Autonomous Mobile Robot Navigation using Active Stereo Vision

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Abstract

In this paper, we describe an autonomous navigation of a mobile robot using an active stereo vision sensor which we developed. We propose a framework of sensor management system which is necessary when the sensor is utilized for multiple purposes such as obstacle detection and landmark extraction. The system mediates plural sensing requests and manage resources of the sensor hardware. We implemented the system on a robot and perform an experiment of autonomous navigation in an indoor environment.

1 Introduction

When a mobile robot moves to the goal, the robot has to obtain various information about the environment. For example, the robot must detect obstacles which have to be avoided, and also should recognize landmarks which is used for position estimation. The robot generally has independent and exclusive sensors for each sensing purpose, while human beings use one sensor for multiple purposes by turning the sensor towards the direction of interest. We believe that the robot also can recognize the environment well enough by changing the direction of the sensor even if a single sensor is only used. So we have developed an active stereo vision sensor which can move similarly to the human eyes, and tried to realize mobile robot navigation by using the sensor as a sole sensing system.

The active stereo vision sensor is useful for environment recognition, because it can obtain high resolution images for the significant direction corresponding to the situation and also can measure the distance to the object easily by processing the stereo images. However, when the sensor is utilized for multiple sensing purposes, the sensor resource has to be managed properly because plural sensing processes cannot be done simultaneously. To overcome this problem, we also developed a software to mediate between plural sensing requests and to manage the resource.

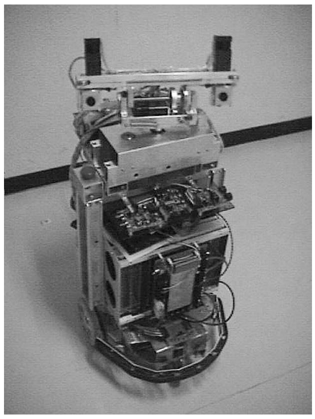

Figure 1: Autonomous Mobile Robot "Yamabico" equipped with the active stereo vision sensor system.

In this paper, our sensor system is described first. Secondly the framework of the sensor management system is proposed. Next the structure of the navigation software is explained. Finally, an experimental result of mobile robot navigation in an indoor corridor environment is also shown.

2 Active Stereo Vision Sensor

A visual sensor is useful for a mobile robot because it can obtain much information about the environment. The stereo vision has an advantage in knowing the distance information or 3D shape of object. The active vision which can move camera actively is able to sense in wide area and to explore target efficiently[1]. It also has an advantage that the sensors for different directions can be replaced with it, namely, only a single sensor. The active stereo vision can be a useful sensor for mobile robot[2]. It can be used for landmark extraction for self-localization, obstacle detection for collision avoidance, and so on. The purpose of this

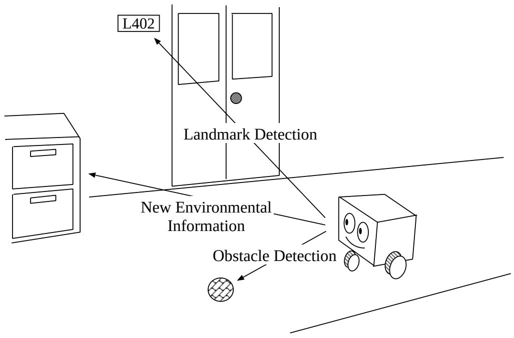

Figure 2: Sensing needed on navigation.

study is to realize an autonomous mobile robot navigation using the active stereo vision sensor.

We developed an active vision sensor which has 4 degrees of freedom: pan, tilt and vergence of each camera. Figure 1 shows the autonomous mobile robot "Yamabico" equipped with the sensor.

3 Sensor Management System

3.1 Necessity of management system

There are many tasks which is required to the active vision sensor as follows: A) obstacle detection, B) landmark extraction, C) acquisition of new landmark information. The robot needs to perform these tasks sequentially/parallel during the navigation as shown in Figure 2. When one single sensor is used for these multiple purposes, the system which can manage the use of the sensor will be needed[3]. The management system should have the following functions: 1) Mediation of plural sensing request, 2) Management of sensor resources (e.g. camera, frame buffer), 3) Interface between sensor hardware and each process which requests a sensing.

