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STEREOSCOPIC SIGHTING SYSTEM FOR INTERACTIVE MOBILE ROBOT

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Abstract: *The paper deals with the two view geometry that is an essential principle of the stereoscopic sighting system for an interactive mobile robot, developed within the scope of Internal grant activity at Faculty of Applied Informatics at the Tomas Bata University in Zlin. First, a hardware solution and characteristics of a swiveling stereo vision system founded on the Surveyor SVS are briefly introduced. In the following part, mathematical-geometrical principles of two central projections are described.*
Key words: *stereoscopy; homography; epipolar geometry*

1. INTRODUCTION

With the present growing development of the robotics, the computer vision, which is an important aspect of a sensory set, is a subject of intensive research. From video data produced by a camera or a camera system, it is already possible to extract a depth map of each single pixel on the scene (Hartley & Zisserman, 2004) and consequently reconstruct a virtual ambience in order to determine the robot position. Another published research is concerned with automatic object recognition on the static or dynamic scene (Sonka et al., 2007). The computer vision is a very complex and multidisciplinary issue. The aim of this paper is a proposal of a passive depth measuring system with the use of two digital cameras for the navigation of a mobile robot and for object tracking.

The first part of the paper contains a proposal of hardware configuration, the second part deals with the two view geometry, which forms fundamentals of software algorithms.

2. HARDWARE PART

The hardware part is based on the Surveyor camera system SVS, which is composed of two SRV-1 modules containing 500 MHz processors interconnected via SPI bus. The modules are equipped with 1.3 megapixel cameras OV9655. The positioning system consists of two HS422 servomotors and DC motor (Fig. 1.).

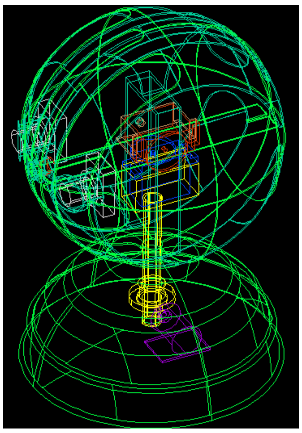

Fig. 1. The turret – positioning system

The elevation and the azimuth of the turret which carries stereoscopic system provide two RC servomotors HS422 and operate withing the range of ±90°. The extension of the azimuthal rotation operates withing the range of ±360° and is realized by a DC motor connected via coax. This motor is driven via the H-bridge (Beneda, 2009). The system is controlled by wireless connection from a PC to the SVS, which transfers image data from cameras to the PC and drives simultaneously the positioning system.

Proposed turret shape is determined for a separate testing of the camera and the positioning system. It will be further modified to satisfy a possible demand for mounting it on the mobile robot. All components of the positioning system are composed to the compact turret.

3. TWO VIEW GEOMETRY

3.1 Projective linear transformation

The projective transformation is an invertible transformation between two projective planes and their essential feature is the point-to-line mapping. Therefore, the synonym also used is the **colineation**. Among other names for the projective transformation found in academic literature, the **projectivity** and the **homography**0 can be used (Hartley & Zisserman, 2004). Projectivity expresses the changes in the perception of the observed object, if the position and/or angle of the viewer's perspective simultaneously changes.

An example of the projective transformation (see Fig. 2.) is the central projection with the centre in point O and two planes π and π'. This projection is mapping the points from the first plane to the second one $\boldsymbol{x}_i \leftrightarrow \boldsymbol{x}_i^{'}$. It is also obvious that straight lines are mapped from one plane to another. Points in homogeneous coordinates can be written as $\boldsymbol{x}_i^{'} = H\boldsymbol{x}_i$, where H represents the transformation of 3x3 homography matrix:

$$H = \begin{pmatrix} h_{11} & h_{12} & h_{13} \\ h_{21} & h_{22} & h_{23} \\ h_{31} & h_{32} & h_{33} \end{pmatrix} \tag{1}$$

$$\boldsymbol{x}_i^{'} = H\boldsymbol{x}_i = \begin{pmatrix} h_{11} & h_{12} & h_{13} \\ h_{21} & h_{22} & h_{23} \\ h_{31} & h_{32} & h_{33} \end{pmatrix} \begin{pmatrix} x_i \\ y_i \\ 1 \end{pmatrix} = \begin{pmatrix} x_i^{'} \\ y_i^{'} \\ 1 \end{pmatrix} \tag{2}$$

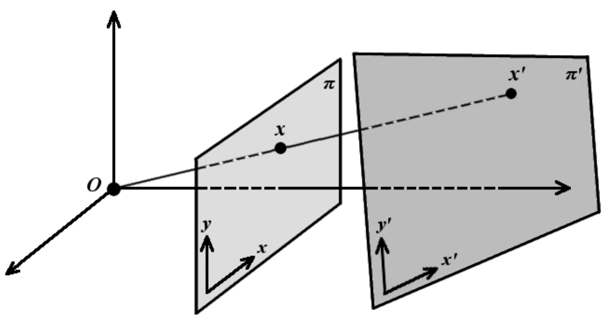

Fig. 2. Homography

At least 4 correspondences $\boldsymbol{x}_i \leftrightarrow \boldsymbol{x}_i^{'}$ are needed for a calculation of the H, but it is desirable to know more then 4 of them to minimize the inaccuracy. The proof of this proposal and non-trivial procedure of the homography calculation can be found in Drbohlav (2002) and Criminisi et al. (1997).

