An Outdoor Autonomously Moving Robot Using a Distributed Image Processing System

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Abstract

This study aims at building an autonomous robot that is capable of comprehending complicated image processing algorithms rapidly and concurrently via a wireless communication network. The entire system includes a mobile robot, a network camera mounted on the mobile robot, a wireless LAN, and a distributed image processing system. Images captured by the network camera are first transmitted to one of the clustered computers through the wireless LAN. The computer receiving the images then distributes the images to the other computers in the cluster. The image processing results will be collected and reported back to the robot through the wireless LAN also by the same computer. With the clustered computers, multiple image-processing algorithms could be applied to a single image in a concurrent fashion. As an experiment, the mobile robot has been put on a street. In order for the mobile robot to move autonomously on the street, three targets including white lines on the road, static and moving obstacles, have been identified necessary for the distributed image processing system to detect. The experimental results indicate that the distributed image processing system successfully meet the needs for the autonomous movement of the mobile robot.

Keywords: Network, Distributed Image Processing, Autonomously Moving Robot

1 Introduction

This study aims at the research and development of an autonomously moving robot so that the quality of our daily living could be further improved. The potential applications include the automated car driving, ITS (Intelligent Transport System), environmental and safety issues, and social welfare improvements such as the replacement of the guide dogs.

The fundamental problem with an autonomously moving robot is the computational intensiveness. While moving autonomously, the robot needs to process all kinds of information such as the dynamically changing scene, sensor data, path finding, control of the movement, and so on. Recognition of the dynamically changing scene requires running a lot of complicated image processing algorithms, which consumes a lot of resources in terms of memory and CPU usages. The computer carried by the robot is overwhelmed by data processing needs.

Over the past few years, network based communication technologies have made remarkable progress. Sharing the computational resources such as memory and CPU power and load balancing could easily be achieved through the network. This makes us think the possibility for the mobile robot to have its computational burden shared with others through the network, as well. With the computational burden shared, real-time processing of all the data could be possible and thus an autonomously moving robot could be expected.

Based on the above-mentioned idea, we mounted a network camera on the mobile robot so that the robot could have the image processing load shared by a couple of high performance computers through a wireless LAN. The feasibility has been verified and the experimental results will be reported in this article.

2 System Organization

As shown in Figure 1, the entire system could be divided into the following three subsystems.

- Mobile robot
- Network communication
- Data processing for the autonomous movement

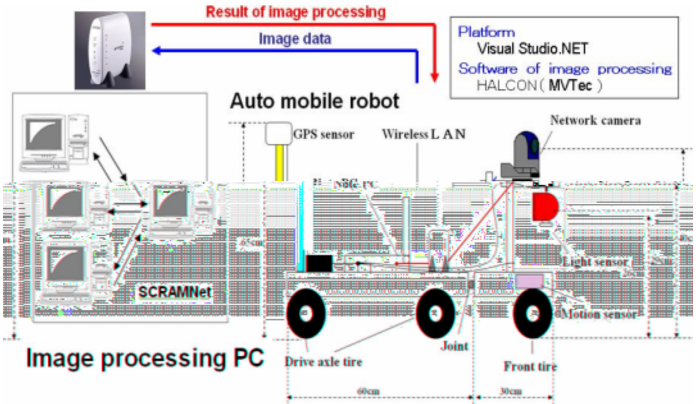


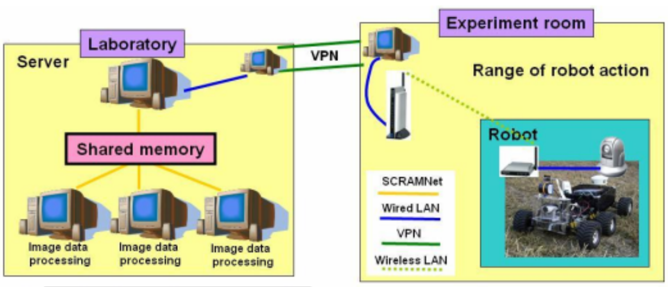
Figure 1: System organization of the autonomously moving robot.

2.1 Mobile Robot

The mobile robot used in this research is 90 cm long and 60 cm wide. A network camera is mounted on the front of the mobile robot. The network camera keeps transmitting images through the wireless LAN to a high-performance server machine. The network camera has its own IP address, with which the communication with the remote server machine will not consume any of the computational resources on the computer carried by the robot. Images are transmitted through an IEEE 802.11a wireless router that is mounted on the robot as well.

In addition to the network camera, the mobile robot is equipped with photoelectric sensor, GPS (Global Positioning System) sensor, and 3D motion sensor. The computer carried by the robot processes the data from all these sensors. The same computer will also control the servomotor of the robot. Since the remote high-performance computers have shared the heavy-load data-processing tasks such as image processing and path finding, the computer on the robot could have more computational resources for the overall control of the movement. Visual Studio.NET from Microsoft has been used for the software development. The image processing tasks are executed with HALCON, an image processing software package from MVTec, a German company.

