STEREO DISPARITY ESTIMATION USING DISCRETE ORTHOGONAL MOMENTS

Tomasz Andrysiak and Michał Choraś
Institute of Telecommunications, University of Technology and Agriculture, ATR Bydgoszcz

Keywords: Stereo Disparity, Discrete Orthogonal Moments, Robotics Vision.

Abstract: In the article we present various theoretical and experimental approaches to the problem of stereo matching and disparity estimation. We propose to calculate stereo disparity in the moments space, but we also present correlation based method. In order to calculate disparity vector we decided to use discrete orthogonal moments of Tchebichef, Zernike and Legendre. In our research of stereo disparity estimation all of these moments were tested and compared. In the article we also propose the original method of determining the global displacement vector between the stereopair images in order to find the common part of these images (adequate for matching) and the margins of these stereo images. Experimental results confirm effectiveness of the presented methods of determining stereo disparity and stereo matching for robotics and machine vision applications.

1 INTRODUCTION

One of the main research fields in machine and robotics vision is 3D scene perception based on techniques of measuring shapes, positions and relations between 3D objects that are visible in the scene. There are many known methods of retrieving information about the scene basing on 3D perception (Andrysiak and Choraś, 2005a). Those methods are based on disparity of stereoscopic scene elements and on information from the common part of stereo images. After extracting the pair of corresponding points in two stereo images, which are related to the same point in the scene, we can define the difference between coordinates of those points. Then basing on such differences, it is possible to create depth map for the visible scene by means of simple trigonometric transformations.

Recently discrete orthogonal moments have gained much attention and have been successfully used in many applications of computer vision (e.g. pattern recognition) (Makundan et al., 2002, Lio and Pawlak, 1996). Therefore in our research we decided to take advantage of discrete orthogonal moments' properties in order to calculate stereo disparity. Therefore in our research we used the discrete orthogonal moments of Tchebichef, Zernike and Legendre.

In the article we are concerned with the images acquired from the axe-parallel robotics vision system. In such system optical axes of both cameras are parallel to each other, and image planes of stereoscopic pair are situated within the same distance from the centre of the scene coordinates system. Only the common scene area covered by both cameras is further analysed (even though it is only a part of each of the image).

In Section 2 the method of displacement vector calculation in order to determine the margins and common part of stereo images is presented. Then in Section 3 two approaches to calculate stereo disparity are described. In Sections 4 and 5 experiments and conclusion are given.

2 CORRESPONDENCE PROBLEM - STEREO DISPLACEMENT SEARCH

In order to find the displacement vector d_t between stereopair images we perform calculation of the discrete orthogonal moments of right I_P and left I_L stereo image.

We search for the displacement vector d_t by determining the minimum from the set of values:

Andrysiak T. and Choraś M. (2006).
STEREO DISPARITY ESTIMATION USING DISCRETE ORTHOGONAL MOMENTS.
In *Proceedings of the Third International Conference on Informatics in Control, Automation and Robotics*, pages 504-507
DOI: 10.5220/0001209805040507

$$\{U(0), U(1), \ldots, U(d_{t_{\max}})\} \quad (1)$$

calculated accordingly to (2) characterizing adequately subtraction of reconstructed images I_L and I_P regarding to maximal displacement vector d_{tmax}:

$$U(d_t) = \sum_{x=0}^{N-d_t} \sum_{y=0}^{N-1} \left| I_L(x+d_t, y) - I_P(x, y) \right| + \\ + \sum_{x=0}^{d_t-1} \sum_{y=0}^{N-1} I_L(x, y) + \sum_{x=N-d_t}^{N-1} \sum_{y=0}^{N-1} I_P(x, y) \quad , (2)$$

where $I_L(x+d_t, y)$ and $I_P(x,y)$ can be calculated on the basis of reconstructed intensity function values, for the Tchebichef, Legrande and Zernike moments, respectively (Makundan, 2004).

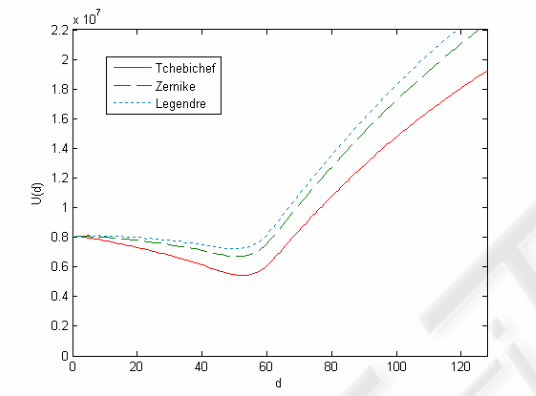

Figure 1: Values of function $U(d_t)$ for $d_t=0,1,\ldots,128$.

3 DISPARITY ESTIMATION

Hereby we present two approaches of solving the problem of disparity estimation in stereo vision. These approaches are based on the orthogonal moments calculation (Mukundan, 2004, Mukundan et al., 2002).

