Application of self-location system using a floor of random dot pattern to an automatic guided vehicle

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Abstract –

Application of the AGV (automatic guided vehicle) has broadened in factories and warehouses. Although most AGVs use magnetic tape for the guide path, the guided method has some problems. Once a path has been set, you require re-installation of the magnetic guide tape on a floor in order to reset the path. Also it is difficult to set intricately branched. For this reason, the application of AGV in the field of logistics, such as day-to-day transport route changes, has been difficult. In recent years, in order to solve these problems, several navigation methods using various self-location systems have been developed.

We have been developed a self-localization system which uses dots patterns on a floor. At first we construct the floor on which there are random dots patterns and make a database of the all dot positions on the floor. A camera captures an image of the floor and several dots are cropped in the image. The cropped dots are matched in the database of all the dot positions on the floor and then we can detect position and direction of the captured image on the floor.

We have set the floor which has dots pattern for detecting position at a factory where several forklifts move around and tire marks of those forklifts are attached. And an AGV using the developed self-localization system has run autonomously in the factory. In this paper we report the interim results of the experiment.

Keywords –

Automatic Guided Vehicle; Self-localization System

1 Introduction

A mobile robot programmed to move autonomously in indoor must be equipped with a self-localization system to operate effectively. Several types of self-localization systems are therefore being pursued.

A number of strategies using electric devices installed inside buildings have been developed. One system deploys a pseudo satellite (Sakamoto, Niwa, Ebinuma, Fujii, & Sugano, 2010 [1]); another detects differences in radio field intensity among several wireless LAN access points (Umetani, Yamashita, & Tamura, 2011 [2]); the third one uses an ultrasonic 3D position sensor (Nishida & Takeda, 2010 [3]). Yet in each case, non-uniformity of the electromagnetic or acoustic environment causes instability the detection position.

Other methods rely on ceilings or floors for position detection. One, for example, uses arrayed marks on ceilings (Nakazato, Kanbara, & Yokoya, 2008 [4]), while another tracks communications transmitted LEDs on ceilings (Uchiyama, Haruyama, & Nagamoto, 2009 [5]). Both of these methods fail when the ceilings in a room are tall. Kodaka, Niwa, and Sakamoto (2009) developed a floor-based system by placing a series of RFID tags on a floor and reading them to detect positions [6]. At about the same time, Nishizaka, Hiyama, Tanikawa, and Hirose (2009) printed position-coded patterns on a floor and read them with a camera [7]. These latter floor-based systems are costly, however, as the first requires many RFID tags and the second requires the printing of code patterns on a floor. Another floor-based system relies on cracks in a floor as landmarks (Kelly, 2000 [8]). This method is difficult to adopt for floors with finishing materials, though it is effective for factories or warehouses with solid concrete floors.

Our group is attempting to surmount these challenges by devising a method using random dot patterns on floors. Floors are often paved with vinyl or coated with epoxy resin in structures such as hospitals, factories, or office buildings. To improve the appearance and durability and to recycle materials, some floors are finished with dot patterns formed by mixing milled plastics into the flooring materials at the manufacturing or construction phase. These dots spread in a random manner, hence one pattern at one position is statistically different from all of the other patterns. Our group has taken advantage of this property to develop a practical self-localization system for mobile robots with a focus on low cost and high detection stability.

We have applied our developed self-localization system to an automatic guided vehicle. A problem, which was caused by changing the height of the sensor camera, had happened. We have solved this problem and presently we are having an experiment of the AGV control in a machinery factory. An interim report of the experiment is shown in this paper.

2 Self-localization System Using a floor with random dot pattern

The basic configuration of our developed location-system is shown in Figure 1. In a floor manufacturing process random dot patterns are generated. After that the floor is scanned to make a dot-position database. As the robot moves, a sensor-camera on the bottom captures images of the dot patterns. To determine the robot's position and direction of travel, the system matches the position and orientation of the dot pattern in the captured image with the data in the dot-position database of the entire floor.

