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GEOMETRICAL CALIBRATION OF ROBOTIC WEB-CAMERAS

The paper addresses a new camera calibration problem arising in Internet applications. It is based on the fitting of a 2D affine transformation that describes the correspondence between the collective user request and the feedback image of the web camera. It proposes a new technique of feature extraction with new expressions for model parameters and their covariance, for estimating the calibration accuracy.

INTRODUCTION

Currently there are thousands of webcams across the world providing Internet users with visual information from various geographical locations or remote terrains investigated by robots [1]. Among them, an increasing number of robotic web-cameras [2] enable viewers with pan-tilt-zoom control capabilities and panoramic control, which require precise correspondence between the request frame and the robotic camera feedback image. Since users present their requests in a static panoramic image navigation window, this correspondence can be distorted for a number of reasons, such as changes in the camera location, in the camera internal parameters, or in the calibration of the pan-tilt-zoom drive. Additional distortion can be introduced by the wide panoramic image itself, which is created from a mosaic of smaller aligned and stitched together images. So, there exist a number of factors that pose this type of camera calibration problem.

The known works, related to the camera calibration [3…5], mainly deal with determining the intrinsic and/or extrinsic camera parameters. Most of them are based on the pinhole model, which defines the relationships between 3D point and its 2D image as the perspective projection, which matrix is defined by 11 independent parameters. Some recent papers also focus on the **self-calibration of a 1D projective camera, which model** incorporates 5 intrinsic parameters. Another popular model is the affine camera, which is derived from the general one by imposing some constraints on the projection matrix. The latter is defined by 8 independent parameters that represent both intrinsic and extrinsic properties; its advantage is simplification of the calibration routine and reduced sensitivity to image measurement noise. This paper proposes a new method for the web-camera calibration, which is based on the affine model and specific feature extraction technique.

PROBLEM STATEMENT

Let us assume that the "feature-to-feature" mapping can be approximated by a superposition of three geometrical affine transformations (translation, rotation and scaling), which is defined by the following expression

$$\mathbf{g}_i = \mu \mathbf{R} \mathbf{p}_i + \mathbf{t};\ \ i = 1:m \tag{1}$$

where $\mathbf{g}_r^i$ and $\mathbf{g}_p^i$ are the center points vectors of the *i*-th requested and presented frame respectively, $\boldsymbol{R}$ is the orthogonal 2×2 rotation matrix, $\boldsymbol{t}$ is the 2×1 translation vector, μ is the scaling factor (scalar), and m is the number of pairs available for the calibration. Then the model parameters may be identified using the following theorem.

Theorem 1. *Let* $\left\{\left(\mathbf{g}_r^i, \mathbf{g}_p^i\right)\right\}$ *be a set of corresponding center points for the requested and presented camera frames respectively. Then the least square fitting of the camera model is achieved for the following parameters*:

$$\mathbf{R} = \mathbf{V}\,\mathbf{U}^T; \quad \mu = \sum_{i=1}^{m} \widehat{\mathbf{g}}_i^T \mathbf{R}\,\widehat{\mathbf{p}}_i \Big/ \sum_{i=1}^{m} \widehat{\mathbf{p}}_i^T\,\widehat{\mathbf{p}}_i\,; \quad \mathbf{t} = \frac{1}{m}\sum_{i=1}^{m}\mathbf{g}_i - \frac{\mu}{m}\mathbf{R}\sum_{i=1}^{m}\mathbf{p}_i\,; \tag{2}$$

where

$$\widehat{\mathbf{g}}_i = \mathbf{g}_i - \frac{1}{m}\sum_{i=1}^{m}\mathbf{g}_i; \quad \widehat{\mathbf{p}}_i = \mathbf{p}_i - \frac{1}{m}\sum_{i=1}^{m}\mathbf{p}_i.$$

and the orthogonal matrixes ***V***, ***U*** *are computed via the following SVD-decomposition*

$$\sum_{i=1}^{m} \widehat{\mathbf{g}}_r^i \widehat{\mathbf{g}}_r^{i\,T} = \mathbf{U}\,\mathbf{S}\,\mathbf{V}^T. \tag{3}$$

