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An Autonomously Moving Robot Using Network Cameras

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Abstract: This research aims at constructing an autonomously moving robot system using network communication technologies. All the sensor data are sent to one of nearby access points through a wireless LAN. With this infrastructure, any new functionality could be added to the robot system without changing the overall architecture of the robot system. Moreover, there will be no performance impact. Even if an accident happened to the robot during the experiment, the damage will be minimized. The system includes a mobile robot, two network cameras that are mounted on the robot, a wireless LAN, and an image processing system. This paper focuses on the image processing system. A computer is dedicated to the images captured by the cameras, and processes the images. As soon as the images are processed, a set of control instructions will be transmitted to the robot. The robot can therefore autonomously move by repeating this process.

Keywords: **Autonomously moving robot, Network, Image processing**

I. INTRODUCTION

Many robot systems have been developed in the past. The majority of the robot systems, however, is designed to perform one and only predefined task. In order to design a robot system that could help people to perform a variety of tasks, communication with people in a timely fashion is considered one of the basics. It is therefore necessary for a robot system to interact with people through the speech and gesture recognition. For instance, in the case that a user points with his finger to the object that he wants the robot to pick up and carry back to him, the current location of both the robot and the user will be needed for determining the object location. This means that both environment recognition and object location are required to perform a communication task that was considered not directly relevant to the task. As a matter of fact, a couple of different type of information must be processed simultaneously. As soon as a request from the user has been received and successfully interpreted, the robot system must build a plan for the execution of the task. The plan includes the environment recognition necessary for moving toward the target and avoiding obstacles during the movement as well as the actual control sequence of the movement.

As seen from the above mentioned cases, different type of information must be processed in parallel. This requires the robot to be equipped with many high performance computers, which will substantially increase the weight and cost.

To solve these problems, this research proposed an approach that keeps the number of computers mounted on a robot as few as possible. The basic idea is to send all sensor information to one of nearby access points through a wireless LAN. All the data-intensive processing that is needed for the robot to perform the assigned task is actually happening on the computers available through the wireless LAN. Those computers are made available through the wireless LAN anytime and at any physical location as long as they are reachable through the network.

This paper focuses the discussion on the image processing system for the environment recognition, which is used by the robot system.

II. SYSTEM ORGANIZATIONS

Fig.1 shows the system organization of the autonomously moving robot.

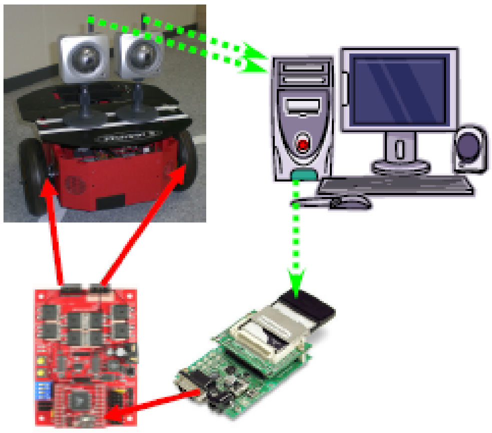


Fig.1 Organization of the robot system.

The mobile robot used in this research is 39cm in width, 44cm in length, and 53cm in height. Two network cameras are mounted on the front of the mobile robot. The axes of the two cameras are parallel to each other. The distance between the two cameras is about 10cm. Since the speed of the robot is slow, cameras need to capture the images of the nearby environment rather than a distant environment. For this reason, the axial directions of the two cameras are tilted down a little bit. Each of the network cameras has its own IP address, which makes it easy to transmit images through the wireless LAN to server machine. Images are transmitted through an IEEE 802.11b/g wireless router.

As soon as the computer receives the images, it begins image processing. Images are received at a rate of up to 30 images per second. The computer generates the control commands for the movement of the robot at the time of finishing processing the images. The same computer will transmit the control commands back to the robot.

A microcomputer that is capable of handling the network communication is mounted on the robot. The microcomputer receives the control commands and then converts the commands into the motor signals.

Microsoft Visual Studio.NET has been used for the software development. The image processing tasks are executed with the help of OpenCV, an open-source library from Intel. The program code from the Independent JPEG Group was used for the conversion from JPEG to BMP image file format.

Ⅲ. IMAGE PROCESSING

Fig.2 shows the flow of the entire processing.

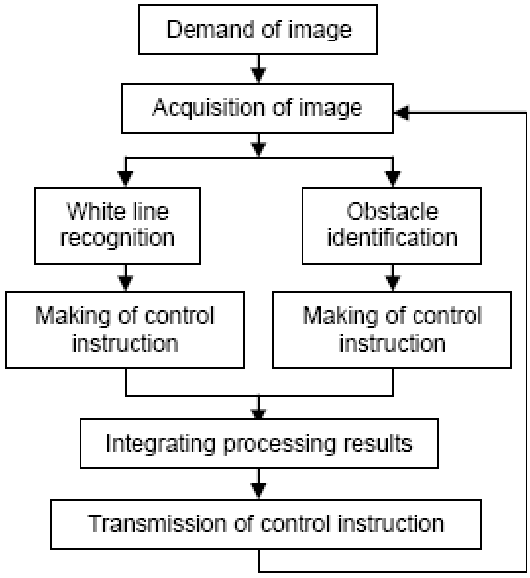


Fig.2 The flow of the entire processing

White line recognition and the obstacle identification are processed in parallel for the autonomous movement. Depending upon the feature analysis of each of the targets, a corresponding image processing algorithm has been developed. The control commands are generated through the integration of the image processing results.

