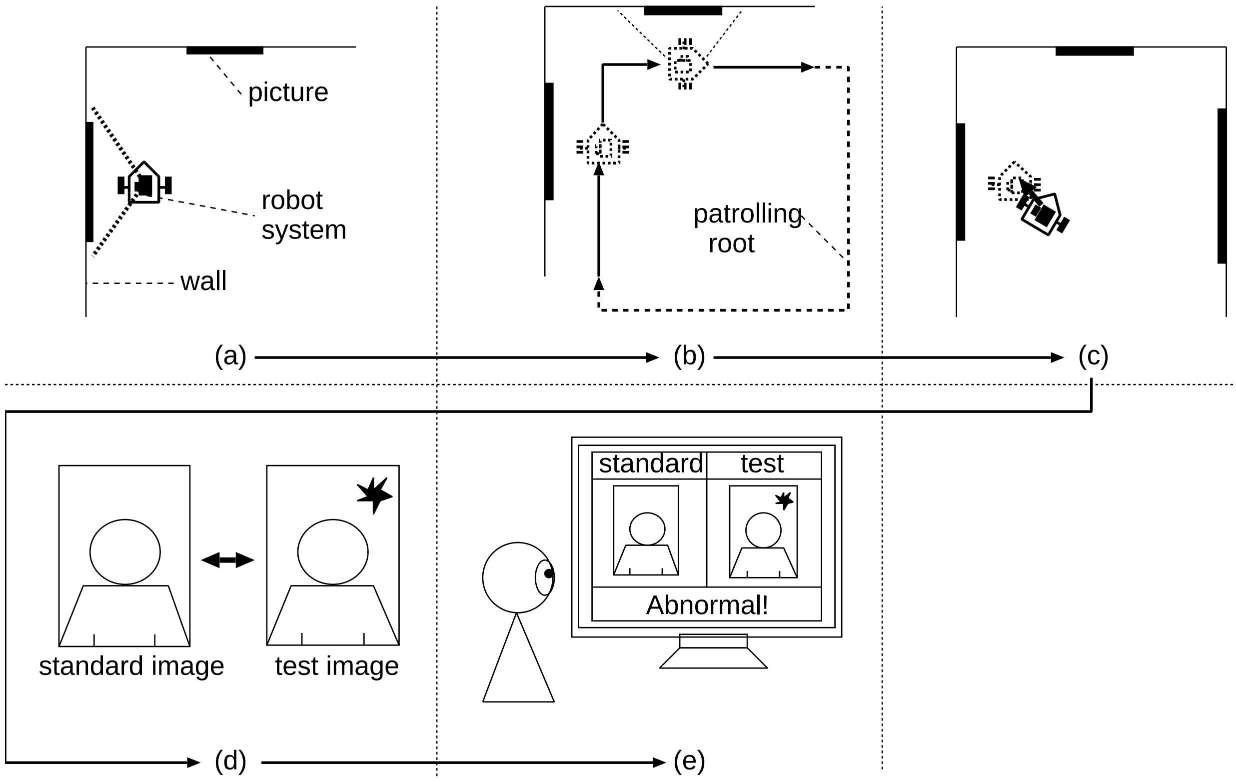


Fig.10 Action of the monitoring system ((a): Taking a standard image and calculating the robot's position, (b): Taking standard images and calculating a robot's positions for all pictures, (c): Taking an image after moving and correcting a robot's position, (d): Taking a test image for modification and comparison with the standard image, (e): Sending a comparison result)

