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A Real Time Detection Algorithm for Direction Error in Omnidirectional Image Sensors for Mobile Robots

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Abstract

A novel algorithm for the real time detection of the direction error in heading of the mobile robot is proposed. The proposed algorithm is designed for an omnidirecional image sensor. For the omnidirectional image sensor, the hemispherical mirror, one CCD camera, and a vision board are used. This configuration has the low cost and the efficiency in collecting omnidirectional data with one image compared with other types of image sensors. The proposed algorithm is verified through computer simulations and a practical mobile robot.

1 Introduction

For the AMR to be able to move around in a narrow environment without collision, high resolution data and detection of closer object are necessary. It may be more necessary in FMS plant. In this case, slight error in heading of the AMR will lead to a collision with the wall and other machines.

In general, ultrasonic sensors are used in navigation systems for mobile robots, because it gives cost efficiency and an easy way to find the distance to obstacles. But the ultrasonic sensors have two major problems. One is that ultrasonic sensors have low resolution. The other is that ultrasonic sensors often fail to detect an object which lies close to the mobile robot. To overcome these problems, many configurations using multiple ultrasonic sensors have been suggested[1,2,3,4].

There are two kinds of errors in the movement of the AMR. One is a distance error can be detected and compensated by mutiple ultrasonic sensors in most situation. The other is a direction error. It is hard to detect direction error if the mobile robot is equipped only with ultrasonic sensors. This is more likely to cause serious problems. These kinds of errors will eventually result in a serious navigation error to the target point.

For these reasons, various image sensors have been developed and implemented for mobile robots[5,6,7]. But these systems have a high complexity in computation and additional mechanical parts. To overcome these problems, omnidirectional image sensors have been studied[8,9,10]. The image-based homming system was proposed by Hong[8]. A sensing system with a hyperboloidal mirror was proposed by Yagi[9,10]. But these researches were focused mainly on the structure of omnidirectional sensor without practical application to mobile robots. Previous works lack from experimenting with real data to show how omnidirectional image sensors operated well. For practical applications, the detection of the direction error are demanded.

Our aim is to develop a omniderectional image sensor capable of performing accurate and reliable detection of direction error for the mobile robot. The proposed omnidirectional image sensor can detect natural landmarks in real time, because it has low complexity in computations. The proposed configuration has the low cost and the efficiency of collecting omnidirectional data with one image compared with other types of image sensors. Using the proposed image sensor, the AMR detects direction error easily, and estimates the present location efficiently.

In this paper, an algorithm for real time detection of the error in heading of the mobile robot is suggested. The developed algorithm is applied and tested to the omnidirectional mobile robot developed. Section 2 gives a brief description of an image sensor. In Section 3, a filtering algorithm for preprocessing data and the detection algorithm for the direction error is suggested. Section 4 presents he performance of detection algorithm through computer simulations for a practical mobile robot. Finally, the conclusion is drawn in Section 5.

2 Image Sensor

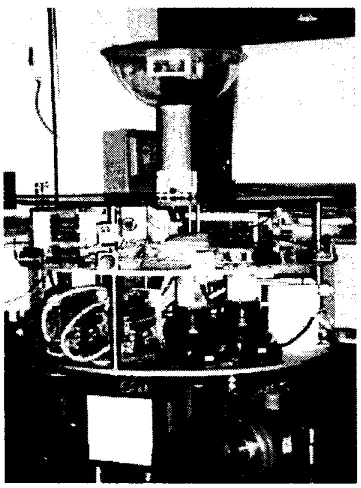

Figure 1: Image Sensor with Experimental Mobile Platform

The developed mobile robot is shown in Figure 1. The image sensor is mounted on the center of the top plate, as shown in Figure 1. The image sensor is composed of a camera, a image processing board and a sensor housing. The design guideline of the image sensor is as follows. First, the image sensor must be able to collect data from all directions around the mobile robot. This property is necessary for the developed omnidirectional mobile robot. Secondly, it must be appropriate for the detection of the heading angle error in real-time processing. And thirdly, cost must be as low as possible. In this configuration, data from all directions can be extracted with one image effectively. So, potential errors in the image sensor are minimized because the camera is fixed on the mobile robot. And the building cost is virtually minimized by it's simple architecture. Based on the idea explained above, the image sensor has been built. Figure 2 shows a prototype of the image sensor.

