Accuracy of Stereo Matching using Color CCD Camera

Takashi Hoshi
Institute of Information Sciences and Electronics
University of Tsukuba
Ibaraki 305 JAPAN

Takayuki Matsushita
Fujisawa Development Laboratory
IBM Japan
Kanagawa 252 JAPAN

Yoshinori Koishikawa*)
Master's Programs in Scientific Technology
University of Tsukuba
Ibaraki 305 JAPAN

Abstract

The objective of this study is to establish experimentally the searching procedure for improving accuracy of matching stereo images which are taken outside by CCD camera, and to evaluate accuracy of stereo matching on each method. With regard to the procedure, authers examine the effect on accuracy concerning the points as degrading the brightness at surrounding area of image, balance of color tone, elements of color tone, correspondence between edge patterns and the size of matching window. Among all, the correspondence between edge patterns is examined about the effect on accuracy using not only interval corresponding method which is generally adopted in the previous study but also corresponding method for edges nearby control points and superposing method for labeling images. Then stereo matching methods as cross correlation method, SSDA (sequential simirality detection algorithm) method, Fourier cross correlation method and linear interporation method are compared on the accuracy of matching under same experimental condition adopting image data which consists of principal components, according to the procedure established here.

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*) Presented at the SONY Corporation.

Background

Numbers of researchers on photogrammetric engineering (e.g. Kelly 1977) and image processing (e.g. Baker 1982) have spended much time to study stereo matching method. Authors have studied about the stereo matching for the areas, where eithor of farms, residential land or forests dominant land, using a pair of aerial photographs. Through this study , it is concluded that the frequency of mis-matching becomes too much for analysis if the matching window size is set less than at least 17x17 pixels for rectangular windows (Hoshi and Matsushita 1983). Next the stereo matching for color TV images has been examined. Then four color elements G, B, V, L among nine elements (Ostwald 1931), R,G,B,H,S,V,H,S,L experimentally turned to be used for performing better stereo matching compared with other elements (Hoshi 1985). Moreover authors have developed the algorithm to correct the brightness at surrounding area of images, where the brightness decreases according to Lambert's law, using color CCD camera of 512x512 pixel (Hoshi and Koishikawa 1986). lor And the coefficients to correct color balance of RGB image have been determined by utilizing color bar chart image.

This paper describes the case of stereo matching concerning images which are taken outside by CCD camera based on the results mentioned above. Here orientation procedure is performed independently for each image,and the rectification image is produced from original image using calculated nine orientation elements. Besides authors select better matching image between the first principal component images of nine color elements and four color elements mentioned before, instead of G image which has been generally used for this study.

1. Elements of Color Image for Analysis

In order to perform stereo matching procedure, appropriate color tone image should be selected as element for analysis since color image contains three elements R,G,B. In the prvious study, some elements are proposed and they are listed as following,

(a) G

(b) (R+G+B)/3

(c) |Rl-Rr|+|Gl-Gr|+|Bl-Br|

Three elements, however, cannot consider the color tone factor of hue or brightness, which is generally adopted in the field of art. Therefore in this paper, the first principal component image derived from the elements listed below in the case(d) and (e) (T.Hoshi, 1985) are selected as image element for further analysis.

(d) R,G,B,H,S,V,H,S,L

(e) G,B,V,L

The reason of selection is that the first principal component image of case(e) resulted in showing the best matching compared with the case of individual nine elements using correlation method under a fixed condition. Another reason is that the case(e) is expected to improve the processing time compared with the case(d).

On examination of stereo matching about the first pricipal component image of the case(d) and (e), the frequency of

mis-matching becomes fewer in case of adopting the first principal component from nine color elements, than the case of four color elements. Also we have found that the first principal component image of case(e) cannot substitute for the first principal component image (see Photo 1-1,1-2) of case(d).

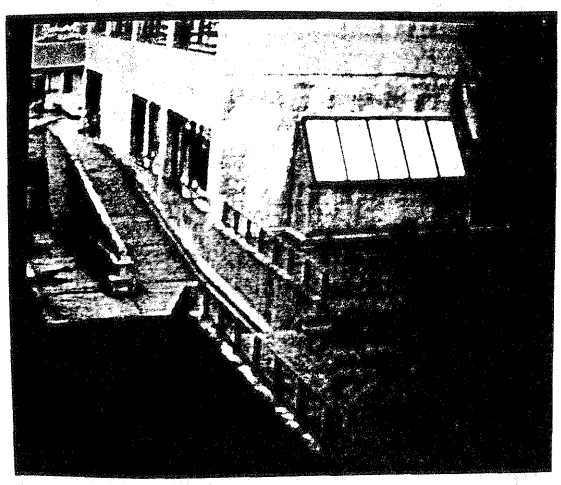


Photo.1-1 left f.p.c. image.

