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Effective Route Decision of an Automatic Moving Robot(AMR) using a 2D Spatial Map of the Stereo Camera System

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Abstract

This paper proposes a method for an effective intelligent route decision for automatic moving robots(AMR) using a 2D spatial map of a stereo camera system. In this method, information about depth and disparity map are detected in the inputting images of a parallel stereo camera. The distance between the automatic moving robot and the obstacle is detected, and a 2D spatial map is obtained from the location coordinates. Then the relative distances between the obstacle and other objects are deduced. The robot move automatically by effective and intelligent route decision using the obtained 2D spatial map. From experiments on robot driving with 240 frames of stereo images, it was found that the error ratio of the calculated distance to the measured distance between objects was very low, 1.52[%] on average.

Key Words : AMR(Automatic Moving Robot), Stereo Camera System, Disparity Map, Effective Route Decision, 2D Spatial Map

1. Introduction

The development of automatic moving robots and manless vehicles have been widely subjected to investigation using automatic pursuit systems equipped with powerful cameras and recent image process technologies. The technology developed in this study can be applied to artificial intelligence to increase the path setting capability and decision making of moving robots by enable them to have three-dimension information about the position of moving obstacles, and changing direction.

Generally, to set a path and to control the automatic movements of robots and manless vehicles, the topology and natural features or obstacles ahead must be detected and estimated to be able to move and travel without colliding. Particularly, the path for a safe travel to the destination by a system must be secured by sounding alarms and/or warning signs when any walker or moving object appeared.

To maximize the sight function of such a system. the eyesight system built on intelligence type camera imitating Human Visual System (HVS) has been introduced as a vision technology

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to enable a robot to travel effectively. Robots or and vehicles can achieve this by evaluating the distance separating them from an obstacle with the three dimension information they get, and by analyzing the stereo image inputted from the stereo camera attached to them[1-4].

To be able to apply the eye sight system built in intelligence camera to automatic moving robots or manless vehicles, it is necessary to be able to recognize a simple three dimensional information like that three dimensional position, the magnitude, and the direction of anything corresponding to the object travelling at a high speed rather than having a full understanding of the complicated periphery and environment of the object. It is also not much important to reconstitute it[5-11].

The present study used the detecting technique of a two-dimensional space map able to set an intellectual and effective path for the automatic moving robot. It enables the robot to recognize moving things and obstacles ahead, and getting three-dimensional information using the principle of sight error on both eyes within the stereo vision. Based on test results, the implementation of automatic moving robots is proposed. The robot can detect two-dimensional space maps with the stereo camera system, and travel automatically according to an intellectual path. The robot can detect obstacle with a distance error of less than 1.52[%].

2. Disparity detection of stereo image

Figure 1 shows the flow chart used to obtain the two dimensional space map of the stereo camera that determines the path of the automatic moving robot proposed in the present paper.

In the first step, the occlusion region is detected with the left and right image obtained by the parallel type stereo camera attached to the automatic moving robot.

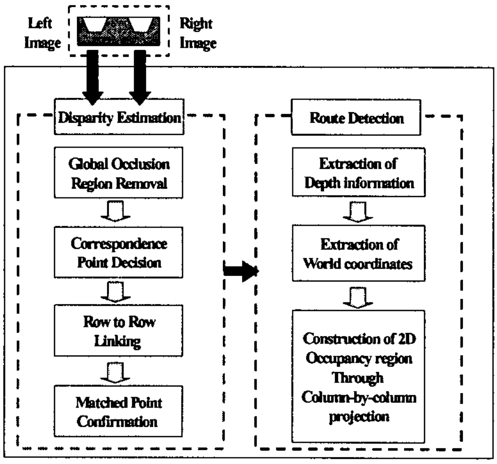

Fig. 1. Flowchart for composition of 2D spatial map using a stereo disparity

In a meeting point locating at the exact sum of the stereo image of subjection region in the left and right excluded the occlusion region detected, the sight error is detected, then analyzed by a technique that detects the sight error of tree structure. Finally, the map of sight error is drawn.

