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METHOD OF ENVIRONMENT RECONSTRUCTION USING EPIPOLAR IMAGES

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Abstract: *In this paper the method for 3D Environment reconstruction usingepipolar images is presented. Method allows to fuse stereoimages within certain time depending on acceptable computational resources.*

Keywords: *3D Environment Reconstruction, Stereovision, Computer Vision, Epipolar Images.*

1. INTRODUCTION

The 3D reconstruction is an important task of computer vision that consists in a computation of 3D model of an environment on the basis of its 2D images and is widely used in industry, robotics, computer graphics, augmented reality.

Modern computer vision systems for 3D reconstruction on the basis of image set are based on Time-of-Flight Principle or parallax [2, 3, 18-20]. Computer vision systems based on Time-of-Flight Principle uses cameras with a source of modulated light and a specialized sensor [18-20]. Their disadvantages are low image resolution, errors in a reconstruction of mirror-like surfaces, expensive cost and big power consumption that limits the working time of a camera in autonomous mode. Therefore computer vision systems based on parallax are used broader. A stereocamera in conjunction with 3D reconstruction methods and algorithms is an example. There are many commercial models of stereocamera with expensive cost that depends on stereocamera specification.

Methods of stereoimage fusion are used for 3D reconstruction in a processing of stereoimages acquired from a stereocamera. Such methods search of corresponding points on a stereoimage with subsequent 3D reconstruction on the basis of a formed set of corresponding points and known parameters of the camera geometric model. Nowadays there are many methods of stereoimage fusion in particular:

- methods which use wavelet transform [9-11];
- methods which use interest point detectors and (or) contour segmentation for an initial image processing [4, 5, 8, 14, 16];
- methods which use contour segmentation with subsequent determination of straight lines and connections between them on images [1, 6, 7];
- methods which use Kalman filter [1, 12];
- methods which use dynamic programming for search of corresponding points on stereoimages [13, 15];
- methods which use neural networks [17].

Main disadvantage of existed methods is a computational complexity that limits their application in a real-time mode. Therefore a goal of this work is a development of method for stereoimage fusion with acceptable computational complexity.

2. DEVELOPED METHOD FOR FUSION OF EPIPOLAR IMAGES FOR 3D RECONSTRUCTION

The algorithm of the method for fusion of epipolar images presented on fig.1.

The first step of methods for stereoimage fusion on the basis of parallax is an initial image processing with aim of an improvement of image quality, a noise reduction and an image segmentation for detection of certain type of features on it (contours, interest points, etc) and a computation of descriptors for subsequent processing. The search of correspondences for segmented image elements using different types of a correlation of image areas that contains these elements and (or) descriptors with epipolar constraints performs on the next step.

The 3D reconstruction on the basis of found correspondences is the last step.

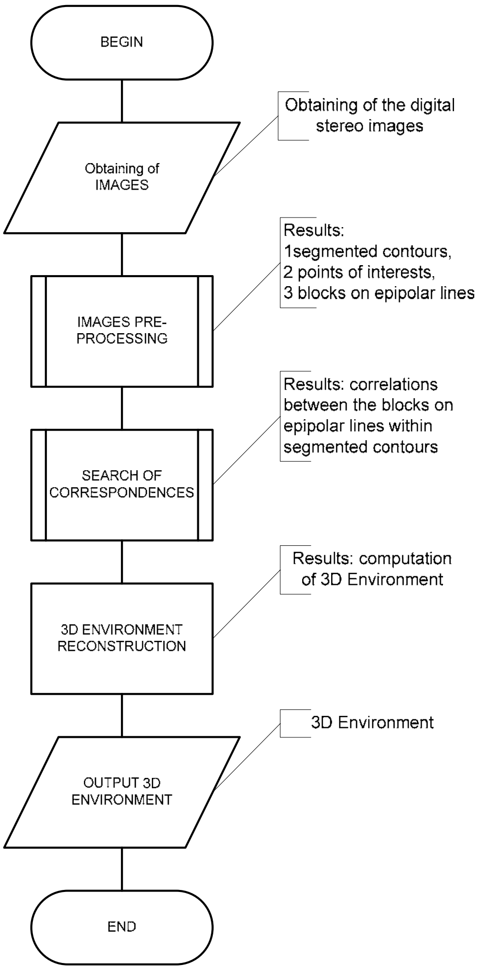


Fig. 1 – Flowchart for epipolar image fusion

The developed method is based on three main algorithms:

- stereoimage formation (image prepre-processing block on fig. 1);
- stereoimage fusion (search of correspondence block on fig. 1);
- computation of 3D coordinates.