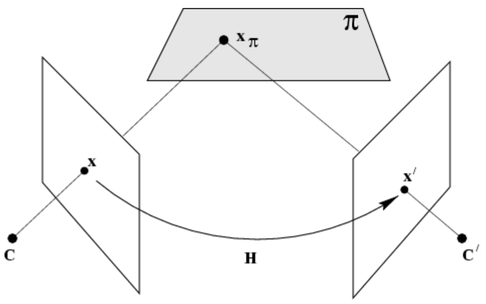

Fig. 3. Example of projective transformation – concatenation of two projectivities is again projectivity

3.2 Epipolar geometry

The reconstruction of a 3D scene from two or more planar projections is a common problem of the computer vision. The elementary problem is a determination of the position of a point in the 3D space. By the projection of 3D scene to the pair of cameras' image planes, stereo images are obtained. The epipolar geometry describes the theoretical bases for a relationship between these two pictures. The epipolar geometry is independent on a scene structure, only intrinsic parameters and a relative position of cameras matters (Riha & Hujka, 2005).0 By means of the epipolar geometry the point from the first image can be mapped to straight line on the second image. This simplifies the problem of correspondence considerably (the point from the first image does not have to be searched on the whole area of the second one).

Two possibilities of the 3D scene reconstruction exist, in principle. Determination of cameras projective matrices is the first way. To acquire internal parameters, calibration techniques have to be used. The second possibility is based on projectivity exploitation. The homography is calculated from detected correspondences, knowledge in internal parameters is not necessary.

In both cases the camera model, which precisely approximates the real camera, needs to be established.

3.3 The epipolar geometry basis

Point X, which is situated in the space, is surveyed by two cameras. Their projective matrices are P a P'. Point X is projected to cameras planes as point $\boldsymbol{x}$ and $\boldsymbol{x}'$ where $\boldsymbol{x} = PX$ and $\boldsymbol{x}^{'} = P'X$. The line connecting centers of cameras C and C' is called the **base line**. The point where the base line intersects the image plane is the epipol $\boldsymbol{e}$ and $\boldsymbol{e}'$. The line linking points $\boldsymbol{e}$ and $\boldsymbol{x}$, eventually $\boldsymbol{e}^{'}$ and $\boldsymbol{x}'$ is the **epipolar line** l, eventually l'. The centers of cameras, epipoles and points X, $\boldsymbol{x}$, $\boldsymbol{x}'$ are coplanar, which means they all lay on the same **epipolar plane** $\boldsymbol{\pi}$, see Fig. 4.

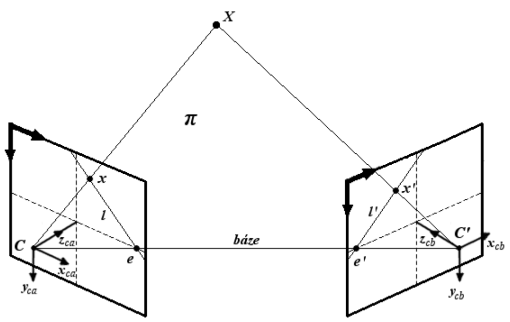

Fig. 4. Epipolar geometry

As mentioned above, the main result of the epipolar geometry is the mapping $\boldsymbol{x} \rightarrow l'$. The internal geometric properties are interpreted by the so-called **fundamental matrix F**. For every two corresponding points $\boldsymbol{x} \leftrightarrow \boldsymbol{x}'$ applies:

$$\boldsymbol{x}'^{T} F \boldsymbol{x} = 0 \tag{3}$$

And the key equation for the epipolar line calculation is:

$$l^{'} = F\boldsymbol{x} \tag{4}$$

The mapping procedure can be separated into two steps. In the first step, the point $\boldsymbol{x}$ is mapped by the help of homography (fig. 3.) to another point $\boldsymbol{x}'$ lying on a different plane. In the second step, the epipolar line l' is obtained as a line connecting the point $\boldsymbol{x}'$ with the epipol $\boldsymbol{e}'$. If any point $\boldsymbol{x}'$, which lies on the epipolar line l', exists, it can be written: $l^{'} = \boldsymbol{e}^{'} \times \boldsymbol{x}^{'} = [\boldsymbol{e}']_{\times}\boldsymbol{x}^{'}$ ($[\boldsymbol{e}']_{\times}$ is a cross-product), because the $\boldsymbol{x}'$ can be written as $\boldsymbol{x}^{'} = H_{\pi}\boldsymbol{x}$,

$$l^{'} = [\boldsymbol{e}']_{\times} H_{\pi} \boldsymbol{x} = F\boldsymbol{x} \tag{5}$$

Hence the definition of the fundamental matrix is:

$$F = [\boldsymbol{e}']_{\times} H_{\pi} \tag{6}$$

Where H_{π} is homography in any plane π. Because the $[\boldsymbol{e}']_{\times}$ has rank 2 and the H_{π} has rank 3, the fundamental matrix F has rank 2. For the complete and detailed computation of the fundamental matrix see Hartley & Zisserman (2004).

4. CONCLUSION

In this paper, the solution of the stereovision sighting system, which is intended as a sensory part of a laboratory robot, which is developed within the scope of the internal grant activity at the Faculty of Applied Informatics at the Tomas Bata University in Zlin, is introduced. I have newly proposed the shape of the compact turret composing all mechanic components. The mathematical-geometrical principles of two views that are exploited by the supporting software are also shown. However, this project is still at the beginning. Further research will lead to optimization of the correspondence issue in order to obtain more accurate 3D position of a targeted object. Then the measured experimental data will determine the most appropriate way of image processing for an object tracking.

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