As the second step, by using the geometric relationship between the sight error map and the camera coordinate system, information about the three-dimensional depth is gained. Then, by allocating the critical value regarding the depth, and separating only the region of the object, the entire width of the object region(x-axis) is calculated.

At the same time, by detecting the minimum value for each column of the depth map, the two dimensional spatial map is formed. With it, the relative position of any object ahead of the automatic moving robot is determined, and the effective and intellectual travel path set.

The images at the left and right taken by the stereo camera on the x-axis of the automatic moving robot are converted into the sight error map by the transformed Sum of Absolute Difference(SAD) to cast function described in equation (1), and carrying out the procedure of exact summing between each block.

$$Min\left[\left(\frac{1}{S\_H\times(S\_W-n)}\sum_{j=0}^{S\_W}\sum_{i=0}^{S\_H}\left|I_R[j][i]-I_L[j][i+n]\right|\right)_{n=0}^{N}\right]$$
$$(If, i+n < S\_W) \qquad (1)$$

Where i, j are the pixel positions of each row and column in the given image, n the difference between the left and right images, and S_H and S_W, respectively the magnitude of the row and column of the image.

Figure 2 shows the entire process that determines the correspondence point(meeting point) of the stereo images: the column which shared more similarity on the left and right image is selected. Then, the initial point of the occlusion region from the left and right of the column is determined. Then, the final step cancel out the occlusion region.

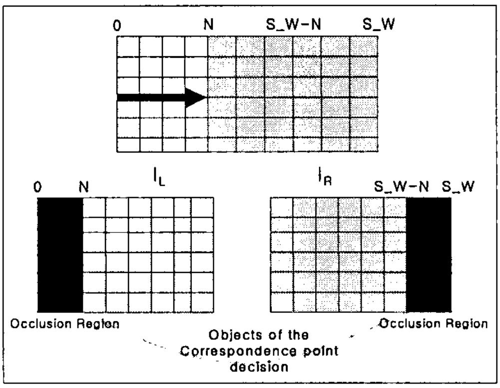

Fig. 2. Diagram for pre-processing stage

The I_L and I_R in Figure 2 represent the left and right images respectively. S_H and S_W are the magnitude of the width and length of each image, and N is the range covers for detecting the column having the maximum similarity.

The meeting points are calculated with equation (2), then the operation is reiterated, and multiple meeting points are generated.

$$S_{(j,i)} \ni \left[abs(I_R[j][i+m]-I_L[j][i-N])\Big|_{m=0}^{M} < T\right]$$
$$(If, 0 \le S_{(j,i)} \le S\_W) \qquad (2)$$

Where, M expresses the range to decide the meeting point, and T the critical value to discern the meeting point.

Figure 3 shows the numerous meeting points detected according to each region. The multiple trees are made by connecting the meeting points on each column according to the condition on the foundation of the multiple meeting points of each first row of the image excluding the occlusion region.

The condition means that if an object "a" in the left image exists in the left of other object "b", and as sameness, if an object "a" in the right image exists in the left of other object "b". The trees constitute in each column are independent between columns.

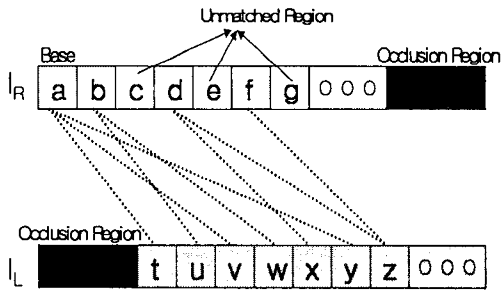

Fig. 3. Diagram for multi-correspondence points

Table 1 shows the trees made on the foundation of multiple meeting points detected in the figure 3.

The value in the region having maximum number of the same value in multiple trees is decided as the meeting point in the region. Then, based on the decided meeting point, the trees are again formed by considering the order. By performing this procedure repeatedly. a single tree S_T[i, j](single tree) having maximum number of meeting points is constituted.