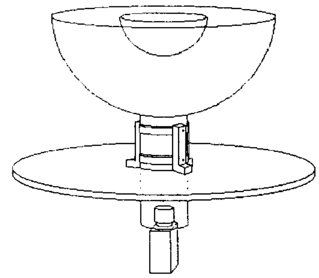

Figure 2: Configuration of Image Sensor

3 Detection Algorithm for Direction Errors

3.1 Filtering Process

The raw image taken from the image sensor is in Figure 3. For the preprocessing data in the each check point, moving average filter(LPF filtering)was applied(Figure 4). The moving average filter has been applied in order to reduce sensor noises. In first, high frequency noises are removed by using moving average filter. In this algorithm, the value of $M = N = 2$ is used for the 5-point moving average filter.

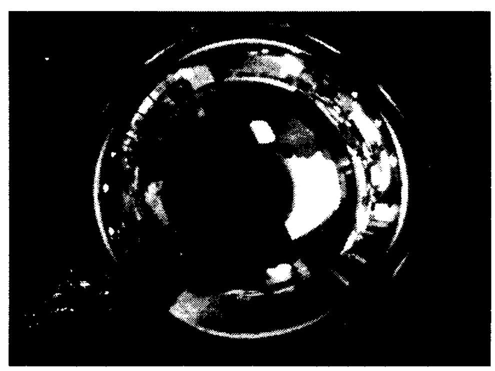

Figure 3: Raw image from Image Sensor

$$y[n] = \frac{1}{N+M+1} \sum_{k=-N}^{M} x[n-k] \qquad (1)$$

And then, neighboring data is connected for vector sets. Local maximum values and minimum values are calculated and pointed in the next step. During the calculation, variations within the threshold value

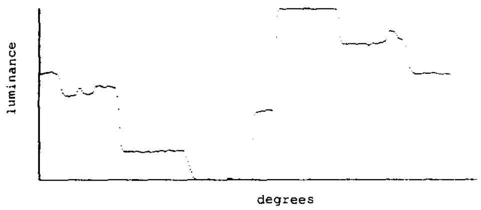

Figure 4: Low Pass Filtered Data

are ignored. Figure 5 represents the procedure of the detection algorithm.

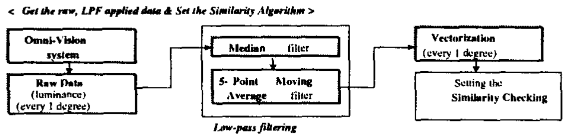

Figure 5: Detection Algorithm for Direction Error

3.2 Detection Algorithm using Similarity Check

The indoor environment has some features different from an outdoor one. That is, almost all structures are vertical in indoor environments. Thus, the feature of a specific location can be determined from series of luminance data(gray level) that are sampled from a horizontal plane. The horizontal plane, on any position in vertical axis between the floor and the ceiling, will give virtually same series of luminance data. Series of luminance data are sampled on one circle which corresponds to a virtual horizontal plane is used for the detection algorithm. Such sampled data can be plotted on a direction angle versus luminance in the coordinate plot, and an example is in Figure 6. In Figure 6, the distance from the center to a point means the luminance value of the present direction. In Figure 6, we can easily observe that the highest luminance value is in directions approximately 5° and 75°. The scheme for the image sensor as a heading error detector is as follows. The PC connected with the image sensor stores series of the luminance data at the every predetermined checkpoint. When the AMR reaches that check point again, the processor gets series of the luminance data from the image sensor system, and then compares it with the one stored before. If there is some shift between these two sets of data, the PC notifies the motor controller about the direction and amount of the heading error.