2.2 Network Communication



Circuit grade		Transmission rate
SCRAMNet	Optical fiber	150Mbps
Wired LAN	Ethernet(100BASE)	100Mbps
Wireless LAN	(IEEE 802.11a)	54Mbps

Fig. 2. Architecture of the network organization.

The needs for the network communication could be divided into two major areas. One is the area where the mobile robot is moving around. The other is the server machine and the other high performance computers. Considering the limited transmission performance of wireless LAN, the usage of wireless LAN is minimized by using the VPN (Virtual Private Network) so that the existing wired LAN could be used as much as possible. It could be a challenge to discover the existing wired LAN when the robot is put into operation in the real world. The benefit of using wireless LAN, however, includes the possibility of extending the area that the mobile robot could move around by the relay of the wireless LAN.

The network communication on the server side, on the other hand, involves large amount of data processing. It requires high-speed and high throughput communication network. SCRAMNet, an optical network is used to reduce the communication delay.

With the above optimization of the network resources, real-time processing could be expected.

2.3 Distributed Image Processing

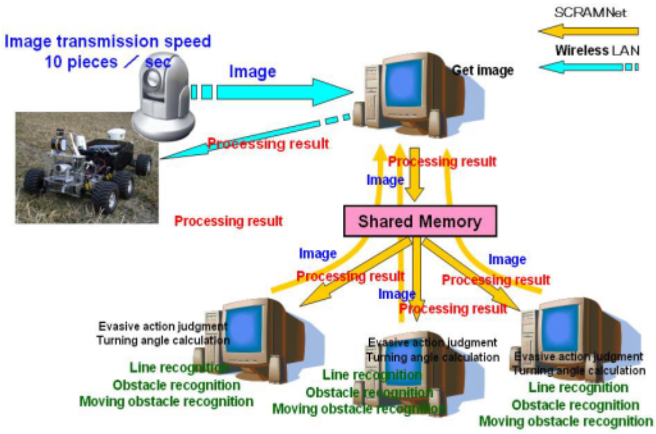


Fig. 3. Distributed Image Processing System

Figure 3 shows the organization of the distributed image processing subsystem. The server machine that is receiving images from the network camera will write the image data into the shared memory. The same server will read the results processed by the other computers and report the results back to the robot.

All the computers involved in the image processing basically share the shared memory. The synchronization is achieved through the SCRAMNet. The server machine is receiving images at the speed of 10 images per second. It will write the image data to the shared memory at the same speed. The other computers will read the image data from the shared memory and start processing. Since the robot is put on a street, at the very least three targets, white lines, static and moving obstacles, need to be detected through the image processing algorithms. Three high-performance computers accomplish the detection of the three targets independently and concurrently. The benefits of this system architecture include the scalability and the maintainability.

3 Image Processing

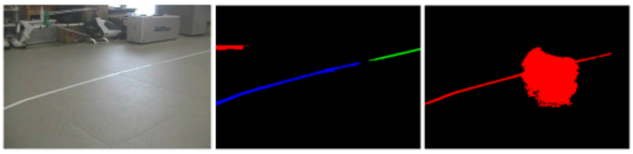
The following three image processing tasks are assigned to the distributed image processing system.

- White line recognition
- Static obstacle identification
- Moving obstacle identification

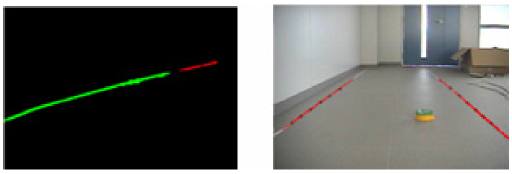
Based on the feature analysis of each of the target objects, a corresponding image processing algorithm has been developed. The outdoor scene is unstable due to the sunlight, shadow, and the vibration caused by the movement of the robot. This requires high robustness to the image processing algorithms.

3.1 White Line Recognition

Basically, two approaches have been taken toward the extraction of white lines. One is color-based. The other is edge element based. The white lines are finally identified by integrating the information from the two approaches. With the information integration, the lighting effects could be reduced to the minimum level. Furthermore, real-time straight line approximation algorithm is introduced to improve the robustness of white line recognition even if when the white lines are shaded by other objects. Figure 4 shows the entire process of extracting white lines.