The correlation is used as a similarity measure of image areas for correspondence point matching on stereoimage:

$$k = \frac{\sum_m \sum_n \left(I_{mn} - \bar{I}\right)\left(J_{mn} - \bar{J}\right)}{\sqrt{\left(\sum_m \sum_n \left(I_{mn} - \bar{I}\right)^2\right)\left(\sum_m \sum_n \left(J_{mn} - \bar{J}\right)^2\right)}}, \quad (1)$$

where I_{mn} (J_{mn}) – pixel value in position (m,n) of image area I (J), and $\bar{I}$ ($\bar{J}$) – mean value of pixels in image area I (J).

The geometry interpretation of the developed algorithm of *stereoimage formation* is presented on fig 2 and the flowchart of it is presented on fig. 3. The main steps of developed *algorithm of stereoimage formation* are:

1) Camera calibration. Computed camera projection matrixes P, P' and fundamental matrix F are results of it.
2) Computation of homogenous coordinates of epipol e on image plane of projection matrix P:
   2.1) Computation of homogenous coordinates of camera centre C' of camera P' with constraint $P'C' = 0$ using singular value decomposition (SVD);
   2.2) Computation of homogenous vector e, as $e = PC'$;
3) Define initial point a with coordinates $[x \quad y \quad 1]^T$ on image plane, which lies on first epipolar line;
4) From 1 to n, n – defined number of epipolar lines:

Compute epipolar line $l_e = e \times a'$ through epipol e and point a' with coordinates $[x \quad y + (j-1) * o \quad 1]^T$ on image plane, o – shift in pixels and $o = (y\_\max - y_a)/n$, y_a – coordinate of point a on axis y and $y\_\max$ – defined maximum coordinate of point a' on image axis y;

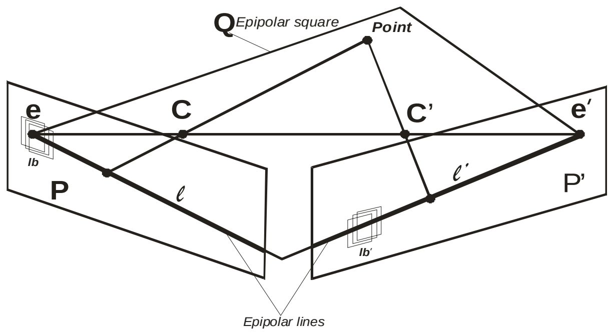


Fig. 2 – Geometry interpretation of algorithm for stereoimage formation during image preprocessing

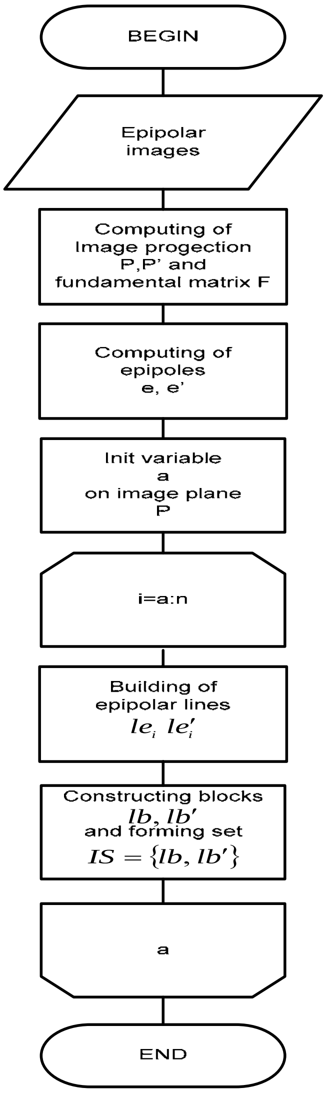


Fig. 3 – Flowchart of the developed algorithm of stereoimage formation

5) Computation of corresponding epipolar line $l'_e = F[e]_\times l_e$ for epipolar line l_e on image plane of P';
6) Formation of image blocks Ib and Ib', which contains points of epipolar lines l_e, l'_e and adjacent points from $y_l + d$ to $y_l - d$ on image axis y, and adding these blocks to set of image blocks IS. Go to step 4.