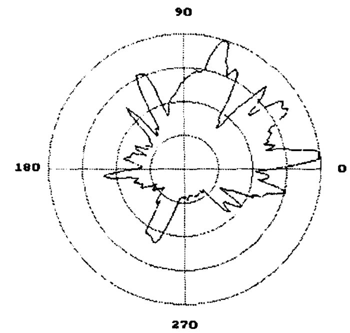

Figure 6: Direction angle versus luminance plot

The core of this scheme is 'How to compare two sets of data that have the same pattern, but there is some angular shift'. First, we consider what it would be like if a person did this process by the human's perception scheme. A human brain will focus on the global shape of the pattern. That is, small fluctuations in data will be ignored, and the luminance data at a direction will be perceived as a part of the 'recognizable pattern'. This means that the relations among neighboring luminances are more important than the individual luminance value in a specific direction. Having this concepts in mind, we try on composing an array that contains the signed difference between the neighboring luminance values. For formal representation, it will be described as follows

$$L = (l_0 \;\; l_1 \;\; l_2 \;\; \ldots \;\; l_{359}) \tag{2}$$

$$D = (l_0 - l_1 \;\; l_1 - l_2 \;\; \ldots \; l_{358} - l_{359} \;\; l_{359} - l_0). \tag{3}$$

where L is an array of the luminance values, D is an array of the signed difference values between neighboring luminance data. It is easier to compare two sets of data, with arrays denoted as D, of each data sets. The comparison scheme is as follows

$$(angular\ shift) = n \tag{4}$$

where n is given as

$$r_n = \min(r_0, r_1, \ldots, r_i, \ldots, r_{359}) \tag{5}$$

$$r_i = \sum_{m=0}^{359} |(D_{stored} - D_{current.i})_m|. \tag{6}$$

$(D_{stored} - D_{current.i})_m$ means the m-th element of $D_{stored} - D_{current.i}$, $D_{current.i}$ means a shifted version of $D_{current}$ by the amount of ith with wrap-around.

But it still needs many calculations(360×3 subtractions and 359 additions), which will result in low comparison speed in computation time. Thus, there must be some modifications as follows

$$(angularshift) = n' \tag{7}$$

where n' is given as

$$s'_n = min(s_0\ s_1 \dots\ s_i \dots s_{359}) \tag{8}$$

$$s_i = S_{stored} S_{current.i}{}^T \tag{9}$$

$$S = [sgn(l_0 - l_1)\ \ sgn(l_1 - l_2) \dots sgn(l_{359} - l_0)]. \tag{10}$$

It is natural that modified equation seems a little more complicated and time-consuming, because there are multiplications and signum functions in the formula. It needs 360×2 subtractions, 360×2 signum functions, 360 multiplications and 359 additions. But the time spent for signum functions and the multiplications can be neglected, because the signum functions can be substituted with a combination of simple and fast bitwise operations. And multiplications can also be substituted with a simple look up table.

4 Experiment

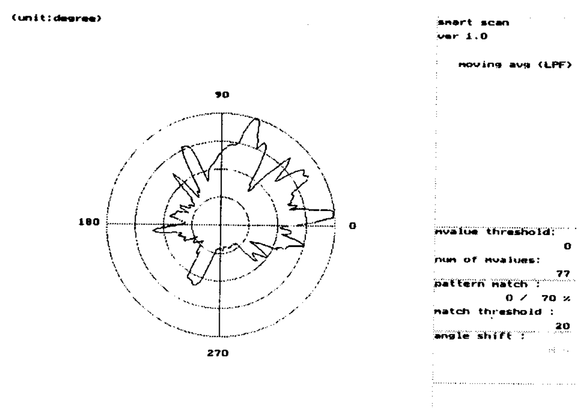

Figure 7: Reference(stored) data

Following experiments are chosen to test the algorithm presented previously. For some typical situation, a rotation up to 180° and a translation of the AMR is tested. Figure 8 shows the result of −24° rotation.