Table 1. Composited multiple trees

meeting point calculated in a region	trees constituted excluding the region unmatched
t	(t u x z) or (t u z 0) (t w x z) or (t w z 0)
v	(v w x z) or (v w z 0)
y	(y 0 0 - z)

Table 2 shows the trees constituted on the foundation of table 1

Table 2. Fixed tree of correspondence points

repeat number	meeting point decided	single tree
1	t	(t 0 0 0)
2	w	(t w 0 0)
3	x, z	(t w x 0) (t w z 0)
4	z	(t w x z) (t w z 0)
Single tree decided(S_T)		(t w x z)

Accordingly, the sight error between the left and the right image can finally be calculated by equation (3).

$$d_{(j,i)} = I_R[j][i] - S\_T[j][i] \quad (3)$$

3. Detection of travel route

Figure 4 shows the geometrical structure of a parallel stereo camera. The parallel stereo camera is easier to calibrate, and the determination of depth is simpler than with the cross type stereo camera. Moreover, it makes fewer errors. The horizontal injection rays of both cameras consist of reference rays and parallel rays.

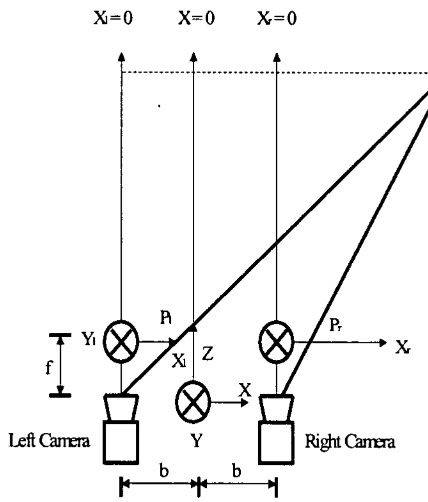

Fig. 4. Geometric Structure of parallel stereo camera

Equation (4), (5), (6) are deduced from the geometric structure of the parallel stereo camera, and finally z the depth can be expressed as in Equation (7) [12].

$$\frac{x - \frac{b}{2}}{z} = \frac{x - \frac{b}{2} - h + l}{f + z} \quad (4)$$

$$l = \frac{fx}{z} - \frac{fb}{2z} + h, \quad r = \frac{fx}{z} + \frac{fb}{2z} - h \quad (5)$$

$$d = (l - r) = 2h - \frac{fb}{z} \quad (6)$$

$$z = \frac{fb}{2h - d} \quad (7)$$

In Equation (7), f and b are respectively the focal length of the stereo camera and the baseline between cameras, whereas h and d express the distance separating the CCD camera sensors, and the sight error between images, respectively.

Since the three dimensional objects are mapped into a plan through far and near transformation centering at a distance f, this causes the real coordinates(X, Y) to be detected by the resemblance triangle shape on the foundation of the position coordinate detected in the image coordinate system and z is obtained from equation (7).

$$X = \frac{iZ}{f}, \quad Y = \frac{jZ}{f} \tag{8}$$

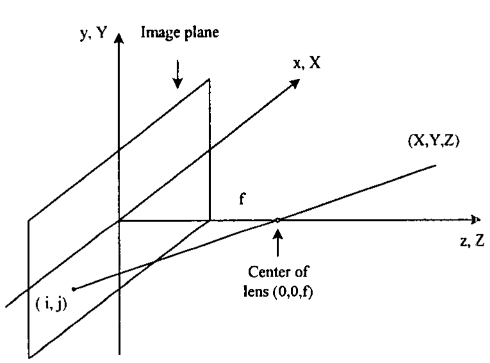

Fig. 5. Perspective conversion method of camera and real coordinate system

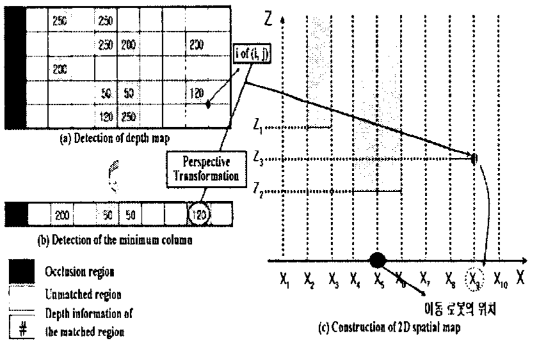

Fig. 6. Diagram for detection process of 2D(X, Z) spatial coordinate

Figure 6 shows the procedure to detect the two dimensional space coordinate(X, Z). It also describes how to analyze the relative position of all objects ahead of the automatic moving robot(the two dimensional coordinates of the objects must be minimized to be able to cover each row of the entire depth map detected.