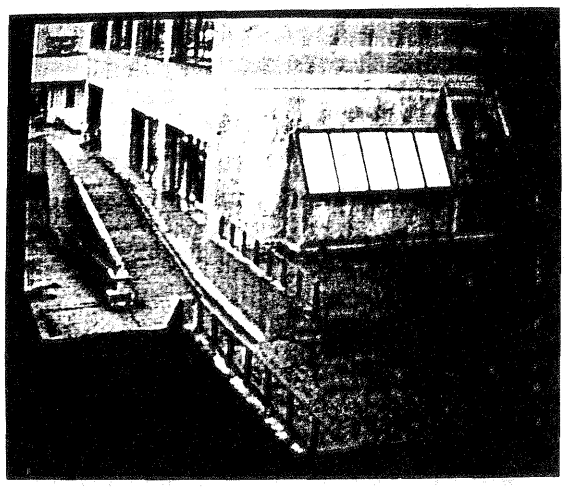


Photo.1-2 right f.p.c. image.

2. Processing of Searching Corresponding Edge

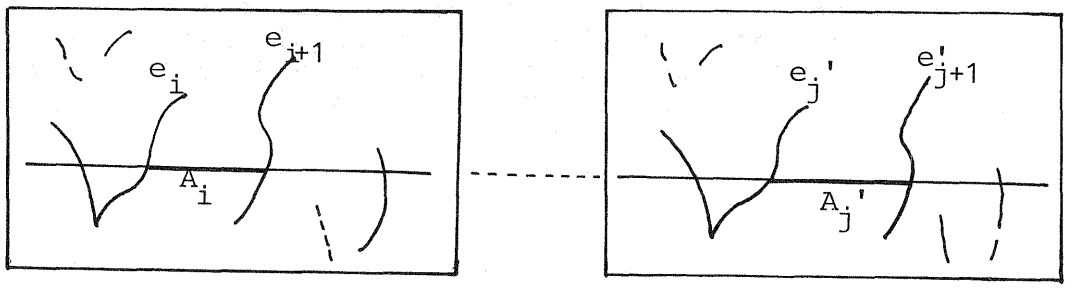
For the purpose of searching edge parts of image, both of left and right imges should be operated by Sobel's operator (Duda and Hant 1973), (Prewitt 1970) at first, and the operated images are transformed from multiple value data into binary data by thresholding method (level 70). Then images are operated by Laplacian operator and zero-crossing method (Marr and Hildreth 1980) in order to reduce the breadth of edge . After thinning operator, labeling image should be produced. At this stage of procedure, all of searched edge is given its labeling. However, it is required that the method to identify corresponding edge on right and left images, because each of right and left image is processed independently. In the previous study, interval corresponding method and the like has been applied for this purpose. But then such method is not suitable for searching edge from fields images because of the low dynamic and spatial resolution. Accordingly authors propose 'three step method', in which the first step is to search nearby control points Pi(i=1~7) used for orientation. For short this method will be called 'NECP method' after this. The purpose of NECP method (Hoshi and Koishikawa 1987) is to search the initial points of corresponding edges. Since the control points are selected arbitrarily and the locational information of them is already known, the probability of existing the corresponding edge is relatively high at the point where the location is estimated from the locational information. This estimation is reasonable only for the edges located at the very short distance from the control point Pi. Therefore in this paper, the square area, which is constituted of $\pm$10 pixels from control points Pi, is to be effective for searching initially corresponding edge with considering the distance from the subject to camera. It is, however, difficult to search corresponding edges in these situation, since labeling images which consist of only a few pixels or images with slender twigs of edges are frequently appeared. Then we add the treatment of

removing labeling images that consist of less than five pixels and eliminating all twigs of edges. These treating images with label are used for further matching procrdures. If the length is different between corresponding edges, longer edges is to be shortened and fit to shorter edges.