The dot patterns in the image are matched with those in the dot-position database using an attitude-detection technology applied for satellites. In a satellite, an on-board camera captures an image of the space and the camera orientation is identified by matching the stellar constellation in the captured image with a known star map. This technology, otherwise known as the *Star sensor* technology, is illustrated schematically in Figure 2. Our detection method shares the following elements with the Star sensor method.

1. Naturally occurring random pattern

Both the star constellation and floor dot pattern are random dot patterns.

2. Foreign dots and disappearing dots

Countless stars may appear in a satellite image, hence the stars used for matching are limited to those above a preset threshold for brightness. Yet in the brightness range just above and below this threshold, non-target stars may inadvertently appear or target stars may disappear. The same principal applies in our system, as previously unregistered dots (hereafter, "foreign dots") may inadvertently appear or database-registered dots may disappear.

To cope with this problem we apply the Polestar algorithm (Silani & Lovera, 2006 [9]), an attitude-detection algorithm with a robust ability to handle the blending of non-target stars or the disappearance of target stars. We call this method "database matching method" in this paper.

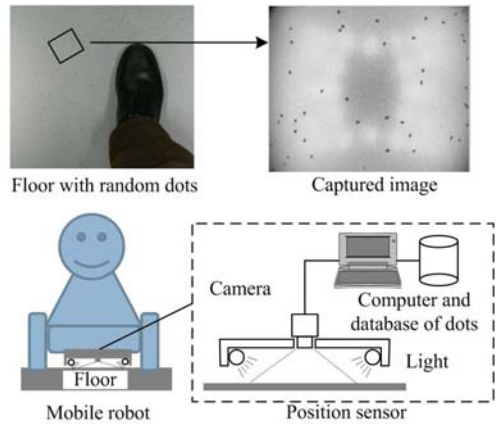

Figure1. Developed Self-localization system

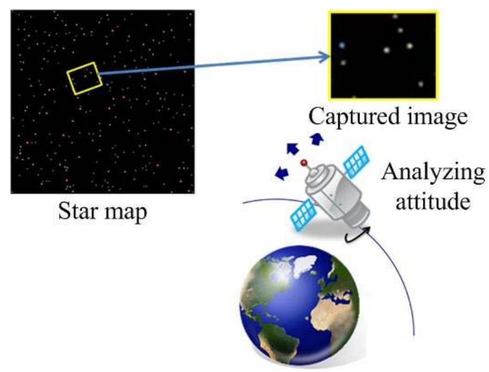

Figure 2. Pole Star algorithm

Sometimes, there are too many foreign dots to match the dot-position database on the floor. In that case, when we apply the database matching method to control a mobile robot, the robot will stop. In order to continue detecting position, we have devised another method. By detecting the movement of dot patterns in two images back and forth in time and accumulating it, we can calculate the position. In this paper, we call the method "detecting movement method."

Even if the database matching method fails, the position will be detected by the detecting movement method. And while it spends shorter time than the database matching method, it generates errors. Thus the two methods run in parallel. The detecting movement method calculates the position in a short cycle and when the matching database method calculates the position, the position calculated by the detecting movement method is modified. Thus, if the self-localization device goes into an area where there are many foreign dots, the position could be detected continuously and quickly. The device, which is showed in figure 4, can detect position in 14[ms] interval and with an accuracy of 1[mm] and 0.5[deg].

We have mounted the self-localization device on a mobile robot and properly controlled it using the detected position. Figure 5 shows the robot.