After the minimum value existing between each row of the depth map has been detected as the representative value of the row as described in figure 6 (a), the two dimensional spatial coordinate (X, Z) is formed through mapping into x coordinate correspondence to this (representative value).

The two dimensional spatial coordinate formed through figure 6 is not only use for detecting the distance between obstacles including moving things ahead of the robot but also to forsee and avoid collision by setting an effective and intellectual travel path. This is possible because the automatic moving robot can analyze even the relative distance between moving thing and an object thanks to equation 8.

4. Test and result analysis

The test was carried out as described in figure 7 with the automatic moving robot manufactured for this study. The robot was then loaded with the parallel type stereo camera system. This system consists of an apparatus capable of photographing 30frame/sec with a pixel resolution of 640×490, a Pioneer-3DX made by Active Media Inc and Bumblebee, a parallel stereo camera made by Point Grey, and a computer of 1[GB] memory equipped with a 3[GHz] Pentium. The Pioneer 3-DX uses three batteries of 12[V] each. The entire system was run with other battery of 12[V], 400[W].

The focal length (f) and the base line (b) required in equation (4) were 4[mm] and 120[mm], respectively as specify by the manufacturer (Bumblebee). With those values, the depth was calculated.

The algorithm and system used are the kernel of the automatic moving robot proposed. They aim at establishing an effective and intellectual path that will prevent collision by detecting the relative and absolute coordinates of moving objects that will be on the way of the robot.

Figure 8 shows four randomly selected frames among the 240 frames used in the test. The initial photographs were color pictures taken with a resolution of 1024×768, but were latter converted into 320×240 grey.

First the stereo image inputted in real time was pre-treated, and the occlusion region was removed. Then, the meeting points in each region were detected.