Next, the interval corresponding method (Ohta and Kanede 1985) is applied to search corresponding edges by means of examining the similarity of density level at intervals between edges on epipolar lines. Here, when E=e1,e2,....eu is edges on horizontal scanlines in left image, E'=e'1,e'2,....e'u is edge in right image, Ai=ai+1,ai+2,....ai+m is the group of interval pixel numbers between ei and ei+1, and A'j=a'j+1,a'j+2,....a'j+n is the group of interval pixel numbers between e'j and e'j+1 (see Fig.2-1), we introduce an estimating measure S, and the interval with minimum value of S is defined as corresponding interval. Estimating measure S is formulated as

$$S = \{\frac{1}{m}\sum_{k=1}^{m}(ai+k-a'j)2 + \frac{1}{n}\sum_{l=1}^{n}(a'j+l-ai)2\}\cdot L$$

where ai,a'j is averaged value of Ai, A'j, respectively, and L is given as m/n (m>n) or n/m (n>m).



left labeling image right labeling image

Fig.2-1 internal corresponding (INCO) method.

The third step is to determine the best suited position in which the whole labeling images are well superposed by way of shifted left and right labeling imaged on epipolar line, and to examine corresponding edges by pixels as a unit. Afterward this method will be called 'SHIFT method' for short. In this method judged corresponding pixels must be satisfied three conditions listed in the following, and then the corresponding edge should be found at the nearest edge point satisfying each condition.

(1) The ratio of Sobel operator strength Sos is within the range of $0.6 \leq Sos \leq 1.0$

(2) The difference of sobel operator gradient is below $\pi/4$.

(3) The correlation value of 3x3 Laplacian operator is above 0.6.

This 'three step method' has the advantage of saving cost and time to search corresponding edges, since it is not necessary to search corresponding edges simultaneously from numerous labeling images because the initial corresponding edge has been given. Photo.2-1, 2-2 represent the labeling image after processing for edge, and Photo.2-3, 2-4 represent the correspnding edge only processed by three step method.

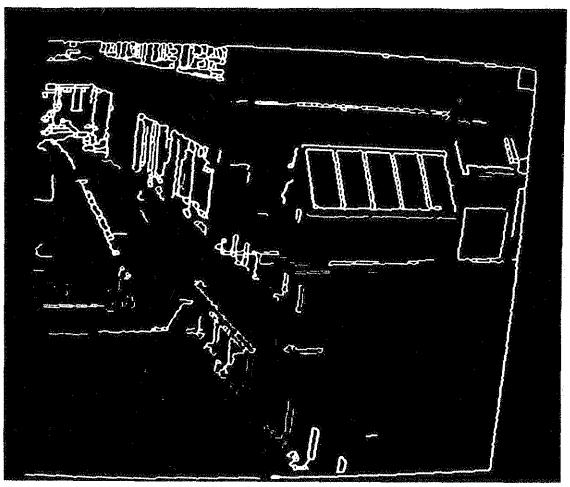


Photo.2-1 left labeling image.

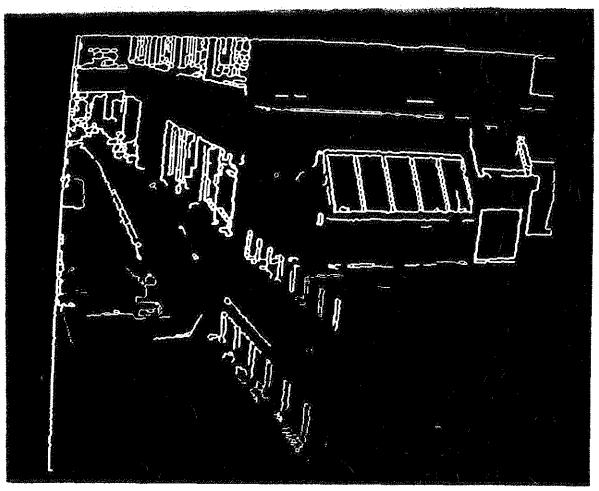


Photo.2-2 right labeling image.