3.1 Stereo Matching Based on Correlation of Moments

In order to determine the stero disparity d_x of the common part of the stereopair, the corresponding points on the epipolar lines have to be found in the process of stereo matching.

In practice, in this approach, we search for the correlation between reconstructed intensity functions of the images I_L and I_P in the regions bounded by the window function:

$$W_z(x, y_e) = \left\{ u, v \left| \begin{array}{l} x - \frac{z}{2} \le u \le x + \frac{z}{2} \\ y_e - \frac{z}{2} \le v \le y_e + \frac{z}{2} \end{array} \right. \right\}, \quad (3)$$

where z characterizes the size of window function, and (u,v) are the coordinates describing the localization of window $W_z(x,y_e)$, where y_e is the epipolar line.

The correlation matching process is realized in the common part of stereopair (determined by the vector d_t) according to the following steps:

- for each point of the right image $I_p(x,y_e)$ choose its neighbourhood by the window function $W_z(x,y_e)$ where (x,y_e) is the centre of the window W_z,
- for all the points from the linear neighbourhood of the left image $I_L(x)$ choose its neighbourhood by the window function $W_z(x+d_x,y_e)$ where d_x characterizes the stereo disparity interval and d_x is within $<-d_{max}, d_{max}>$,
- for the determined points and their neighbourhoods search for the minimum of the function C_{SSD}:

$$C_{SSD}(d_x) = \sum_{(u,v) \in W_z(x,y)} \left[I_P(u, v_e) - I_L(u + d_x, v_e) \right]^2 \quad (4)$$

The minimum of the C_{SSD} function determines the value of stereo disparity d_x for the matched points of the left and right stereopair image.

3.2 Stereo Matching Based on the Similarity of Vectors in the Moments Space

An alternative approach to correlation matching method based on function (4) minimum search can be similarity search in the feature vector space according to:

$$\Psi(d_x) = \min_{d_x} \left\| \lambda_x^{(L)} - \lambda_{x+d_x}^{(P)} \right\| \quad (5)$$

where $\lambda_x^{(L)}$ is a vector consisting of moments values $\phi_i^{(L)}$ of the intensity function in a given window W_z

with the centre in point (x,y_e) on the left image of stereopair given by:

$$\lambda_x^{(L)} = \left[\phi_1^{(L)}, \phi_2^{(L)}, \ldots, \phi_i^{(L)}, \ldots \phi_M^{(L)}\right]_{\phi_i \in W_z(x,y_e)} \quad (6)$$

and $\lambda_{x+d}^{(P)}$ is a vector consisting of moments values $\phi_i^{(P)}$ of the intensity function in a given window W_z with the centre in point $(x+d,y_e)$ on the right image of stereopair given by:

$$\lambda_{x+d_x}^{(P)} = \left[\phi_1^{(P)}, \phi_2^{(P)}, \ldots, \phi_i^{(P)}, \ldots \phi_M^{(P)}\right]_{\phi_i \in W_z(x+d_x,y_e)} \quad (7)$$

The similarity measure between the moments is calculated on the basis of the Euclidean distance.

The obtained minimum of the similarity measure $\Psi(d_x)$ determines the stereo disparity d_x between points (x,y_e) on left image and $(x+d_x ,y_e)$ on the right stereo image.

4 EXPERIMENTAL RESULTS

In the experiments we used our own stereo images database of resolution 512×512 and 256 greyscale levels. All the images were acquired by the well-calibrated axe-parallel camera system.

Before disparity estimation we calculate the displacement vector d_t between image stereopair (we find the common part of stereo images). This stage is based on search of the global minimum of the function $U(d_t)$ in the interval $<0;d_{tmax}>$, where d_{tmax} is set as ¼ of the image resolution.

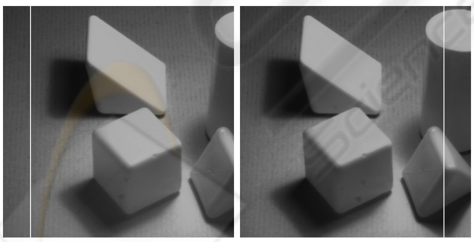

Figure 2: Stereoscopic image 'blocks' with the marked margins.

Table 1: Displacement vector values.

Reconstraction for	d_t	$U(d_t)$
Tchebichef	52	$0{,}58 \cdot 10^7$
Legendre	59	$0{,}76 \cdot 10^7$
Zernike	55	$0{,}71 \cdot 10^7$

For sample stereo image 'blocks' from our database (Figure 2), the values of the displacement vectors d_t and the values of the function U are presented in Table 1.

Such situation was caused by imprecise approximations in the reconstruction formulas and by the larger sensitivity of Legendre moments on intensity function deformations in the process of stereoscopic projections. Moreover the errors were caused by the high orders of the used moments.