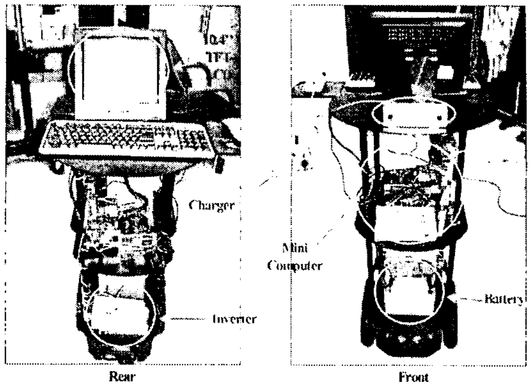

Fig. 7. Automatic moving robot(AMR) system

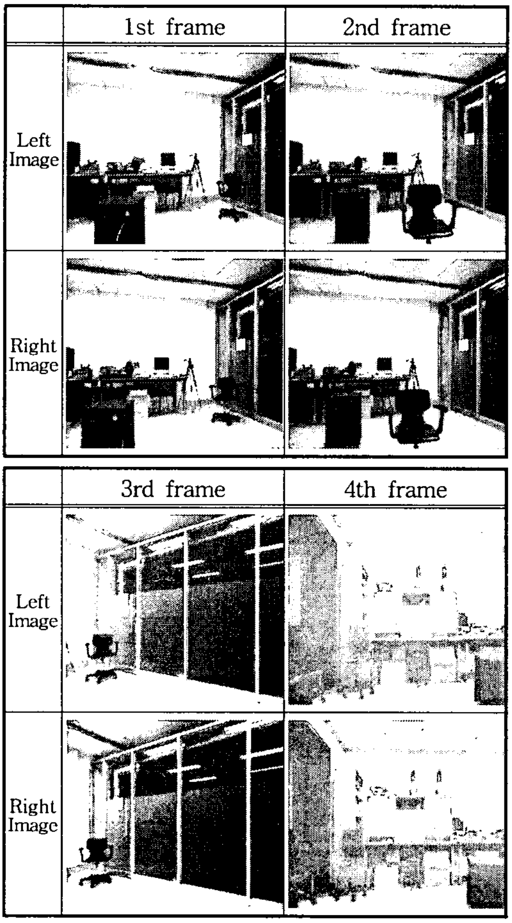

Fig. 8. Real time stored stereo image

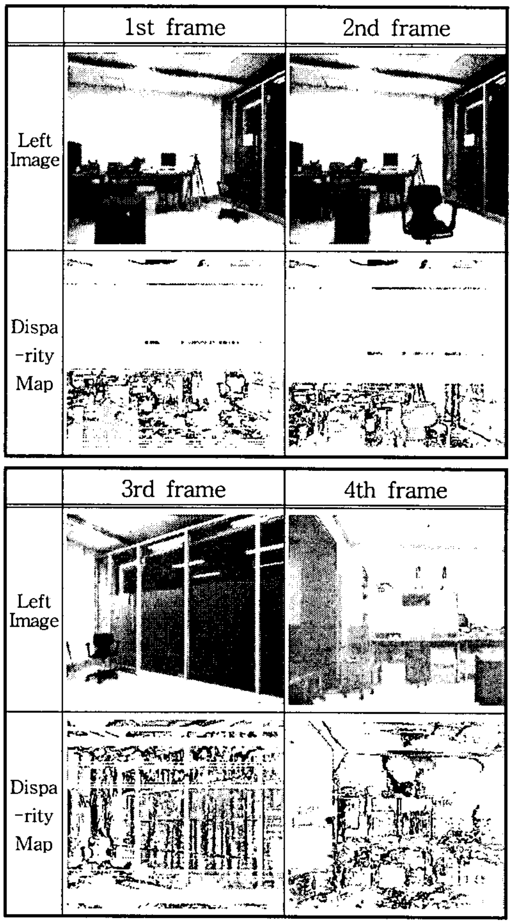

Fig. 9. Left input image and detected disparity map

The multiple trees are formed by linking the meeting point of each row as considering the order condition on the foundation of the meeting points detected, and where the same values exceed the unified critical value is selected as the meeting of the region, and a single tree is formed.

Figure 9 shows the left image, and sight error map. Due to the occlusion region and the region unmatched, it shows a map sparsely filled.

In figure 9, the bright region is the occlusion or unmatched region. In the magnitude distribution of the sight error, the grey corresponds to where the sight error was great, and the black where it was small.

Figure 10 shows the two dimensional spatial coordinate able to analyze the position between the robot and objects on its way by estimating the minimum distance between the rows and the center of the depth map.

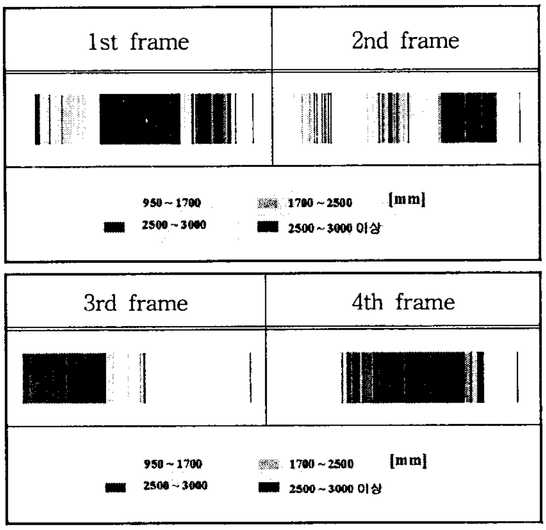

Fig. 10. Minimum row detection for route decision of AMR

The distance to the object from the robot was calculated with the minimum depth value existing in each row of the depth map evaluated using equation (7) and the sight error map in figure 9. Where the value of depth suddenly increases or decreases, the calculation was done by interpolation using the pixel values between frames.

