Journal of the Korean Institute of Illuminating and Electrical Installation Engineers Vol. 21, No.9, pp. 32~38 November 2007 (21-9-6)

Measurement of Distance and Velocity of Moving Objects using Single Camera Pseudo-Stereo Images

Jae-Soo Lee* · Soo-In Kim · In-Ho Choi

Abstract

In this study, a new algorithm for measuring the velocity and distance from a camera to a moving object by using pseudo-stereo images obtained from a single camera with a stereo adapter is proposed. The proposed system is similar to a parallel visual stereo system using a two-camera system, but because this system can obtain pseudo-stereo images form a single camera, it has advantages not only in the aspect of cost but also in stereo conformity by arrangement and the calibration of the left and right stereo cameras upon image processing.

Key Words : Stereo Camera System, Parallel Visual Stereo System, Pseudo-Stereo Image, Stereo Adapter, Horizontal Disparity, Measurement Of Distance And Velocity

1. Introduction

Much research has been conducted in a variety of fields over the past several decades towards creating an intelligent visual system. While most information is processed into a form of diverse image information owing to the rapid progress of multimedia technology, an intelligent visual system has recently begun to be developed so that images can be processed into a stereo form based on principles of human sight[1-7].

In a stereovision system, the features of both cameras should be identical and the cameras should be aligned accurately on a horizontal line. Another disadvantage of stereovision is the amount of precision required for calibration[8-9]. For this reason, errors are generated upon conformity of stereo images. In this study, to compensate for this disadvantage, pseudo-stereo images were obtained by dividing images, which were acquired by mounting a stereo adapter in front of a single camera, into left and right stereo images.

The objective of this study was neither the expression of a three-dimensional stereo sense nor an accurate reset or three-dimensional representation of the surrounding environment, but the measure of the distance and velocity of moving objects through the rapid acquisition of three-dimensional information from images obtained in the system. Therefore, a single-camera

* Main author : Department of Information and Communication, IT School, Kimpo College
Tel : +82-31-999-4153, Fax : +82-31-999-4775
E-mail : jslee@kimpo.ac.kr
Date of submit : 2007. 6. 4
First assessment : 2007. 6. 5
Completion of assessment : 2007. 6. 22

pseudo-stereo system was simplified and transformed into a parallel stereo system. The largest advantage of a pseudo-stereo system using a single camera is that the stage of system disparity or calibration can be omitted because stereo images are obtained from only one camera. Moreover, since one camera alone is used, it is more advantageous than a common system using two sets of camera in the aspects of camera pan/tilt control and system costs.

2. The single camera pseudo-stereo system

A stereovision system means a system that treats images obtained from two cameras on the left and the right side. When stereo images are acquired using two sets of camera, cost of this system will be twice as expensive as those using one camera. Since images obtained from two cameras also may not perfectly match, the possibility of errors such as timing disparity is high due to image difference (brightness and unevenness by calibration of the cameras) when the images are brought together.

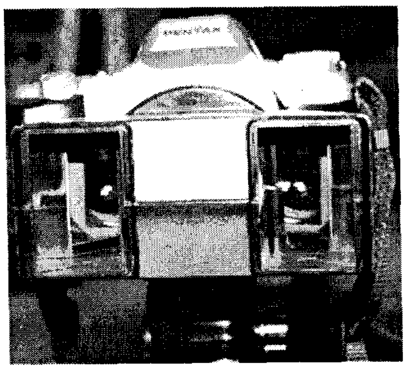

Fig. 1. A pseudo-stereo system using a single camera

Fig. 1 shows a pseudo-stereo system using a single camera, and the adapter for stereo division. Pseudo-stereo images can be obtained as the adapter for stereo division is mounted in front of the single camera as shown in the figure. These images are similar to images obtained with a parallel stereo system. Therefore, the domain of moving objects was extracted through the application of image processing of the existing parallel stereo system using two cameras, and distance and velocity was measured with the stereo timing difference that was obtained.

3. An algorithm for the measurement of the distance and velocity of moving objects from pseudo-stereo images

Fig. 2 shows a flowchart for the algorithm proposed in this paper. First, images from the single-camera system mounted with the stereo adapter are input and saved.