We developed a sensor management system for our active vision sensor to use it commonly for multiple purposes. The system separates the sensing functions from the sensor hardware. This system enables the sensor to be easily utilized by multiple processes on the robot. Each process doesn't have to know about the status of the sensor hardware.

3.2 Structure of management system

Figure 3 shows the structure of the sensor management system proposed in this paper. The system consists of three subsystems. "Job Management" manages "Job" which is sensing request coming from a user process such as navigation program and it includes a set of sequence: the desired direction of obtaining image, number of images and contents of image processing. "Camera Posture Management" controls motors of the active stereo vision sensor to manage the camera posture. "Image Processing Management" executes the image processing program and manage frame buffers on the image processing board. The process which needs to use the active vision sensor should request a job to the job management subsystem. The process must not consider about the other processes which also use the same sensor, because the sensor management system mediates those requests.

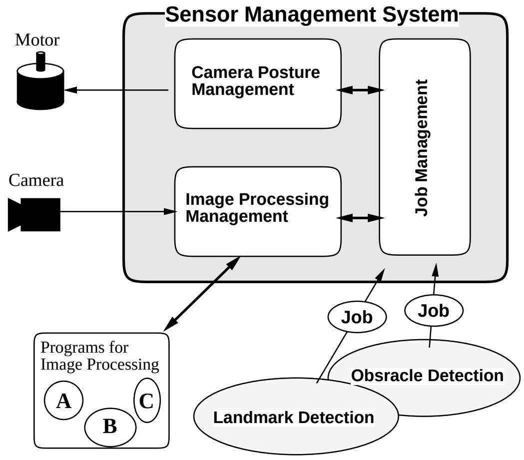

Figure 3: Structure of sensor management system.

3.3 Management of plural jobs

It takes a certain length of time to move motors or to process images. So it sometimes happens that plural jobs are requested during a job is being executed. There is a job which needs to obtain the result quickly like obstacle detection, while some job such as landmark extraction doesn't request so fast processing. To cope with this problem, a priority order is added on the request for the job management subsystem. The subsystem performs a job which has the highest priority first. The jobs are carried out properly as the result. Also at the time when the image acquisition is finished, the movement of the camera for the next job will be started. Since this is performed by the system automatically, the application program doesn't have to consider about the time lag. The easiness of adding a new different kind of job also shows usefulness of the sensor management system.

Figure 4: Target environment of the navigation.

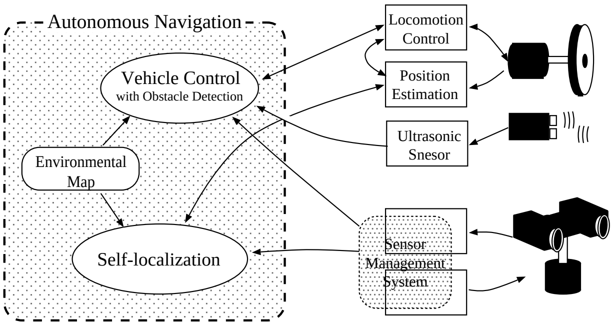

Figure 5: Structure of navigation software.

4 Navigation Software

The purpose of this study is to realize an autonomous navigation of the mobile robot. The target environment is an indoor corridor in the building as is shown in Figure 4.

The structure of navigation software is shown in Figure 5. The navigation software consists of "Vehicle Control" and "Self-localization". "Environmental Map" is giving to the programs as a common data.

4.1 Vehicle control

"Vehicle Control" controls the robot body to follow the pre-defined path. It includes a function of obstacle detection for collision avoidance. The path is denoted by lines and arcs.