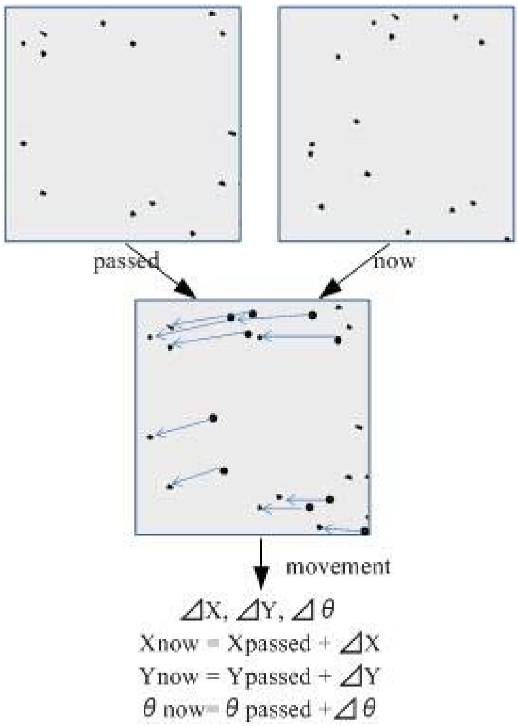

Figure 3. Detecting Movement Method

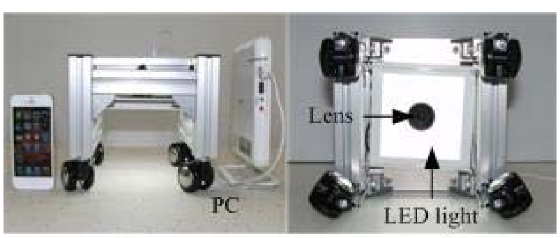

Image sensor: monochrome CMOS
Resolution: 235[pixels]x235[pixels]
Stand-off from floor: 140[mm]
FOV: 90[mm]x90[mm]
CPU: AMD E-450APU 1.65GHz

Figure 4. Self-localization Device

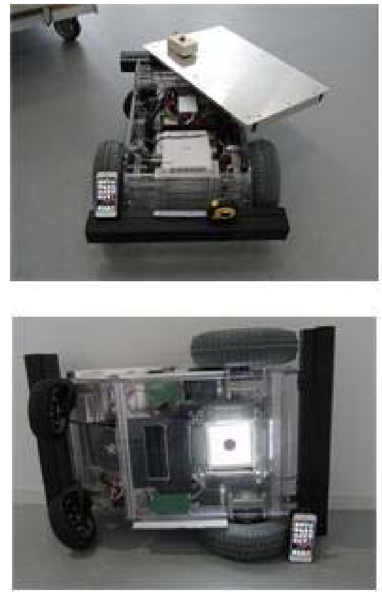

Figure 5. Mobile Robot

3 Automatic Guidance Vehicle

Figure 6. Automatic Guidance Vehicle

Figure 6 shows the automatic guided vehicle (=AGV) which is applied our self-localization system. Table1 shows a specification of the AGV. The AGV has been designed to be navigated with a magnetic guide tape on a floor. It can move omnidirectionally. So we have mounted our developed position sensor on the AGV to detect the position and control it not only on the tape but also on the all floor.

Table 1. Specification of the AGV

Navigation	Magnetic Guide Tape
Communication	Wireless communication
Driving mode	Forward-Back Traverse Spin turn
Tranport weight	1,000[kgf]
Speed	1,000[mm/s] max.
Stopping accuracy	±10[mm]
Size	Length:1,600[mm] Width: 1,250[mm] Height:238[mm]
Weight	450[kgf]
Power	Automatic quick charge Lithium ion battery

4 Undetected Case with AGV

The self-localization device is mounted on the AGV showed in Figure 6. We spread out a random dot pattern vinyl flooring (5[m] by 5[m]) on a concrete floor. When we moved the AGV on the whole floor, the device couldn’t detect the position in several parts of the floor.

Therefore we applied a self-localization device shown in Figure 4. It could detect the positions in most parts of the floor where the device on the AGV could not detect previously.

The difference between these two devices is a length of the wheel bases. When the device is on a carrier with a long wheel base, the height of a sensor camera is variable on a corrugated surface (Figure 7). Matching algorithm was based on the premise that the height is constant.