Since the input data are obtained by computer mouse pointing, they incorporate errors that may be taken into account by using the following model

$$\mathbf{g}_p^i + \xi_p^i = \mu\,\mathbf{R}\left(\mathbf{g}_r^i + \xi_r^i\right) + \mathbf{t}; \quad i = 1:m \tag{4}$$

where all notations match (1) and ξ_p^i, ξ_r^i are the measurement errors, which are assumed to be independent and identically distributed (iid). Then the influence of these errors on the calibration accuracy is defined by the following theorem.

Theorem 2. *Let the measurement errors* ξ_p^i, ξ_r^i *be the iid random variables with zero mean and variances* σ_p^2 *and* σ_r^2 *for each coordinate, and* $\sigma^2 = \sigma_p^2 + \mu^2\sigma_r^2$, *then the covariance of the model parameter errors* $\delta\varphi$, $\delta\mu$, $\delta\mathbf{t}$ *is expressed as*

$$\operatorname{cov}\begin{pmatrix}\delta\varphi\\ \delta\mu\\ \delta\mathbf{t}\end{pmatrix} = \sigma^2\cdot\begin{bmatrix}\mu^2\sum_{i=1}^{m}\widehat{\mathbf{g}}_r^{i\,T}\widehat{\mathbf{g}}_r^i & 0 & 0\\ 0 & \sum_{i=1}^{m}\widehat{\mathbf{g}}_r^{i\,T}\widehat{\mathbf{g}}_r^i & 0\\ \mathbf{0} & \mathbf{0} & m\mathbf{I}_{2\times 2}\end{bmatrix}^{-1}. \tag{5}$$

Corollary. *For the model* (4), *the variance for its parameters can be expressed as*

$$\operatorname{var}(\delta\varphi) = \frac{\sigma^2}{\mu^2}\Omega^{-1}; \quad \operatorname{var}(\delta\mu) = \sigma^2\Omega^{-1}; \quad \operatorname{var}(\delta t_x) = \operatorname{var}(\delta t_y) = \frac{\sigma^2}{m} \tag{6}$$

where

$$\Omega = \sum_{i=1}^{m}\left(\widehat{g}_{rx}^{\,i}\right)^2 + \sum_{i=1}^{m}\left(\widehat{g}_{ry}^{\,i}\right)^2.$$

It should be stressed, that both cov($\delta\varphi$) and cov($\delta\mu$) are proportional to the parameter Ω, which may be interpreted as "the moment of inertia for the test points relative to their center of gravity". It matches the intuitive desire to spread the test points in order to get accurate values for the rotation angle and the scaling factor. In contrast, cov(δt_x) and cov(δt_y) do not depend on the test point distribution in the navigation window.

APPLICATION EXAMPLE

The developed technique has been applied to the calibration of the web-camera installed in AlphaLab (http://tele-actor.net/sharecam/, University of California at Berkeley, USA). The panoramic image covers a wide viewing area with all lab facilities and was prepared before the actual camera location was decided. It led to inconvenience of the user who must request viewing of a desired object by pointing essentially different area on the fixed navigation image. Because zoom errors were not noticed by users, the calibration was limited by correcting of "center-to-center" mapping for the requested/presented frames.

To obtain the initial data, 10 static, easily recognizable objects were selected, which are to remain unmoved after the fixed image has been created. Initially, before the calibration, the mean square error was 25.0 pixels. Several calibration strategies were then applied which differ only in the transformations included in the camera model. As discovered, the simplest translational model reduces the navigation error by 2.8 times, and the model translation/ rotation also yields similar improvements. Another simplified model, translation/scaling, as well as the full model give relatively better result, reducing the error by 3.8 times. Further research shows that the achieved value of the navigation error is higher than can be expected for such measurement noise; it indicates that some other nonlinear effects are present, which are not described by the model (1). However, the achieved calibration accuracy seems satisfactory for this particular application. This research was partly supported by the RSEP/IREX grant.