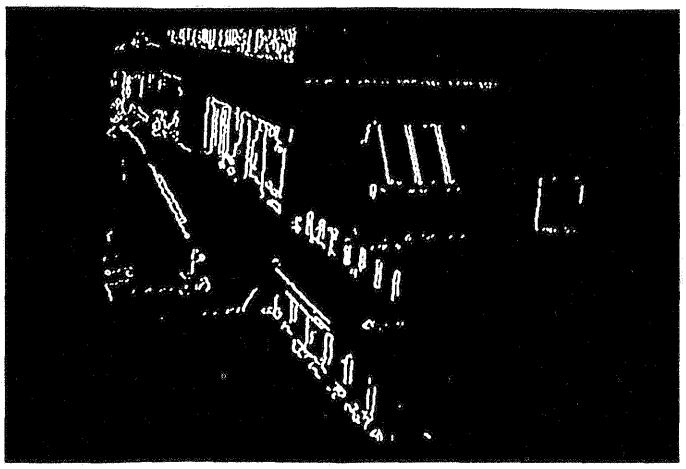


Photo.2-3 edge matching image of 3 step method.

3. Strero Matching

Matching procedure scans transversely from the edge top of left image as starting point to downward. If a corresponding edge exists on a scanning line, the location of the edge will be used as a preceding information for matching. In case of existing plural edges on one scanning line, the center of edge portion will be found by scanning and counting edges. Although such complicated scanning procedure increase spending time, the frequency of mis-matching might be as small as possible (Koishikawa and Hoshi 1988).

The following four methods are applied for stereo matching procedure, and comparison and evaluation will be performed among every methods from the point of frequency of mis-matching and processing time.

(1) cross correlation method.
(2) Fourier cross correlation method.
(3) SSDA method.
(4) linear interpolation method.

Linear interpolation method is executed on the assumption that the part between edge interval represents the surface of cube or polyhedron. Therefore it is effective to apply this method to the objectives such as wall of building or window

pane. In this method the corresponding point is searched not by directly matching procedure but by calculation. This is to be respresented as the relation of the corresponding pixel on left image bi+r(r=1,~m) to pixel on right image bi+r'(r'=r n/m) using pixels between edge interval on left image B=bi+1....bi+m and pixels on right image B'=b'j+1....b'j+n.

Four methods mentioned above will be applied under the same operational condition according to Fig.3-1. The result of processing is shown in Photo.3-1~3-4. In order to compare and evaluate these methods, six linear shaped portion represented in Photo.3-5 will be adopted. That is to examine the transverse residual value from lines by performing matching procedure to points originally on lines, and to compare the value of standard deriviation of it. The result on value of standard deviation Sd and processing time T is summarized in Table.3-1.