The results of algorithm for stereoimage formation is given on fig. 4.

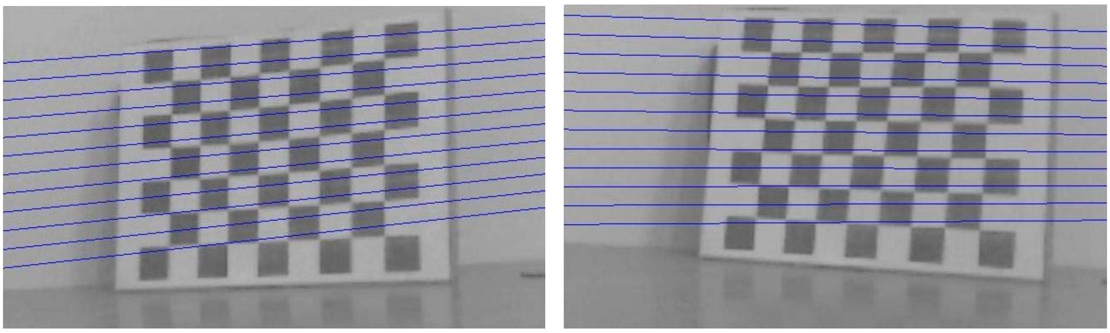
The next task for environment reconstruction is to search the correspondences (see fig. 1) between the set of blocks from the previous algorithm. This task is reached by using of the developed *algorithm of stereoimage fusion* (see the flowchart on fig.5). The algorithm of stereoimage fusion contains the following steps:

1) For each block Ib_i and Ib'_i of formed stereoimage IS, where $i = 1 \ldots n$, and n – defined number of epipolar lines:
2) Detect interest points on each block Ib_i and Ib'_i using developed method of interest point detection.
3) Determine matrix FPs (FPs') that contains coordinate vectors of interest points on epipolar lines of image blocks Ib_i (Ib'_i) in columns.
4) For each column FPs_t of matrix FPs:
   4.1) Compute similarity measure of image area with size $m \times m$ and center in FPs_t and image area with size $m \times m$ and center in each interest point in image block FPs' using (1).
   4.2) Corresponding point is determined as point with minimal value $\min\limits_t (k_t)$ of similarity measures with subsequent deleting of column of matrix FPs' that contains coordinates of corresponding point.
   4.3) Add coordinates of corresponding points to set Cp.
   4.4) Go to step 4
5) Compute 3D coordinates of 3D point for each pair of corresponding image points using developed algorithm.

Main steps of developed *algorithm for computation of 3D coordinates* are:

1) For each pair of coordinate vectors of corresponding points x_i and x'_i of set Cp on image planes of cameras P and P':
   1.1) Compute 3D coordinate vector $X^+ = P^+ x_i$, $X^+ = X^+ / W$, W – fourth component of homogenous vector X^+, P^+ – pseudoinverse matrix of camera projection matrix P (P^+ is computed while camera calibration).
   1.2) Compute coordinate vector x^+ for projection of 3D point X^+ on image plane of camera P' using $x^+ = P'X^+$.
   1.3) Solve system of linear equations $Aa = x'_i$, $A = [x^+ \quad e]$, e is coordinate vector of epipol on image plane of camera P' and $a = [\lambda_1 \quad \lambda_2]^T$.