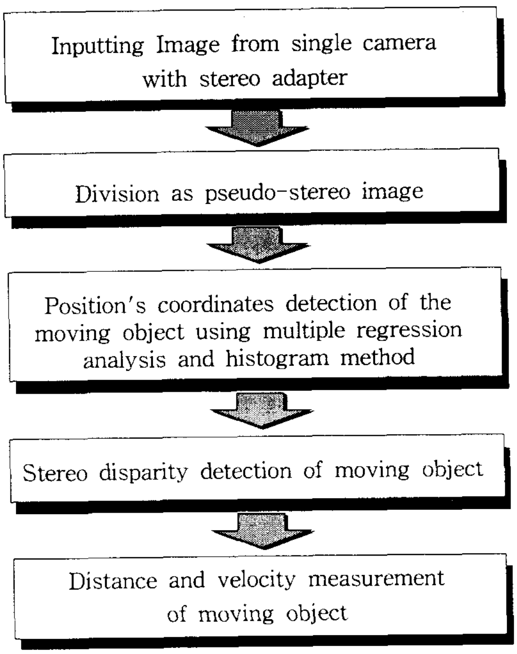

Fig. 2. The flowchart of the proposed algorithm

Next, these images are divided into left and right stereo images and saved as pseudo-stereo images, similar to a parallel stereo camera. Position coordinates and the domain of the moving objects are detected using a multi-regression analysis and histogram technique of the pixel induction algorithm from these pseudo-stereo images [10]. Finally the distance and velocity to the moving objects is measured using the stereo timing difference between the left and right images.

3.1 The division of single-camera input images into pseudo-stereo images

Fig. 3 is an image input from a single camera. By means of the stereo adapter, the input from the single camera is saved as two pseudo-stereo images in one screen.

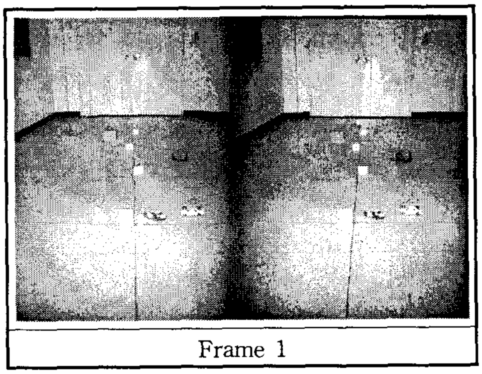

Fig. 3. Image input from a single camera mounted with a stereo adapter

Next, the images input from the single-camera are divided into left and right images in order to process them into stereo images. Fig. 4 shows the parallel stereo images divided from the single-camera input images in Fig. 3.

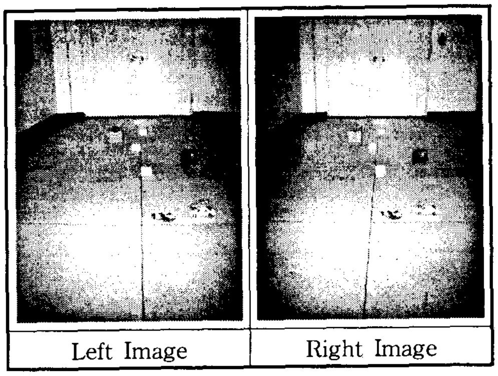

Fig. 4. Divided pseudo-stereo image

3.2 Extraction of the position coordinates of the moving objects

The algorithm to extract the moving component and moving domain detects only the domain of the moving objects by using the multiple regression analysis algorithm of the difference image method of pixel units between the previous and present frames of the divided pseudo-stereo images. The position coordinates of moving objects are obtained through application of the histogram algorithm.

Equation (1) extracts only the domain of those moving objects having moving components with each pixel brightness value ($I_{iL}(x, y)$) of difference image obtained by using the adaptive critical values [10] of the multi-regression analysis.

$$I_{iL}(x, y) = \begin{cases} I_{iL}(x, y, t), & \text{if} |I_{iL}(x, y, t) - I_{iL}(x, y, t-1)| \geq th_{adp} \\ 0, & otherwise \end{cases} \quad (1)$$

Here, $I_{iL}(x, y, t-1)$ and $I_{iL}(x, y, t)$ are the pixel brightness values of the previous image and the present image of the left camera in the pseudo-stereo input image of the i frame. The size of the moving objects was obtained in the form of a window mask through the application of a histogram into images obtained by using Equation (1). Position coordinates for the domain of the moving objects were then extracted by means of obtaining the center coordinates of moving objects through the application of Equation (2) in order to obtain the center coordinates of these window masks.

$$O_L(x_{lO}, y_{lO}) = [\frac{x_{l_S}+x_{l_E}}{2}, \frac{y_{l_S}+y_{l_E}}{2}]$$
$$O_R(x_{rO}, y_{rO}) = [\frac{x_{r_S}+x_{r_E}}{2}, \frac{y_{r_S}+y_{r_E}}{2}] \quad (2)$$

Here, $O_L(x_{lO}, y_{lO})$ and $O_R(x_{rO}, y_{rO})$ are center coordinates for the domain of moving objects in the left image and right image of the present frame, respectively. Moreover, x_{l_S} and x_{l_E} are the start point and end point of the x coordinates respectively for the size domain (window mask) of the moving objects in the left image of the present frame. Likewise, y_{l_S} and y_{l_E} are the start point and end point of the y coordinates respectively for the size domain (window mask) of the moving objects in the left image of the present frame.