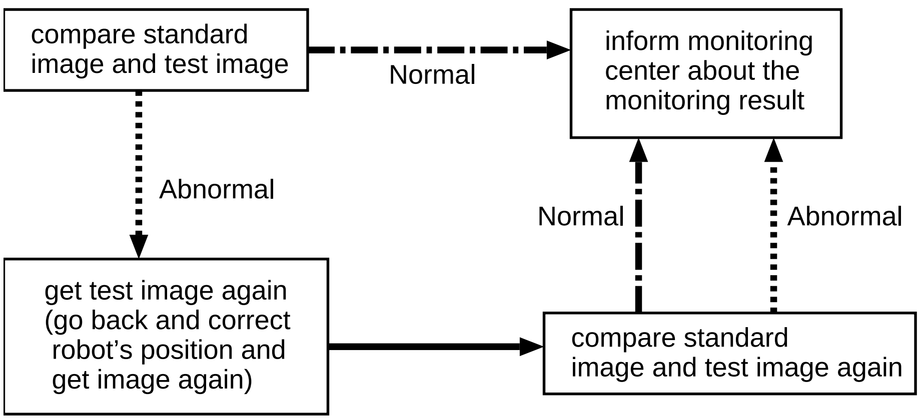
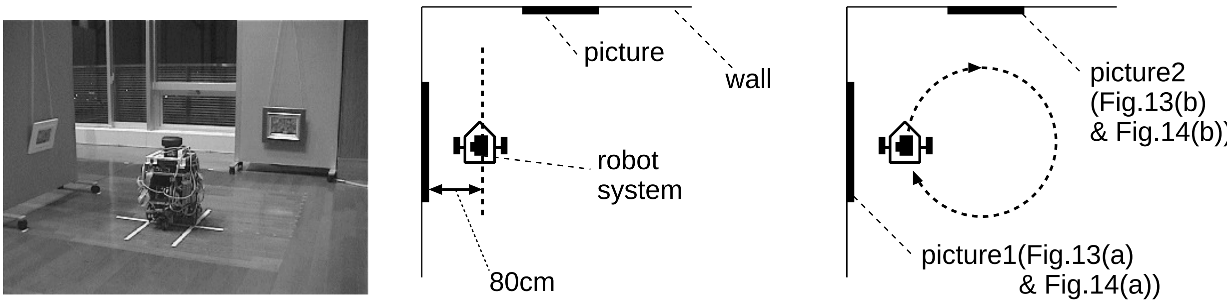


Fig.11 A procedure of a decision of compare result

5.2 Actual experiments

Experiments are performed with the developed monitoring system. It is done in an actual environment with the patrolling route as shown in Fig.12. Before the patrol, the standard image is taken as references. In the first lap of patrol, the target pictures to be taken for monitoring are normal pictures as Fig.13, once taken it will be sent to the monitoring center. In the second lap, one of the pictures is pasted a yellow tape as in section 4.2 in Fig.14 (a) and the other picture is removed as shown in (b), once taken the pictures are sent to the monitoring center as abnormal. The robot repeats correcting its position from twice to four times in front of each picture, modifies each image and compares each image, then each result is sent to the monitoring center in the experiment. The results are shown in Fig.15-Fig.18. The left side of the figures shows the test images, and the right side displays results as normal or abnormal. As these figures show, the results are sent correctly in each case.

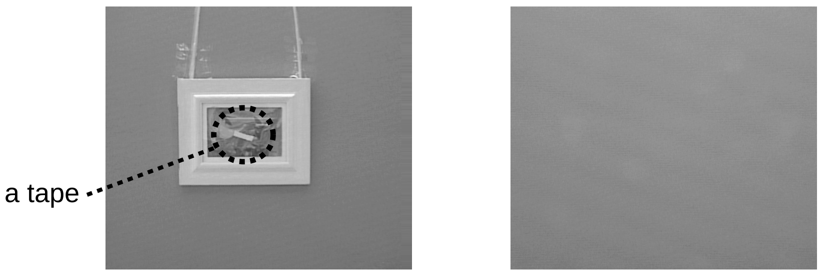


(a) (b) (c)

Fig.12 Actual experiment of the monitoring system ((a): A view of the experiment, (b): Overhead view of the environment in the experiment, (c): Patrolling route and target pictures for monitoring)

(a) (b)

Fig.13 Target pictures for monitoring (Normal) ((a): Picture1 in Fig.12 (c), (b): Picture2 in Fig.12 (c))



(a) (b)

Fig.14 Target pictures for monitoring (Abnormal) ((a): Picture1 in Fig.12 (c), (b): Picture2 in Fig.12 (c))

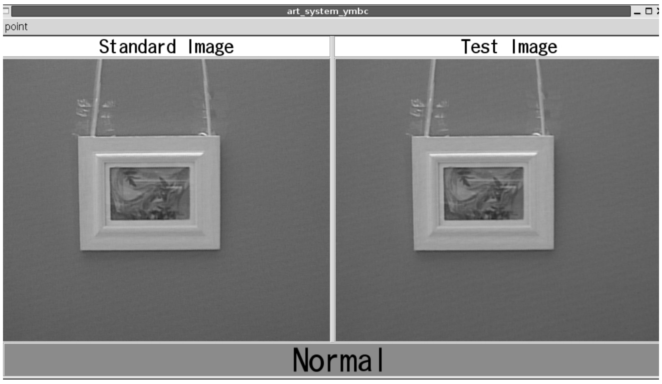


Fig.15 Monitoring result at normal situation (Monitoring target is Fig.13 (a))