Compute 3D coordinates of point X_i using $X_i = \lambda_1 X^+ + \lambda_2 C$, $X_i = X_i / W_i$, W_i – fourth component of homogenous vector X_i.



a) b)

Fig. 4 – Results of epipolar lines construction using image preprocessing: a) left image; b) right image

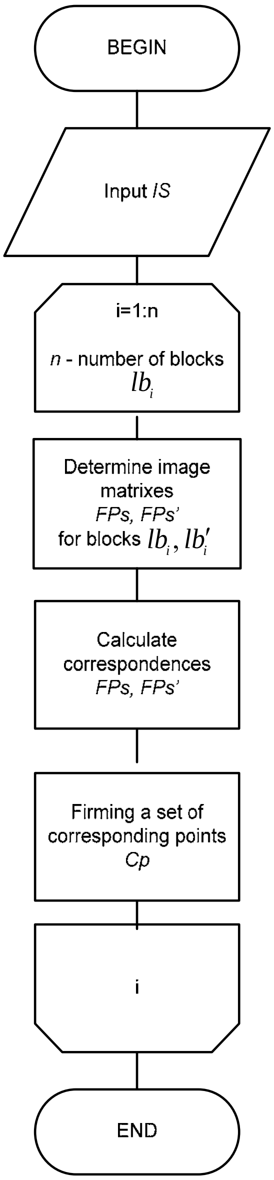


Fig. 5 – Flowchart of the developed algorithm for stereoimage fusion

3. EXPERIMENTS

The time of stereoimage fusion that depends on threshold value T and number of epipolar lines n is shown in Table 1. The time of stereoimage fusion can be controlled by number of epipolar lines n, threshold of interest point detection T and reduced using computer with more computational resources than one used during experiments (CPU Celeron 1.1 Ghz and 512 RAM) in Matlab environment and implementation on programming language C\C++ and (or) CUDA. We can conclude from Table 1: if value of T is more than 6 pixels and number of epipolar lines is not more than 18 then a method has an acceptable performance with mentioned computational resources.

Table 1. Time of Stereoimage Fusion

Number of epipolar lines	Mean time of fusion in seconds
$T = 3.5$ pixels	
$n = 6$	300,721
$n = 18$	1473,808
$T = 7$ pixels	
$n = 6$	3,162
$n = 18$	89,895
$n = 36$	139,425
$n = 72$	366,091
$T = 10$ pixels	
$n = 6$	1,057
$n = 18$	33,936
$n = 36$	54,537
$n = 72$	127,211

The dependence of the time of 3D coordinates computation from a number of epipolar lines for existed algorithm of triangulation using SVD (line with markers „+”) and developed one (line with markers „o”) is shown on Fig. 6. Mean error of 3D coordinates computation was equal to 20.0352 mm for existed algorithm and 58.6495 mm for developed one. We may conclude from graph on Fig. 6 that time of 3D coordinates computation for a developed algorithm in less in two times than for existed one.

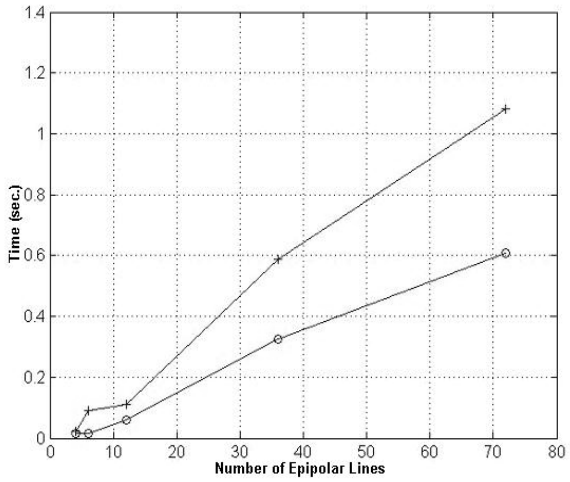


Fig. 6 – The dependence of the time of 3D coordinates computation from a number of epipolar lines

4. CONCLUSIONS AND FUTURE WORK

Authors propose a method which allows to fuse stereoimages within certain time depending on acceptable computational resources. On its base the algorithm was developed providing processing time of 3D coordinates in two times less than existed one.

The implementation of proposed method in CUDA and a development of the interest point descriptor will be objectives of future work.

5. ACKNOWLEDGMENT

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