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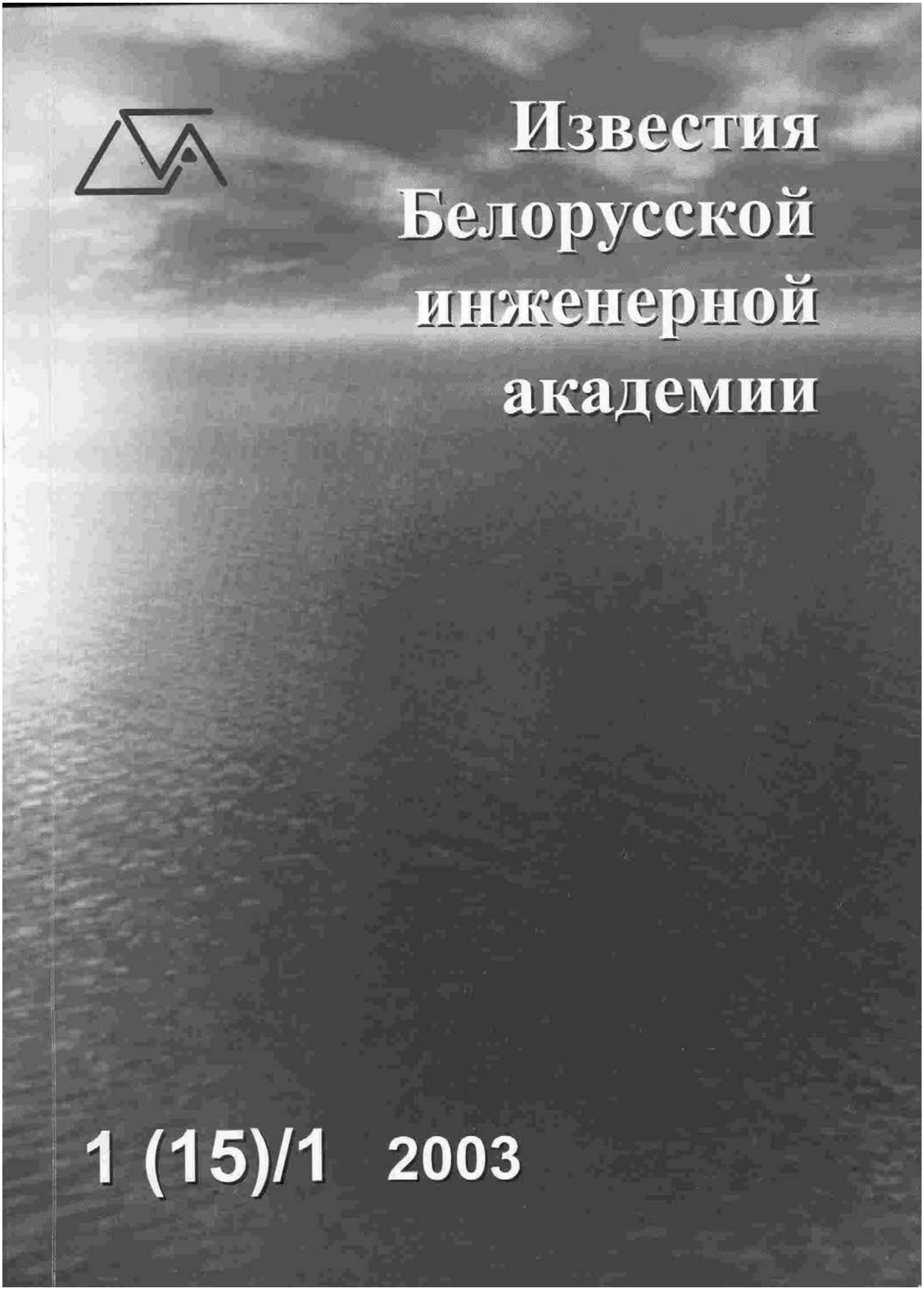

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