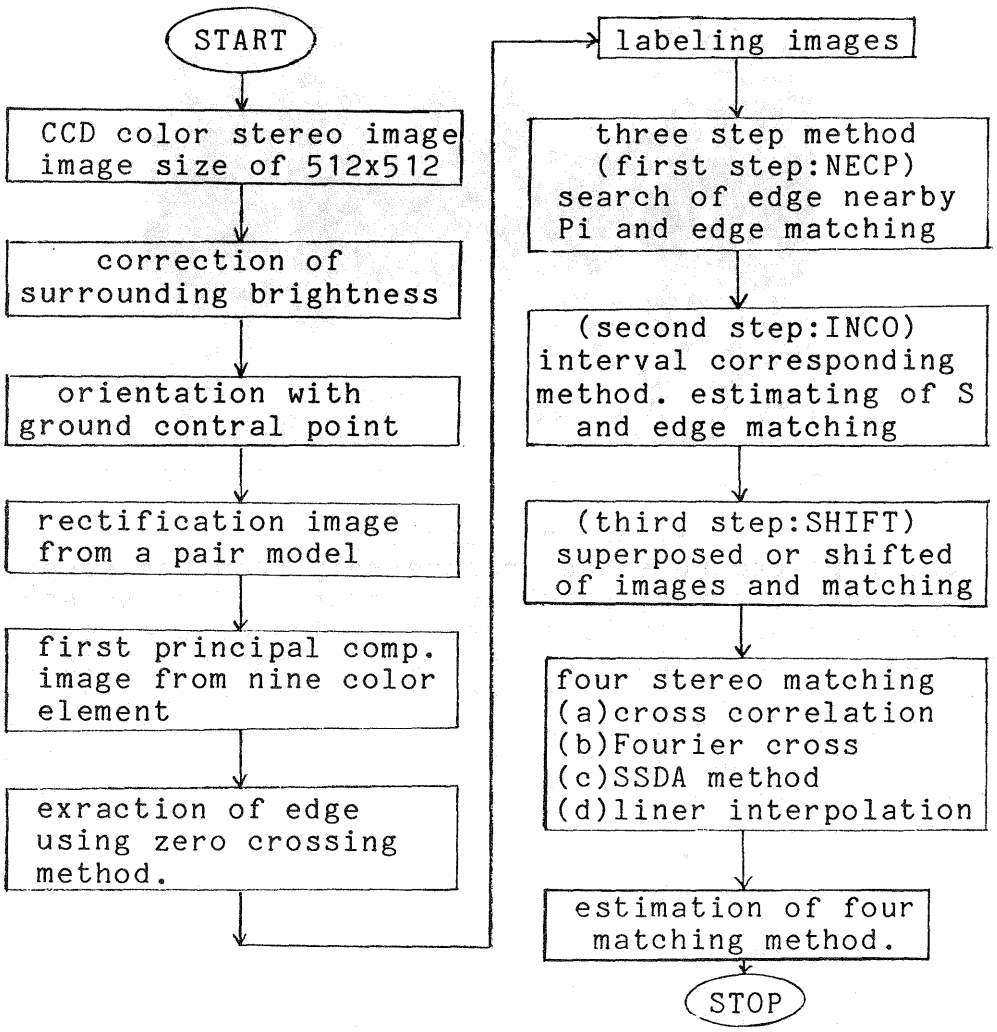


Fig.3-1 processing flow of four matching method

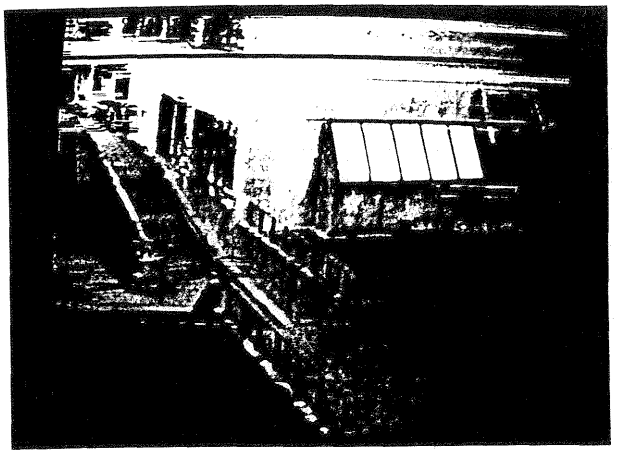


Photo.3-1 cross corr method.

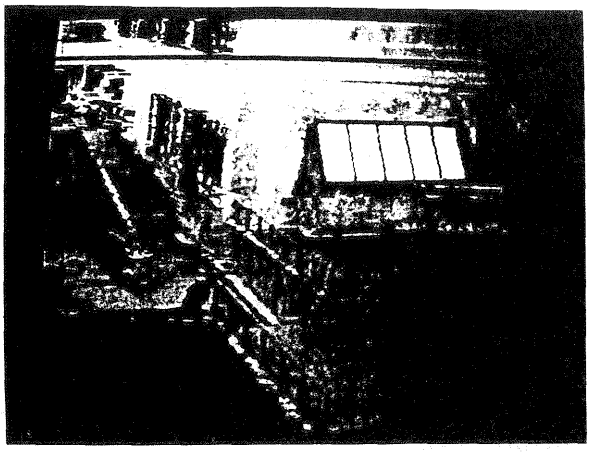


Photo.3-2 Fourier cross method.

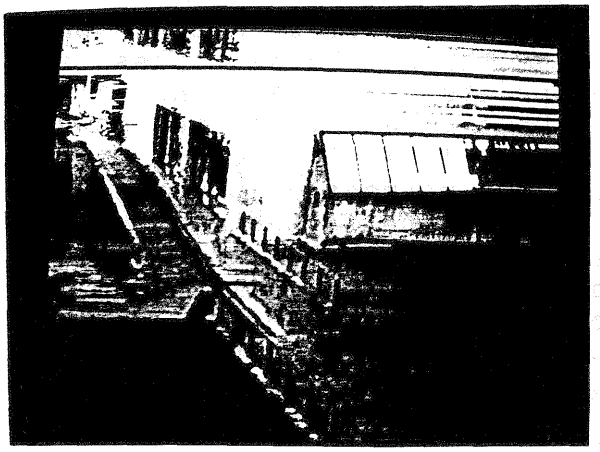


Photo.3-3 SSDA method.