The obstacle detection is realized by a method which doesn't need stereo matching[4]. In that method, it is assumed that everything is painted on the floor. The right image can be estimated from the left image under this assumption using geometrical configuration of the stereo cameras. If there is some difference between the estimated right image and the real one, it means that there is something which is existing not on the floor. In this study, we use a more simplified method to reduce the processing time. In this method, the corresponding points for stereo images are obtained a prior only in front of the robot and only sparsely. The obstacles are detected by comparing the brightness of these corresponding points of the images. This method enables a robot which has only a poor image processing board to detect obstacles in realtime. If some obstacle is detected on the floor, the robot will be stopped by the program. Figure 6 shows an example result of obstacle detection. The white points represent the places judged as obstacle while the black points are judged as floor.

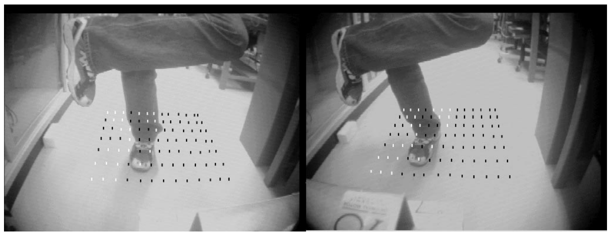

Figure 6: Example of obstacle detection (human leg).

4.2 Self-localization

"Self-localization" keeps watching the position of the robot. It requests a sensing of a landmark, when the robot approaches one of the landmark stored in the environmental map, and it corrects the robot's position using the sensing result[5]. Since this program selects the visible landmark automatically, it could be separated from the vehicle control program.

We use vertical edges of doors as the landmark for position correction. The relative position to the vertical edge from the robot is measured using stereo vision. The position of the robot is corrected on the position estimation module by comparing the measured value and the information in the map[6].

An example result of landmark extraction is shown in Figure 7. In this figure, white marks of shape "H" denote the search region for the vertical edge extraction. This region is limited by the relationship between the robot's position and the location of the vertical edge registered in the map. This limitation makes it possible to detect edges robustly. The position of the edge in the image is determined on the place where the differential value is maximum. The distance and the direction to the landmark is calculated by trian-

Figure 7: Example result of landmark extraction.

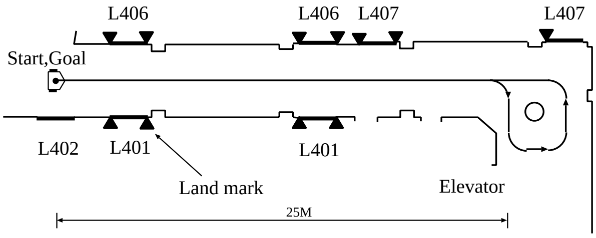

Figure 8: Path of the robot in the experiment.

gulation using the positions of the edge in the stereo images. The accuracy of the landmark extraction is 2cm in distance and 1 degree in direction when the distance to the landmark is 5 to 15m.

5 Navigation Experiment

The navigation program mentioned in the previous section is implemented on our autonomous mobile robot "Yamabico" and verified by the following navigation experiment in a real environment. The path of the robot is shown in Figure 8. The total length of the path was around 70m. The speed of the robot was 40cm/s. The obstacle detection mentioned before was performed every 2 seconds. There were 11 landmarks registered in the environmental map. The robot stopped reliably in order to avoid the collision for the obstacles existing in front of the robot. The position was corrected properly and the deviation of the end position at the goal was less than 10cm even when the start position was shifted.

As a result of the experiment, it is verified that the active stereo vision sensor worked by the requests from the multiple programs. Also plural sensing behaviors are conducted properly according to the priority when these sensing are requested simultaneously. As the result of the mediation process, the movement of the cameras looked randomly. Moreover the application program which uses the active vision sensor could be written very easily.

6 Conclusions

In this paper, we presented the autonomous mobile robot navigation using the active stereo vision. We developed the active stereo vision sensor which can be mounted on the small-size mobile robot. We also propose a framework of the sensor management system which mediates the plural sensing requests and manages the sensor resources. It is especially useful when the sensor system is used for multiple purposes simultaneously. The sensor system became very easy to use since a new sensing process will be easily added.

We implemented the system programs and navigation software on the mobile robot and performed the navigation experiment. As a result, it is verified that the system works well. The implementation of the obstacle avoidance behavior, long distance navigation with this system, new landmark exploration and automatic registration will be future works.

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