Present Image **Edge Processing** **Color Information**



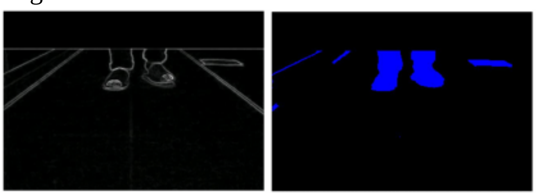
White line extraction

Approximate deriving

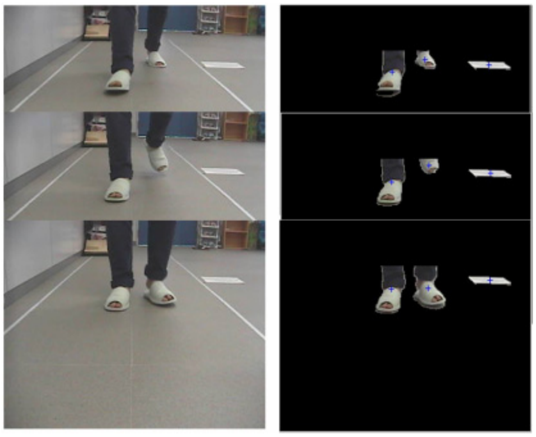
Fig. 4. Results of white line extraction

3.2 White Line Recognition

Figure 5 shows the entire process of extracting a moving obstacle.



Edge Processing ***Making Up***



The person's movement forecast

Fig. 5. Extraction of moving obstacles

Similar to the extraction of white lines, both color information and edge elements are used for the extraction of the static and moving obstacles. With a properly selected threshold, the boundary of obstacles could be extracted. If the area of the enclosed region is larger than a preset threshold, the enclosed region is considered as the existence of an obstacle. The coordinates of the center of the obstacle are persisted to the memory on the computer that is processing the image. As soon as the center of an obstacle extracted from the subsequent image is measured, the results will be compared to the previously persisted data. Whether the obstacle is a static one or a moving one is decided by the difference. The difference could also tell the moving direction and speed of a moving obstacle. The information regarding the moving obstacle is useful for the robot to decide the next movement.

4 Experiments

The experiments are focused on the distributed image processing subsystem and the overall network communication. The main purpose is to verify the response time from the distributed image processing system to the robot. The experimental results have successfully verify the feasibility of the robot system proposed in this study.

4.1 Methodology

1. Capture images with the network camera.
2. Transmit the images to the server machine through the wireless LAN.
3. Distribute the images to the computers dedicated to image processing through the shared memory.
4. Process the images with the algorithms described in Section 3.
5. Suggest the next movement of the robot based on the image processing results by turning on or off the flags in the shared memory.

6. Server machine will check the flags and decide whether and what to report back to the robot.
7. Measure the time from the transmission of image data to the server machine and the response from the server machine.
8. Measure the response time through steps 1 to 7. Also measure the time spent for processing an image by a single computer. Do the comparison between the two.

4.2 Experimental Results

TABLE I

Experimental Result (Time of image processing)

	Possible image processing frequency (1 sec)	Necessary time for image data processing of one time
Necessary time only for image data processing	**8.5 times**	**0.118 sec**

TABLE II

EXPERIMENTAL RESULT (RESPONSE TIME)

	Reception of result for every 100 seconds frequency	Time necessary for reception once(reactive speed)
Robot reaction time	**480 times**	**0.208 sec**

In order to measure the response time, one image processing computer is used for the experiment. The experimental results in table 1 and 2 are all collected from the same computer. In the case that more than one computer are used for more image processing algorithms, the response time will increase. Considering the possible number of images transmitted per second, approximately 8 computers will be possibly used for the image processing. The response time will increase to 0.95 seconds at most. The time needed for processing one image will not exceed 0.2 second. The data in Tables 1 and 2, however, are collected from the indoor scene. To measure the outdoor scene, we have to extend the coverage of the wireless LAN, the response time will for sure increase.

5 Discussion

The experimental results indicate that the proposed system architecture for supporting autonomously moving robot provides fast enough image processing capability.

Assume that the robot is moving at the speed of 1 m per second. It will be considered necessary to do the image processing 10 times per second. The network camera mounted on the robot is capable of transmitting 10 images per second to the server machine. The response time measured from the experiments is 0.2 second. Therefore, doing image processing 5 times per second is possible. In order to further improve the response time, we are investigating the possible of converting image format during the transmission. With the improvement, more complicated image processing algorithms requiring image processing 10 times per second could be achieved.

Furthermore, edge detection, shape features could be further improved so that the entire response time could be substantially shortened. However, in order to deal with the outdoor scene, a lot more different type of obstacles needs to be taken into account. Accordingly, the image processing algorithms need to be sophisticating enough to handle the complicated scene. Algorithms such as obstacle identification based on pattern matching, accurate distance measurement based on stereo matching, and the processing high-resolution images are being considered. With all the availability of all these algorithms, the truly autonomously moving robot could be expected.

6 Future Work

In the current distributed image processing system, one computer is dedicated to process an entire image. It is possible that the lack of responsiveness is due to the completion of a complicated image-processing algorithm. If it is possible to divide the image into 3 portions and have three computers to apply the same image processing algorithm only to one third of the image data. The entire processing time will be reduced by one third. It is also possible that the movement of the robot at the next moment has been decided already while finishing processing only one third of an image. In that case, the image processing algorithms should be applied to the subsequent incoming images. This divide-and-conquer approach is promising and still has a lot of uncertainties that need to be resolved in the near future.

Acknowledgements

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