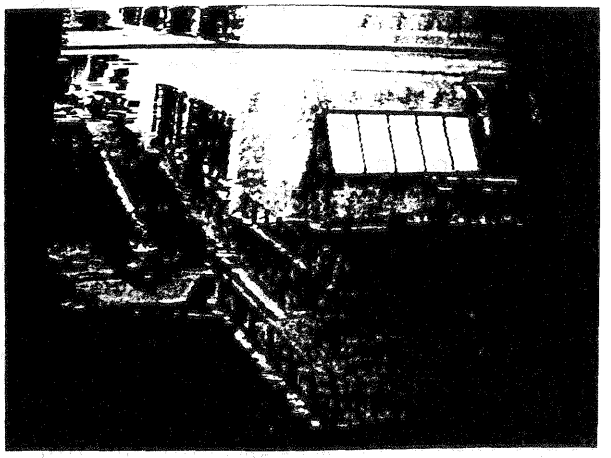


Photo.3-4 linear interpo. method.

Table.3-1 result of four matching method.

: method. :	cross corr.	Fourier	SSDA method.	linear int. :
: St. Dev. :	e1= +1.5	e2= +2.4	e3= +13.9	e4= +2.4 :
: Pr. time :	t1= 55'04"	t2= 16'11"	t3= 31'48"	t4= 0'02":

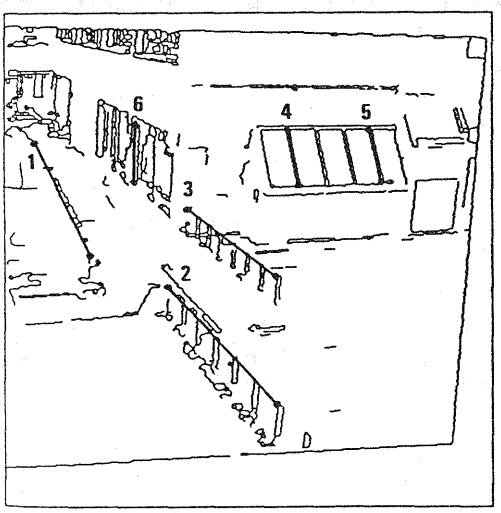


Photo.3-5 lines for performance.

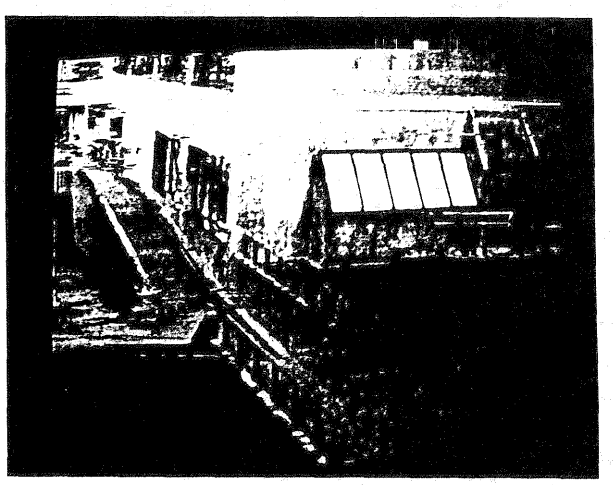


Photo.3-6 cross corr method.

This experiment of stereo matching has adopted a line with 42 cm as base line, then e = 1 pixel corresponds to about 39 cm in the case of near distance (17 m) and about 140 cm in the case of far distance (33 m). For the images represented as Photo 3-1 3-4, the procedure of stereo matching has been performed on the portion where at least one edge exists in the horizontal scanning direction. Therefore matching procedure has not been performed on the portion where edge does not exist at all. Then the portion where edge does not exist has been treated only for the cross correlation method, which represents the best matching among four methods. The result shows in Photo 3-6. At this the result of stereo matching about the line before has been utilized as the preceding information to get Photo 3-6.

4.Discussion

Six lines represented in Fig.3-6 are selected to compare the accuracy of stereo matching methods. These lines are considered to be selected appropriately as a standard for evaluation, only the direction of these lines does not cover every directions. As we can see from Table.4-1, cross correlation method is superior to other methods on the point of accuracy. Linear interpolation method is the fastest processing method among four methods, however this would not perform matching procedure and also its applicability is limited to the objectives such as wall of building. The second fastest processing method is Fourier cross correlation method. Another to comment is that SSDA method makes mis-matching rather frequently and searching point on scanning lines tends to run disorderly if mis-matching occurs.