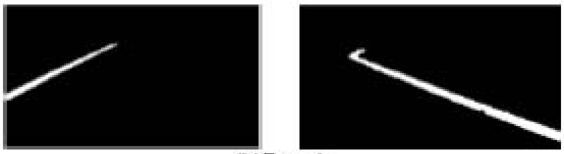
Since the received images are in the format of JPEG, the images are converted from the JPEG format into the BMP format in the memory. In addition, only a region of interest (ROI) is processed. As a result, the delay of image processing was suppressed to an acceptable extent.

1. White Line Recognition

The white line recognition is for the purpose of finding out the route along which the robot will move. The white line recognition algorithm used color information. The white line at the right of the robot is handled with the right side camera and the white line at the left of the robot is handled with the left side camera. The part on the edge of the image is used to identify whether the robot is approaching to the white line or is moving away. When the white line is extracted in the bottom half of the image, it means the robot is approaching to the white line. Therefore, the control command generated will be "to move away".

Fig. 3 shows the experimental results of white line recognition.

(a) Images captured by the cameras



(b)Result

Fig.3 Results of white line recognition

2. Obstacle Identification

The obstacle identification used the stereo image processing algorithm. The stereo image processing algorithm calculates 3D location of objects from the gap between the two images. Using the stereo image processing algorithm, it is possible to exclude the patterns on the floor or a thin object such as a piece of paper on the floor from the category of obstacles. Therefore, the robot will not make the unnecessary obstacle avoiding movement.

The gap of two images is calculated by using the correlation base. The correlation base calculates all 3D coordinates of the image by using the colour. A 5×5 mask was used to calculate the correlation. The correlation is evaluated by Eqn.1.

$$d = \sum_{m=-2}^{2}\sum_{n=-2}^{2}\left|dl_{i+m,j+n} - dr_{i'+m,j'+n}\right| \qquad (1)$$

dl and *dr* show pixel value of one pixel. *d* is a correlation coefficient. Two points are considered correspondence when *d* is minimized.

The gap of the height of the floor has already been measured. A pattern on the floor and a thin thing such as a paper on the floor is excluded by comparing measurement with the image processing results.

Fig.4 shows an actual processing result. An area with a small amount of variance will not be processed.. The area is displayed in black in Fig.4. Obstacles are displayed in white. Areas in gray color are excluded from obstacles because there was no height. The action of the robot is determined from position and area of the white area. The method of generating the control commands is similar to white line recognition.

(a) Image that camera took

(b)Result

Fig.4 Result of obstacle identification

IV. EXPERIMENTS

An experiment has been conducted to verify the effectiveness and reliability of image processing system.

1. Methodology

Fig 5 shows the route specified in the experiment. The robot examines whether it is possible to advance between white lines. Static obstacles are put on a part of the route. The robot avoids the obstacle and keeps advancing. Whenever it is not possible to pass, the robot gets back.

The time required in image data processing indicated below is measured while the robot is moving along the route..

- Time necessary for receiving image
- Time necessary for recognizing white line
- Time necessary for identifying obstacle
- Time necessary from the reception of the image to the transmission of the control commands.

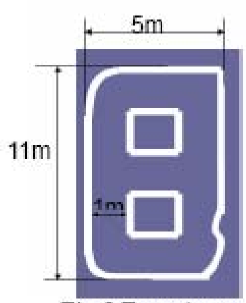


Fig.5 Experimental course

2. Experimental Result

The robot was able to run between white lines and avoid the collision with the obstacles.

The measurement time is shown in Table 1. Each time is an average during the experiment.

Table 1. Measurement result at time

	Time necessary for processing once
Time necessary for receiving image	9.6msec
Time necessary for recognizing white line	3.3msec
Time necessary for identifying obstacle	172.1msec
Time necessary from the reception of the image to the transmission of the instruction.	175.6msec

V. DISCUSSIONS

Experimental results demonstrated that the robot can autonomously move in a simple environment. However, the robot often avoided a thin thing such as a paper during the experiments. This means that the accuracy of the stereo image processing algorithm needs further improvement.

The speed of the robot is about 1m/s. Time spent for image processing is ignorably insignificant so long as it could be assumed that no fast moving object is anticipated to move toward the robot. Currently, the potential of network resources has not yet been maximized. The total processing time could be further reduced when the distributed processing mechanism is fully engaged. One more improvement will be to maximize the usage of the information available from the 30 images captured by the cameras in one second so that the robot could move more smoothly and might be able to adapt to a complex environment.

Although not very often, the network was unstable during the experiment. This still has impact on the autonomous movement of the robot. Further observation of the network stability is needed.

VI. FUTURE WORKS

At present, the robot works well in a static environment. The robot should move autonomously in a more complex environment such as a dynamically changing environment. The dynamically changing environment could be detected by using the difference between a sequence of images. At the same time, it is necessary to consider movement of the robot.

In addition, the present robot only wanders. So, we will give the robot a destination. To select the route to the destination, and to actually attain the destination, the robot needs some more image processing algorithms, which need to be developed in the future.

VII. CONCLUSIONS

This research aimed at the construction of a network-based robot system. This paper presented the image processing system that is capable of recognizing white lines using color information and identifying obstacles using a stereo image processing algorithm. Experimental results proved the feasibility of the proposed network-based approach to the construction of an autonomously moving robot system.

Using the resources available through the network, it is possible to have a complicated computation problem resolved in a distributed and concurrent fashion. At the same time, the robot can be made small and light-weighted.

However, the network sometimes becomes unstable. The construction of the system that considers this instability will be needed in the future.

Moreover, more complex processing is needed. The system should be improved to be adapted to various environments in the future.

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