Changing a distance from the sensor-camera to the floor makes the distances between each dot in a captured image different. In this case, because the matched database is based on the distances between each dot captured from determinate height, the matching process doesn’t work. If the image captured at the location was adequately rescaled, we could detect the position. Therefore failure in detecting positions is thought to be caused by the changing height of the sensor-camera.

Figure 8 shows a captured image. Figure 9 shows a cropped dot pattern. Figure 10 shows difference between cropped dot pattern (white dots) and dot pattern in database (red dots).

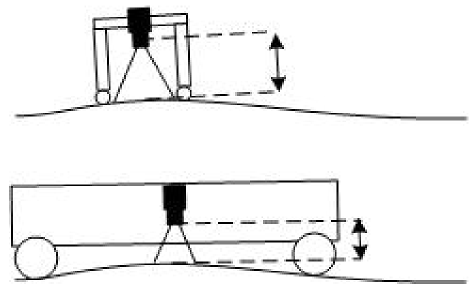

Figure 7. Height of sensor camera on AGV is variable on a corrugated surface

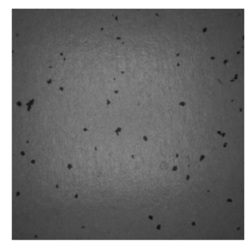

Figure 8. Captured image

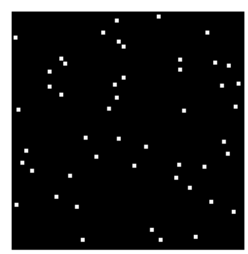

Figure 9. Cropped dots

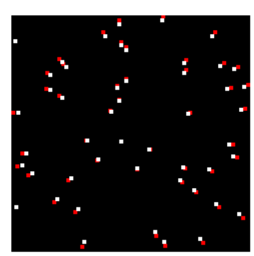

Figure 10. Red dots are pattern in database

5 Experiment for Changing Height

In order to improve the detecting performance, we measured a height of the sensor-camera and rescaled an image in proportion as the height.

We spread out a random dot pattern flooring whose size was 3640[mm] by 9000[mm] on a concrete floor, and set a magnetic guide tape on the floor.

We navigated the AGV by using the guide tape (Figure 11), set a Laser Range Finder (=LRF) near sensor-camera, and measured the distance between the sensor-camera and the floor (Figure 12). Using the measured distance, the image was rescaled in order to detect position. Figure 13 shows a trajectory of the position of the sensor camera. Figure 14 shows the height of the sensor-camera at each travel distance. We can see the changes in approximately 5[mm] range. Figure 15 shows the result of the detection when not using the height measured by the LRF. Figure 16 shows the result of the detection when using the measured height. Red points indicate undetected positions. We can see that the red points decrease from 5.1% to 0.8% on the trajectory.