Meanwhile 'three step method' newly adopting in this paper is suggested to improve the accuracy of interval corresponding method, which has been applied in the previous study. But for any step of this 'three step method', the result has turned to be unsatisfactry.

5.Conclusions

It is not easy to perform stereo matching with sufficient accuracy for images taken outside having a size of 512x512 pixels. However it is suggested through this experiment that the frequency of mis-matching could decrease to insignificant level if the following conditions are satisfied.

(1) To adopt the first principal component image as color tone element for analysis color image.

(2) To correct the brightness decrease in the surrounding portion of image.

(3) It is effective to apply zero-crossing method for searching edge.

(4) For coping with the portion where occlusion occurs, it is effective to use edge informations. 'Three step method', which is utilizing control point method, interval corresponding method and superposing method in that order, could facilitate searching the corresponding edges.

(5) The rectangle window could substitute for the circle window at correlation procedure, and its size should be larger than 17x17 pixels. On the other hand, the window size at Fourier correlation procedure must have the number of power of two, and mis-matching would occur frequently in case that the

window size is less than 15x15 pixels.

(6) It is necesary for determing the corresponding stereo matching area to prepare accurate informations (intelligences). For this purpose the polygon region including control point and its nearly could be adopting as the initial matching corresponding area.

Acknowledgement

The authors wish to express appreciation to Mr. Uchida for his comments on this study. Thanks are also due to the members of Science Information Processing Center, Unversity of Tsukuba. The matching computations were performed by the FACOM M780/20 computer (CPU size:128 MB) at the center.

References

Kelly,R.E.,McConnell,P.H. and Mildenberger [1977], The Gestalt Photomapping System, Photogrametric Engineering and Remote Sensing, Vol.43, No.11.

Hoshi,T. and Matsushita,T. [1983], Research of Matching and/or Searching Method of Identical Point on Stereo Aereal Image and it's Application, Proc. 4th Asian Conference on Remote Sensing (ACRS), pp.G5-1~14.

Ostwald,W [1931], Colour Science, Winsor, London.

Foley,T. and Dam,A. [1982], Fundamentals of Interactive Computer Gaphics, Addison-Wesley Publishing Comp. Inc.

Kingslake,R. [1951], Lenses in Photography, Cuse-Hoyt Corp., New York.

Washer,F.E. [1956], Effect of comera tipping on the location of the principal point, Journal of Research of the National Bureau of Slandards, Vol.57, p.31.

Duda,R.O. and Hant, P.E. [1973], Pattern Classification and Scene Analysis, Wiley.

Prewitt,J.M.S. [1970], Object Enhancement and Extraction, Picture Proc. and Psychopiclorics, Eds. Academic Press.

Marr,D. and Hildreth,E. [1980], Theory of edge detection, Proc. R, Soc. Lond. B207, pp.187-217.

Baker,H.H. [1982], Depth from Edge and Intensity Based Stereo, AIM-347, Stanford AI Lab.

Ohta,Y. and Kanede,T. [1985], Stereo by Two-level Dynamic Programming Considering Inter-scanline Consistency Constraints, Information Processing Society of Japan.

Hoshi, T. [1985], Three Dimensions Measurement Using TV Image-- Result of Image Search Classified by Color Element--, Proc. of 40th Annual Conference, The Japan Society of Civil Engineers, pp. 201-202.

Hoshi,T. [1985],Image Processing System for Field Object Using Radar Transmission, Proc. of 11th Annual Conference on Remote Sensing, Japan Society of Instrument and Control Engineerings, pp.137-140.

Hoshi,T. and Koishikawa,Y. [1986], Basic Research for three Demensions Measurement Using CCD Camera, Proc. of Annual Conference'86 Japan Society of Photogrammetry and Remote Sensing, B-3, pp.25-30.

Hoshi,T. and Koishikawa,Y. [1987], Stereo Matching Using Edge Data, Proc. of 34th Annual Conference, Information Processing Society of Japan, III-4D-8, pp.1739-1740.

Koishikawa,Y. and Hoshi,T. [1988], Estimation of Stereo Matching Using Edge, Proc. of 36th Conference, Information Processing Society of Japan.