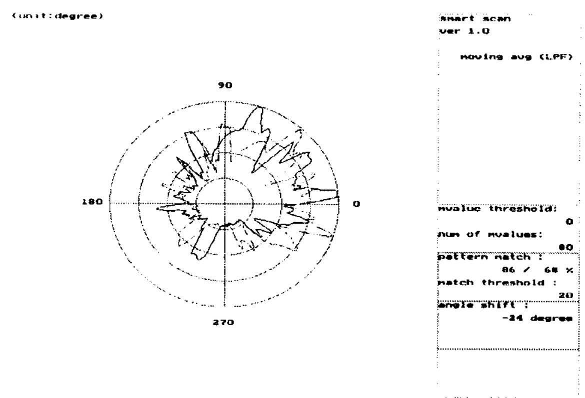

Figure 8: −24° rotation

The minus sign means the data sampled is rotated counterclockwise from the reference data. The calculated value of the angle shift is almost stationary while the sampling was being repeated, with some rare fluctuations which were in the range of ±1° maximum. The second experiment shows the case of 60° rotation.

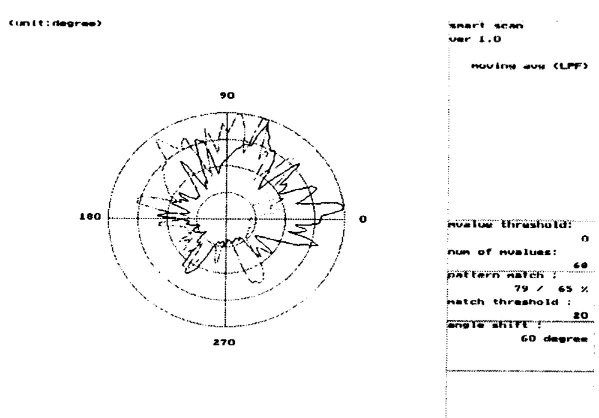

Figure 9: +60° rotation

The calculated rotation angle (i.e., the angle shift value) is as stationary as before. The third experiment shows results for the cases of 120°. The fluctuation of calculated angle shift value was still in the range of ±1° maximum, though the value was a less stationary. We observe that the details of the luminance curve become more and more different from the reference curve as the angle shift value increases. The reference data super-imposed on +60° on from the error in manufacturing the hardware part (i.e., mirror, holder, etc.)shown in Figure 2. It is easy to see that the angle shift value is very precise despite of the variation of the luminance data.

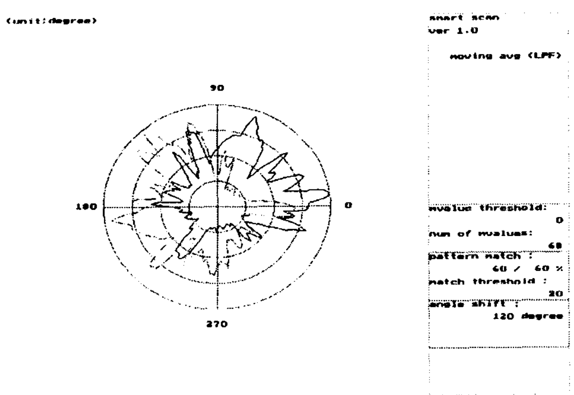

Figure 10: +120° rotation

In Figure 10, we observe that the variation of the data is more eminent, but the algorithm gives a right answer, as long as the global characteristic of the curve is preserved. It is used a value named as the pattern match in Figure 8-Figure 12. This value is represented as current value/minimum requirement value. When this value becomes to smaller than the minimum requirement, the angle shift becomes non-acceptable case(N/A). It means that the global characteristics of the two luminance curves are significantly different, so the mobile robot is not on the exact position of the checkpoint in the navigation. If so, calculating the error in heading angle of the AMR is meaningless. The minimum requirement value is set to decrease linearly, as the absolute value of the angle shift increases. In formal representation, these values are given as follows

$$(current\ value) = (m/360) \times 100 \tag{11}$$

$$(min_{req}) = -(15/180) \times (angleshift) + 70. \tag{12}$$

where m is the number of data which satisfies $|(reference\ data) - (current\ data)| < \theta_{th}$. (min_{req}), θ_{th} represents minimum requirement value and threshold value. Eq. 12 is determined empirically, to form a tight linear boundary of the minimum requirement value. That is, rotations up to ±180° at the reference position may not yield the result that angle shift is N/A. Following experiments(Figure 11, 12) are about cases of the translation errors.