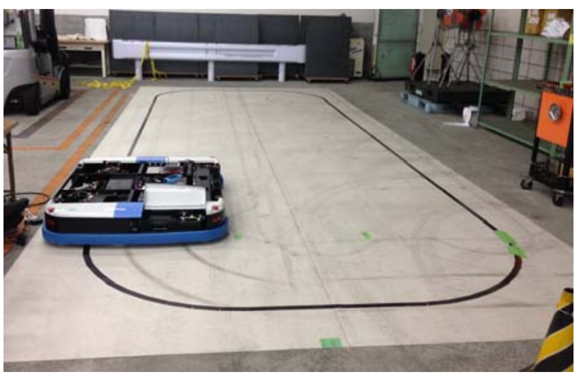

Figure 11. Status of Experiment

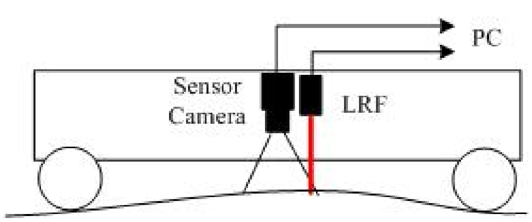

Figure 12. Device with LRF

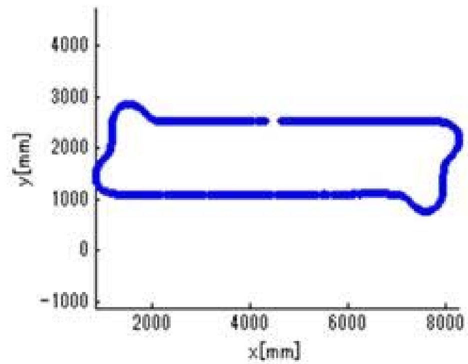

Figure 13. Trajectory of sensor-device

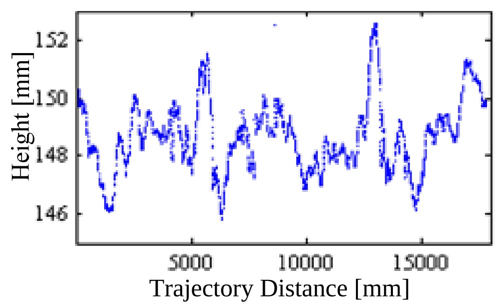

Figure 14. Height of sensor-device

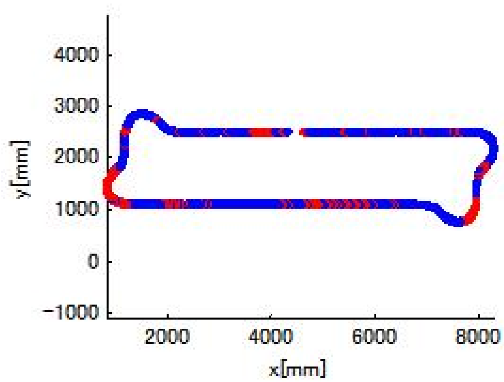

Figure 15. Case of fixed scale
The red points indicate undetected position and the blue points indicate detected position.

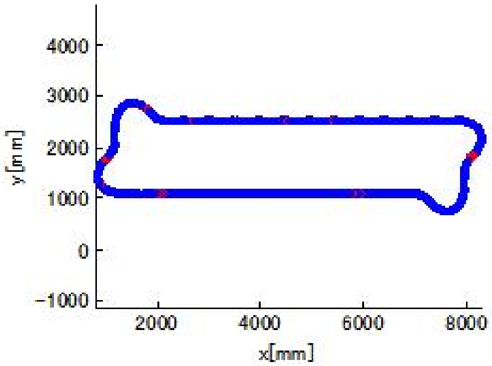

Figure 16. Case of scale changed by height.
The red points (=undetected points) decreased.

6 Experiment In a Factory

Presently we are having an experiment of an AGV controlling with our self-localization system in a mechanical factory. Several folk-lifts are moving around inside and outside the factory. The folk-lifts may put dirt on the floor or damage to the floor. We put a dot pattern floor and three months later we moved the AGV on the floor. In this section, an interim report is shown.

6.1 Experimental Condition

We spread out a flooring in a part of the factory (Figure 17). Figure 18 is a picture of the factory. In the factory there are many numerical control lathes and racks. The folk-lifts carry the racks near the lathes. Oil and cutting chips, which are attached to the tires of folk-lifts, cause the floor dirty (Figure 19). The AGV is controlled autonomously by the position which is detected by the self-localization system. It travels repeatedly approximately 40 [m] from one end to the other end of the floor at 400 to 500[mm/sec].