3.3 Measurement of the distance and velocity to the moving objects

Fig. 5 shows the geometric structure of the parallel stereo camera system. In a geometric analysis, an image plane is located in front of a lens focus. The lens focus becomes the center of the projection, which is called the central projection. A straight line connecting the two lenses' foci is called the base line, and the origin of the base coordinate system (X, Y, Z) is located in the center of this base line.

First, the correlation of the existing coordinate system and the image coordinate system should be obtained in the parallel stereo camera model of Fig. 5. When the focal distance f and the distance between the centers of the two lenses, namely the base line b, are given, a correlation equation between the base coordinate system and the image coordinate (x, y) corresponding to the 3-dimensional position of an object can be obtained.

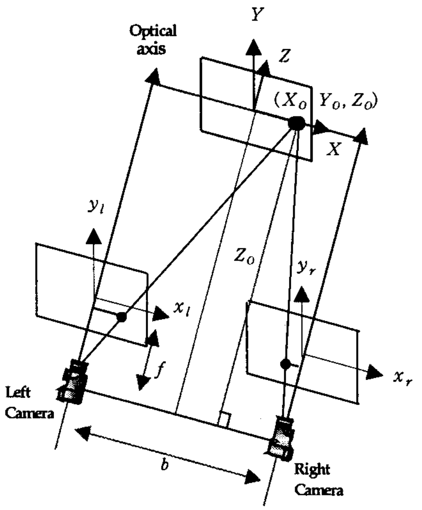

Fig. 5. Geometric structure of the parallel visual stereo system

Denoting the image coordinates corresponding to the left and right image as (x_{lO}, y_{lO}) and (x_{rO}, y_{rO}) respectively, Equation (3) can be obtained by means of a proportional relation to the left image.

$$X_O = \frac{b}{2}\frac{x_{lO}+x_{rO}}{x_{lO}-x_{rO}}, \quad Y_O = \frac{b}{2}\frac{y_{lO}+y_{rO}}{x_{lO}-x_{rO}}$$
$$Z_O = \frac{bf}{x_{lO}-x_{rO}} \quad (3)$$

The focal distance of the camera is not taken into account in X_O, Y_O. Z_O depends only on the ($x_{lO} - x_{rO}$) value of the horizontal disparity and does not take into account the size of x_{lO} and x_{rO}.

When the base-line distance (b) and the focal distance (f) are given, the depth Z is a function of horizontal disparity only. Since two light axes are placed on an epipolar plane including the center of the lens, the vertical disparity $y_{lO} - y_{rO}$ is always 0. Therefore, the distance (Z_O)to the moving objects can be obtained as follows.

$$Z_O = \frac{bf}{x_{lO} - x_{rO}} = \frac{bf}{D_{sd}} = k\frac{1}{D_{sd}} \qquad (4)$$

Here, $k\,(=bf)$ is a constant. It is the value of the distance between the lenses and the focal distance in accordance with the characteristics of the camera. $D_{sd}(=x_{lO} - x_{rO})$ is the stereo disparity D_{sd} of horizontal disparity in the left and right images.

Finally, the distance to the moving objects is inversely proportional to the stereo disparity D_{sd} of horizontal disparity.

Moreover, the velocity (v) of moving objects can be obtained by dividing the calculated moving distance of the moving object with the time for movement.

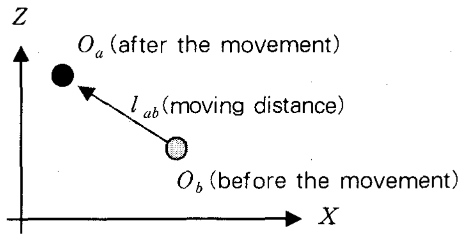

Fig. 6. Distance of movement for a moving object

Since the height of the floor surface is the same in Fig. 5, Y-axis becomes zero. Finally, the distance of movement for the object can be obtained as shown in Equation (5) with the X-axis and Z-axis, in Fig. 6.

$$l_{ab}^2 = (X_a - X_b)^2 + (Z_a - Z_b)^2$$

$$l_{ab} = \sqrt{(X_a - X_b)^2 + (Z_a - Z_b)^2} \qquad (5)$$

Here, $O_b(X_b, Z_b)$ and $O_a(X_a, Z_a)$ are position coordinates before and after movement. These values can be obtained with the base coordinate system in Equation (3). Therefore, the moving velocity (v_{ab}) can be obtained for the period of movement(t), as follows.