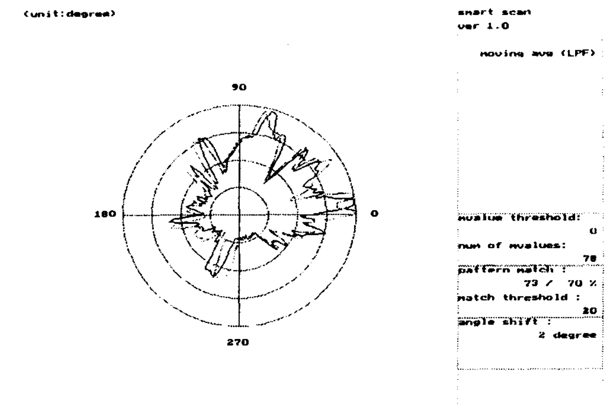

Figure 11: 20cm translation

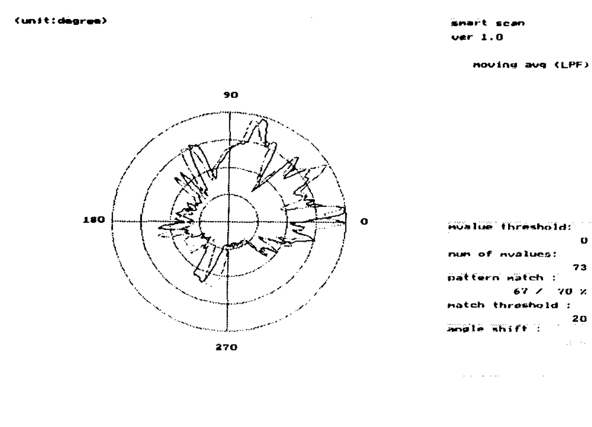

Figure 12: 40cm translation

In Figure 11, we observe that the translation by 20cm is interpreted as 2°rotation. It can be found that this kind of misinterpretation will persist until the distance of translation reaches approximately 40cm, in Figure 12. Figure 12 shows the case of 40cm translation, and the angle shift value is now displayed as N/A. Some more experiments showed that the 40cm is the threshold value of the misinterpretation. That tion by the amount of $40cm$ or farther, the angle shift value becomes N/A. We expect this threshold value will decrease because these experiments are performed in a hall which was a lot bigger and wider than the narrow aisle where the proposed image sensor system had been designed to operate. The image sensor can be used to detect the objects which lie closer than the detection limit of the ultrasonic sensors. This is the reason that we used a hemispherical mirror(Figure 13). We need a slight modification of the algorithm, which means taking a surplus sample on a circle of radius $r2$ along with that of on the circle of radius $r1$(where $r2 < r1$). The surplus data contains the information about objects near the AMR. It can be used to detect an obstacle, which is too close for the ultrasonic sensors to detect.

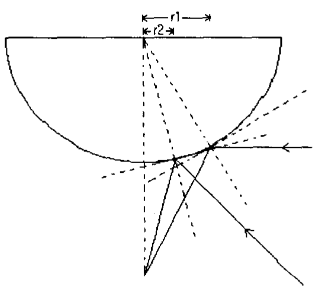

Figure 13: Model of hemispherical mirror

5 Conclusion

In this paper, an algorithm for the real time detection of the direction error in heading of the AMR is proposed. The proposed algorithm is designed for the omnidirecional image sensor for mobile robots. For the omnidirectional image sensor, the hemispherical mirror, one CCD camera, and a vision board are used. The current position and the heading direction of the mobile robot are obtained from a single image projected on a hemispherical mirror.

The proposed algorithm is proved to have efficiency in the computation time. This configuration has the low cost and the efficiency in collecting omnidirectional data with one image, because it uses commercially available projection bulb instead of mirrors. The proposed algorithm also eliminates the need to rotate the camera for tracking obstacles and landmarks.

The proposed image sensor and algorithm can be applied to the case of unmanned moving vehicles and automobiles.

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