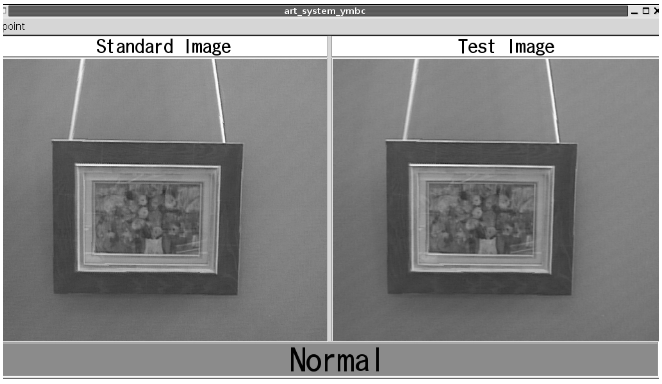


Fig.16 Monitoring result at normal situation (Monitoring target is Fig.13 (b))

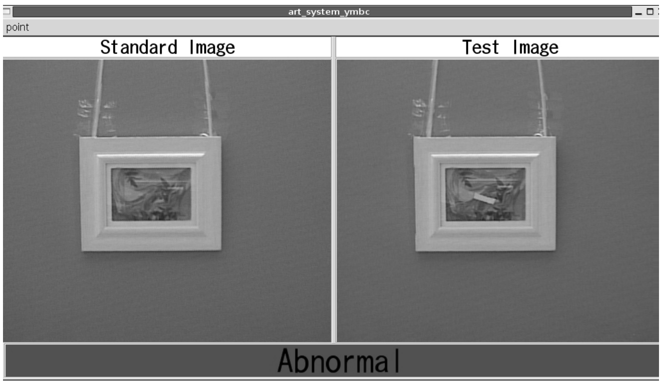


Fig.17 Monitoring result at abnormal situation (Monitoring target is Fig.14 (a))

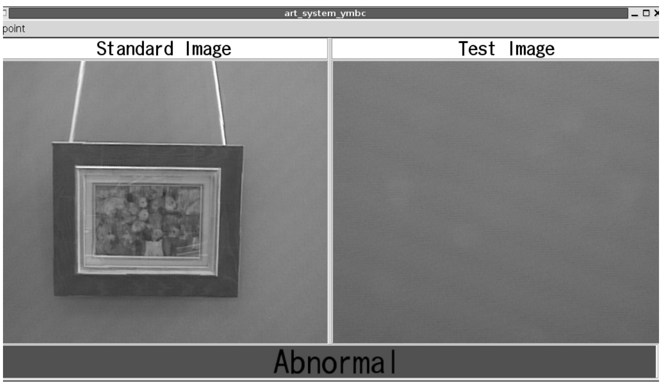


Fig.18 Monitoring result at abnormal situation (Monitoring target is Fig.14 (b))

6. Summary and future work

This paper describes the method of monitoring pictures and the experiments of the monitoring system. It is first described the methods and results of taking a test image with minimal errors from a standard image at normal situation by modifying the robot's position and the image. Second, it is also described the method for detecting abnormalities of monitored pictures based on the differences of images using the test images. Finally, the system was substantiated to be able to detect pictures' abnormalities automatically and correctly by this monitoring method from the results of experiments implementing these techniques. Hereafter, we try to expand monitoring targets of 3-D objects.

Acknowledgments

We would like to thank Michiko Shiratori for letting us use her pictures and Mr. Timoteo Idica, Jr. of the University of Tsukuba for his assistance in preparing this manuscript.

References

1) C.Wren, A.Azarbayejani, T.Darrell and A.Pentland: Pfinder, Real-time tracking of the human body, IEEE Trans. on PAMI, Vol.19, No.7, pp.780-785, 1997.
2) K.Hayashi, M.Hashimoto, K.Sumi, and K.Sasakawa: Multiple-person tracker with a fixed slanting stereo camera, Proc. of 6th International Conference on Automatic Face and Gesture Recognition, pp.681-686, 2004.
3) K.Takahashi et.al: Combined Detection Method in a Sea Surveillance System, EICE Trans. on Information and Systems, E88-D(2), pp.230-238, 2005.
4) tmsuk Co., Ltd.: http://www.tmsuk.co.jp/
5) SOHGO SECURITY SERVICES CO.,LTD.: http://www.alsok.co.jp/news/press2003/security_robo.html
6) J.J.Leonard et al: Simultaneous map building and localization for an autonomous mobile robot.
7) A.Davison and N.Kita: 3-D Simultaneous Localisation and Map-Building Using Active Vision for a Robot Moving on Undulating Terrain, In CVPR, 2001.
8) RoboGuard, a Teleoperated Mobile Security Robot: www.faculty.iu-bremen.de/birk/publications/CEP2002_guard.pdf
9) An automated security response robot: www.nosc.mil/robots/pubs/spie3525a.pdf