In figure 10, places where the robot is near(95 [cm]) an obstacle appear white. Other objects were detected at 3[m]. When the object was located beyond 3[m], it was considered as a back ground image. It was not taken into consideration in the present frame, but set into the regions for future detection.

Accordingly, the value in the least row of depth map detected was regarded as a upright distance from the point, and as the equation (8), the equation for calculating X coordinate correspon-ding was deduced. This also is usful for calculation of left and right width in real of moving body and hindrance, and of the distance between a hindrance by hindrance.

Table 3 shows the relative distance between the objects from the spatial map detected through figure 10 to set the effective travel path of the automatic moving robot.

Where there exist an object ahead of the robot, it is necessary to determine the distance separating them to avoid collision.

Table 3. Measured value and calculated value of relative distance between AMR and object

Frame		Distance([cm])		Error ratio([%])	Average ([%])
		Calculation	Measurement		
1st	Object 1~2	93.00	92.32	0.73	1.52
	Object 3~4	38.00	38.89	2.29	
2nd	Object 5~6	44.00	44.58	1.31	
	Object 7~8	60.00	61.08	1.76	

Figure 11 is a two dimensional spatial map obtained by using the least row value in figure 10.

As the spatial map is two dimensional and composed of X(left and right width of the object) and Z(upright distance from the robot), it was used for setting the a safety path for the robot.

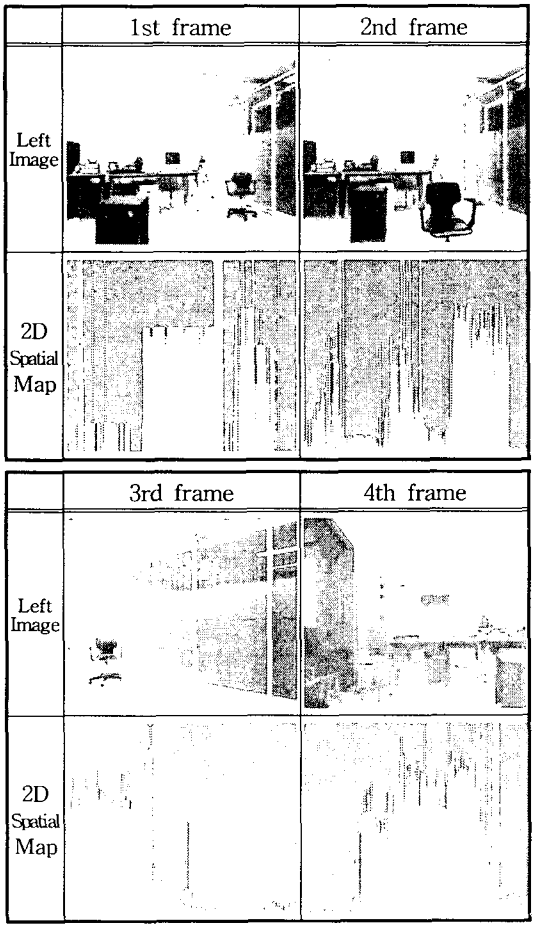

Fig. 11. Spatial map for route decision of AMR

5. Conclusion

In the present paper, an algorithm for detecting new two dimensional spatial map using parallel type stereo camera was proposed in order to set a more effective and intellectually safe path for automatic moving robots.

A two dimensional spatial map was formed by detecting from the two dimensional spatial coordinate the coordinate of objects ahead and their relative distance. Through the algorithm proposed, this was used for setting the path for a collision free movement for the robot.

The error on the distance between the automatic moving robot system and an obstacle ahead was maintained at less than 1.5[%], and even the relative distance between an obstacle and other objects was possible. With the system present in this paper, it is possible to preset an effective and intellectual travel path that will avoid collision for automatic moving robots and manless vehicles. Consequently, it is suggested that for practical purposes automatic moving robots and of manless vehicles be equipped with stereo cameras.

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