$$v_{ab} = \frac{dl_{ab}}{dt} \quad [cm/\sec] \qquad (6)$$

4. The experiment and a review of the results

Fig. 7 shows the continuous images of frame 1 and 2 out of the input frames used in the experiment. In Fig. 4 it was shown that the single-camera input images (frame 1) are divided into pseudo-stereo images. These left- and right-divided stereo images were regarded as input images to the parallel stereo camera. These images were treated with a geometric analysis of the parallel stereo system.

In Fig. 8, the domain of the moving objects was extracted through the application of a multi-regression analysis and histogram into the 1st and 2nd frames.

Fig. 9 shows the calculated values (CA) obtained by calculating the distances to the moving objects in a single camera through the processing of the images in frame 4 as well as the substitution into Equation (4), the actual measurement values (AV), and the error rates (Er) in Equation (7). Here, $Er_{1,2,3,4}$ refers to the error rates of the frame 1, 2, 3, and 4.

$$Er = \left|\frac{AV - CV}{AV}\right| \times 100\,\% \qquad (7)$$

Table 1 shows the values of the moving distance (l_{ab}) and the moving velocity (v_{ab})

obtained after the distances of movement and input images were saved every 5 minutes for the treatment results of Fig. 9. They are then treated for image processing.

As a result, it was found that it is possible to measure the distance of movement and the velocity of moving objects both by mounting a single camera and stereo adapter and also by using a pseudo-stereo system.

The information on the distance and velocity of moving objects obtained by the proposed algorithm provides useful auxiliary information with which the determination of action can be made when using a system that does not require highly precise values.

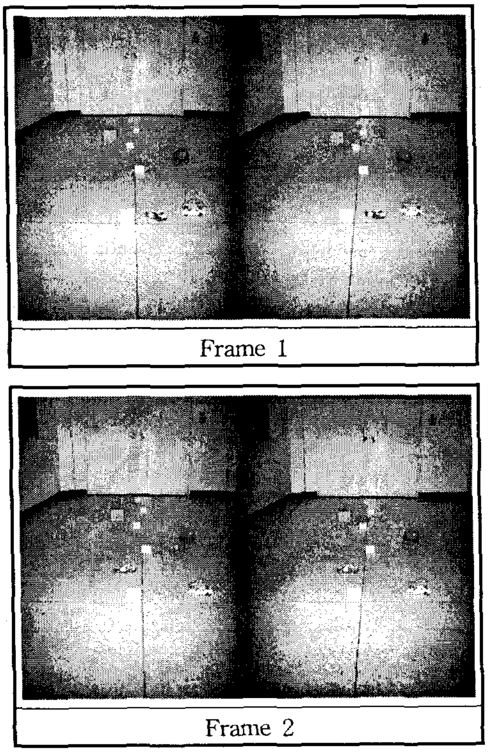

Fig. 7. Input images of the single camera

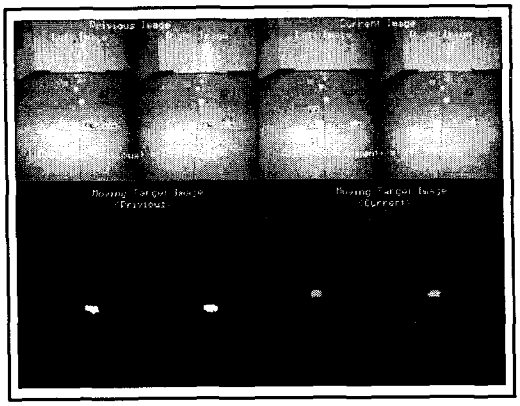

Fig. 8. Extraction of the domain of moving objects from input frames 1 and 2

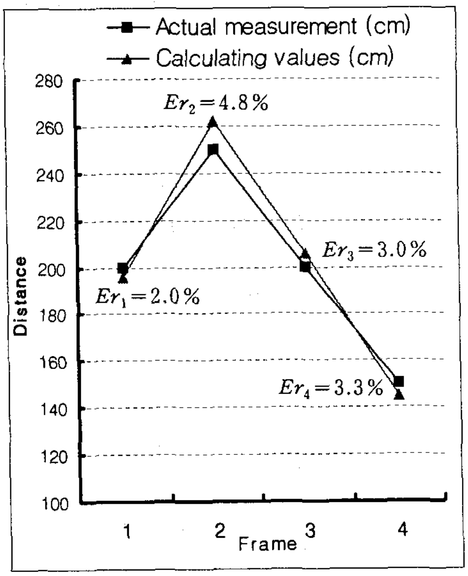

Fig. 9. Results

Table 1. Distance of movement and the velocity of moving objects

Frame	Moving distance [cm]	Moving velocity [cm/sec]
frame 1→ 2	$l_{12} = 69.0$	$v_{12} = 13.8$
frame 2→ 3	$l_{23} = 63.5$	$v_{23} = 12.7$
frame 3→ 4	$l_{34} = 73.0$	$v_{34} = 14.6$