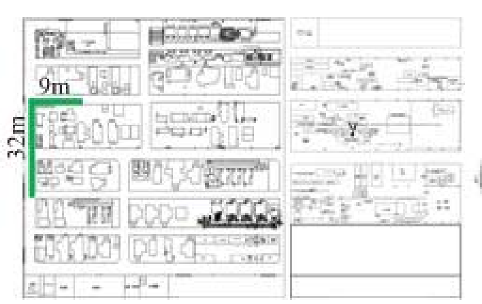

Figure 17. Floor in part of the factory

Figure 18. Mechanical factory

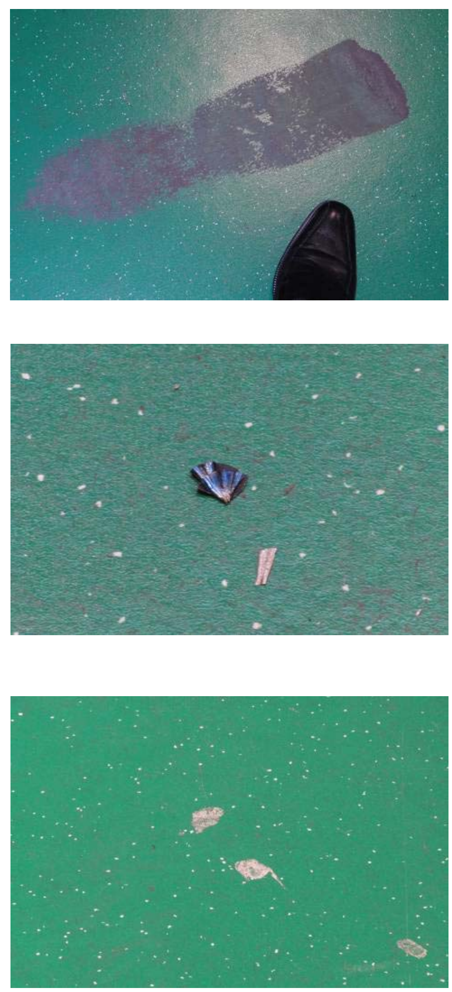

Figure 19. Dirt on the floor

6.2 Result

Followings are the result of detection of the AGV running 216 [m] in 8 [min.].

Output Interval (average) : 14 [msec]

Movement detection success rate: 99.1[%]

Matching database success rate: 92.4[%]

Figure 20 shows a trajectory of the AGV. The blue points are detected positions and the red circles are points where the matching database error occurred. The matching database failure rate is 7.6%.

Pictures in figure 21 are the images with which matching database failure occurred. In some cases dots were disappeared because of oil spots and in the other cases cutting chips became foreign dots. Even, in those cases, self-localization system could be continuously working using the detecting movement method in parallel with the matching database method and the AGV was controlled without problems.

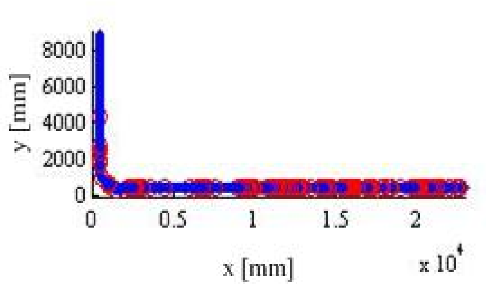

Figure 20. Trajectory of AGV

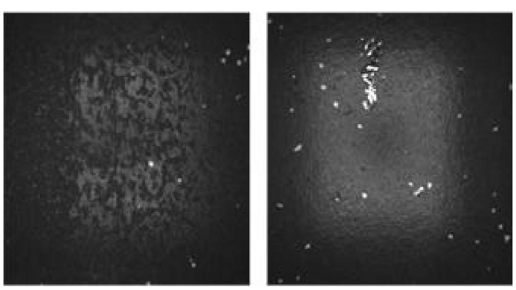

Figure 21. Mactching Failure Images

7 Summery

We applied the self-localization system which we developed using a floor of random dot pattern to an AGV. At first the system did not work properly because of the height variation of the sensor camera. We solved the problem by using the magnification adjustment of the image by measuring the height with a laser measuring instrument. Currently, laying the point cloud pattern floor in the machine factory, we have implemented a running experiment of AGV. After about three months since spreading out the floor, the self-localization system could detect the position properly and the AGV was controlled autonomously without problem. We plan to have the same experiment after six months and after one year in order to evaluate the effectiveness of the self-localization system.

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