In order to verify the proposed methods of stereo disparity calculation (sections 5.2-5.3), we use the normalized disparity error, given by:

$$NDE = \frac{1}{N \times N} \sum_{x=0}^{N-1} \sum_{y=0}^{N-1} \frac{\left| d_x(x,y_e) - \hat{d}(x,y_e) \right|}{d_{x_{\max}}}, \quad (8)$$

where: $d_x(x,y_e)$ is the calculated stereo disparity in the specified point (x,y_e); $\hat{d}(x,y_e)$ is the ideal stereo disparity calculated by other methods (e.g. correlation matching) and $d_{x_{\max}}$ is the maximal stereo disparity for the given image.

Due to such formula (8), the normalized stereo disparity error values are varying within the interval <0;1>.

In the Figure 2 we presented the influence of the number of the used moments on the *NDE*. It decreases with the larger number of the used moments. Such situation reflects the impact of moment order on the reconstruction precision of image intensity function.

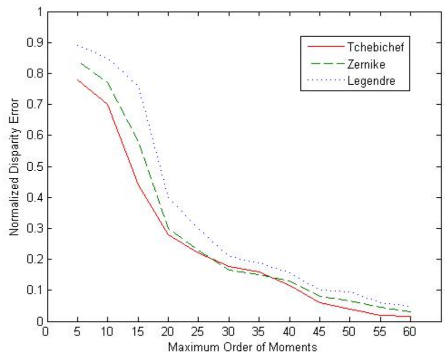

Figure 3: Stereo disparity calculation error on the basis of the correlation of moments.

The results of stereo disparity estimation method implementation on the basis of the vectors similarity in the moments space and an interesting phenomenon of moments order adjustment are shown in the Fig 2. The obtained value of *NDE* is optimal for the moments of order 20-25. Then with the higher order of moments the results become worse, which is caused by the increased distance between vectors (5) in the Euclidean space.

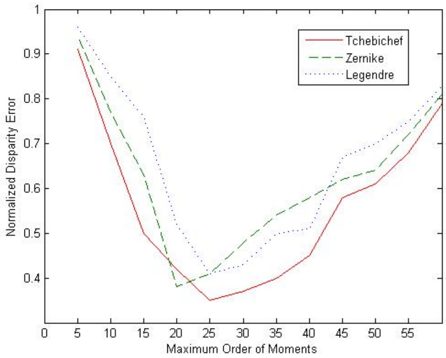

Figure 4: Stereo disparity calculation error on the basis of the similarity of vectors in the feature space.

5 CONCLUSIONS

In the article we presented the idea and implementation of using discrete orthogonal moments of Tchebichef, Legendre and Zernike in the process of matching and stereo disparity estimation. In order to optimise those procedures, in the first stage we extracted the common parts of stereo images (which is important for matching) and the margins of stereo images.

In the article two approaches to the problem of stereo disparity estimation were presented and tested. The first approach was based on the correlation analysis of the reconstruction of image intensity function on the basis of discrete orthogonal moments. In the second approach the problem of stereo disparity estimation was solved by similarity search in the vector space for the calculated moments characterizing the corresponding points of stereo images.

In the described methods we used the discrete orthogonal Tchebichef, Legendre and Zernike moments. After experiments we concluded that Tchebichef and Zernike were the most appropriate for stereo estimation moments, respectively. Much worse results were achieved by Legendre moments.

REFERENCES

Andrysiak T., Choraś M., Multiresolution Matching and Disparity Calculation of Stereo Images in Frequency Domain, Information Extraction and Processing, no. 23 (99), 2005.

Andrysiak Tomasz, Choraś Michał, Stereo Matching for Robotics Vision, Proc. of International Conference PELINCEC 2005 (10 pages).

Liao S. X., Pawlak M. On image analysis by moments, IEEE Trans. Pattern Analysis and Machine Intelligence, vol. 18, pp. 254–266, Mar. 1996.

Mukundan, R., Image Analysis by Tchebichef Moments, IEEE Trans. on Image Processing, vol. 10, no. 9, 1357-1364, 2001.

Mukundan R, Ong S.H., Lee P.A., Image Analysis by Tchebichef moments, IEEE Trans. on Image Processing, vol. 10, no. 9, 1357-1364, 2001.

Mukundan, R S. H. Ong, P. A. Lee, Image analysis by Tchebichef moments, IEEE Trans. on Image Processing 10 (9) 1357{1364, 2001.

Mukundan R, Pang A., Khee N, Stereo Image Analysis: A New Approach Using Orthogonal Moments, Proc. Of Asian Technology Conference in Mathematics, 513-522, 2002.

Mukundan, R., A New Class of Rotational Invariants Using Discrete Orthogonal Moments, IASTED Conference Signal and Image Processing, 80-84, Hawaii, USA, 2004.

Chong C-W,, Paramesran R, and Mukundan R, "Translation and Scale Invariants of Legendre Moments," Pattern Recognition, vol. 37, no. 1, pp. 119- 129, 2004.

Mukundan R, A new class of rotational invariants using discrete orthogonal moments, in: Proc. of the 6th IASTED Int. Conf. on Signal and Image Proc. (SIP'04), pp. 80-84, 2004.

Mukundan R, "Some computational aspects of discrete orthonormal moments,", IEEE Trans. on Image Processing, vol. 13, no. 8, pp. 1055-1059, 2004.