5. Conclusion

In this study, a method which measures both the distance and velocity of moving objects by mounting a single camera and stereo adapter to acquire pseudo-stereo images was proposed and tested.

The results of the distance measurement had an error rate of 3.3%. Since this rate of error is affected by the precision of the camera and stereo adapter, error can be reduced through improvement of precision.

When the system is realized using the proposed algorithm, possible applications include unmanned image monitoring systems or moving-objects chase systems, self-controlled mobile robot, and unmanned vehicle systems.

References

[1] Grinberg, V. S., G.W.Podnar, and M.W. Sigel, "Geometry of Binocular Imaging", Proc.SPIE Vol. 2177, pp. 56-65, 1994.

[2] Z. F. Wang and N. Ohnish, "Intensity-based Stereo Vision: from 3-D to 3-D", SPIE, vol.2, pp.434-443, Nov. 1994.

[3] S. Z. Li, "Recognizing multiple overlapping objects in image: an optimal formulation," IEEE Transaction on Image Processing, vol.9, no2, pp.273-227, Feb., 2000.

[4] T. Fujiwara et al., "3D modeling system of human face and full 3D facial caricaturing," Seventh International Conference on Visual Systems and Multimedia, pp.625-633, Oct., 2001.

[5] T.J. Olson and D.J. Coombs, "Real-time vergence control for binocular robots", Intl. J. of Computer Vision, vol.7, no.1, pp.67-89, 1991.

[6] M. Asada et al., "Adaptive binocular visual servoing for independently moving target tracking," IEEE International Conference Robotics and Automation, vol3, pp.2076-2081, April. 2000.

[7] J.S. Lee, J.H. Ko and E.S. Kim, "Real-Time Stereo Object Tracking system by using Block Matching Algorithm and Optical binary phase extraction joint transform correlation", Optics Communications, vol.191, pp.191-202 2001.

[8] P. Puget and T. Skordas, "An optimal solution for mobile camera calibration," Proc. IEEE Trans. on system Man and Cybernetics, vol.19(6), pp.1426-1445, Nov./Dec., 1988.

[9] Z. Zhang and O.D. Faugeras, "Calibration of a mobile robot with application to visual navigation," Proc. IEEE Work, Visual Motion, Irvin, California, pp.306-313, Mar., 1989.

[10] Soo-In Kim, Jae-Soo Lee, Young-Woo Shon, "Distance Measurement of the Multi Moving Object using Parallel Stereo Camera in the Video Monitoring System". Journal of KIEE vol.18, no.1, pp.137-145, 2004.

Biography

Jae-Soo Lee

1987: Graduated from the Department of Electronic Engineering, Kwangwoon University(B.A.). 1989: Graduated from the Department of Electronic Engineering, Graduate School, Kwangwoon University(M.A.). 2001: Graduated from the Department of Electronic Engineering, Graduate School, Kwangwoon University (Ph.D.). 1989~1994: The Annex Research Center, Gabeul Electronics Co., Ltd. 1994~1995: KOPEC KDN Co., Ltd. 1996~present: Associate professor, Department of Information and Telecommunication, School of IT, Kimpo College.

Soo-In Kim

1984: Graduated from the Department of Electronic Engineering, Kwangwoon University (B.A.). 1991: Graduated from the Department of Computer Engineering, Graduate School, Kwangwoon University (M.A). 2003: Graduated from the Department of Computer Engineering, Graduate School, Kwangwoon University (Ph.D.). 1984~1991: The Annex Research Center, Gabeul Electronics Co., Ltd. 1991~1995: You-Can Computer. 1996~present: Associate professor, Department of Internet Information, School of IT, Kimpo College.

In-Ho Choi

1990: Graduated from the Department of Electronic Engineering, Kyunghee University (B.A.). 1992: Graduated from the Department of Electronic Engineering, Graduate School, Kyunghee University (M.A.). 2000: Graduated from the Department of Electronic Engineering, Graduate School, Kyunghee University (Ph.D.). 1996~present: Associate professor, Department of Information and Telecommunication, School of IT, Kimpo College.