Fred A. Hamprecht
Christoph Schnörr
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LNCS 4713

Pattern Recognition

29th DAGM Symposium
Heidelberg, Germany, September 2007
Proceedings

Springer

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29th DAGM Symposium
Heidelberg, Germany, September 12-14, 2007
Proceedings

Springer

Volume Editors

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Library of Congress Control Number: 2007934521

CR Subject Classification (1998): I.5, I.4, I.3.5, I.2.10, I.2.6, F.2.2

LNCS Sublibrary: SL 6 – Image Processing, Computer Vision, Pattern Recognition, and Graphics

ISSN 0302-9743
ISBN-10 3-540-74933-0 Springer Berlin Heidelberg New York
ISBN-13 978-3-540-74933-2 Springer Berlin Heidelberg New York

Springer is a part of Springer Science+Business Media

springer.com

Printed in Germany

Typesetting: Camera-ready by author, data conversion by Scientific Publishing Services, Chennai, India
Printed on acid-free paper SPIN: 12122677 06/3180 5 4 3 2 1 0

Lecture Notes in Computer Science 4713

Lecture Notes in Computer Science

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Preface

In 1996, the 18^{th} Annual Symposium of the Deutsche Arbeitsgemeinschaft für Mustererkennung (DAGM) was hosted by the recently established research group on image processing of the University of Heidelberg, headed at that time by a single associate professor (Jähne) at the Interdisciplinary Center for Scientific Computing (IWR).

This year, it was a pleasure to host again the 29^{th} Annual Symposium of the DAGM in Heidelberg. Meanwhile, image processing at the IWR consists of three Chairs (Hamprecht, Schnörr, Jähne). It will be complemented in 2008 by the Heidelberg Center for Image Processing (HCI) and involve eight industrial partners as founding members.

This development reflects the fact that image processing and pattern recognition are research and business areas which keep growing in both volume and importance. The Fraunhofer Institute for Technological Trend Analysis (INT, Euskirchen) has recently identified image processing and pattern recognition among the "scientific-technical areas of the future"[1], and the National IT Summit has called for a strategic research effort to foster the real-world awareness of IT systems in its 2006 white paper on "HighTech Strategies for the Information Society." Such systems should be able to "understand" and to orient themselves in their environment, and the development of sophisticated techniques for image processing and pattern recognition is a prerequisite to meet these challenges.

DAGM made English its sole conference language in 2001. Since then, it has continuously strenghtened its position as the most important conference on pattern recognition and related fields (image processing, computer vision, machine learning) for the German-speaking community. It is increasingly attracting scientists from all over Europe and beyond.

The selection of contributions as oral or poster presentation does not signify a quality grading. Consequently, posters and oral presentations were given the same number of pages in these proceedings. The accepted papers have roughly been sorted by subject area, and within each section alphabetically by first author. During the symposium, much space was devoted to discussions by extending both the poster sessions and the discussions following the presentations.

We were honored to have the following three invited speakers at the symposium:

- *Sabine Huffel (KU Leuven, Belgium)*, Quantification and Classification of Magnetic Resonance Spectroscopic Images with Applications in Cancer Diagnosis
- *Robert Massen (University of Applied Sciences, Constance and Baumer Inspection GmbH, Germany)*, History of the German Machine Vision Industry and Its Influence on Academic Research

[1] www.zukunftsstiftung.at/innovationstag/pdf/Technologie-%20und%20Innovationstrends_Kretschmer.pdf

– *Shimon Ullman (Weizmann Institute of Science, Israel)*, Image Interpretation by Feature Hierarchies

We would like to extend our sincere thanks to:

– All authors and attendees who helped make this symposium a success
– All reviewers from the Program Committee whose dedication and timely reporting helped ensure the punctuality of the selection process
– UniTT, Barbara Werner and Karin Kubessa-Nasri for their commitment to ensuring a smooth organization
– Our own labs who helped in the elimination of many of the typos that remained in the final submissions
– Björn Andres and Thorsten Dahmen for their help with the compilation of the proceedings

Last but not least, we would like to thank:

– Robert Bosch GmbH (Gold Corporate Contributor),
– MVTec Software GmbH (Silver Corporate Contributor),
– Basler, PCO imaging, Philips, Silicon Software, Stemmer, and Volume Graphics (Bronze Corporate Contributors)

for their donations that allowed, in particular, low registration fees for students.

We were happy to host the 29^{th} Annual Symposium in Heidelberg and look forward to DAGM 2008 in Munich!

September 2007

Fred Hamprecht
Christoph Schnörr
Bernd Jähne

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Prizes 2006

Olympus Prize

The Olympus Prize 2006 was awarded to

Daniel Keysers and *Andrés Bruhn*

for their outstanding contributions to the area of pattern recognition and image understanding.

DAGM Prizes

The main prize for 2006 was awarded to:

Paul Ruhnau, Annette Stahl, Christoph Schnörr: On-line Variational Estimation of Dynamical Fluid Flows with Physics-Based Spatio-temporal Regularization

Simon Winkelbach, Sven Molkenstruck, Friedrich M. Wahl: Low-Cost Laser Range Scanner and Fast Surface Registration Approach

Further DAGM prizes for 2006 were awarded to:

Janina Schulz, Thorsten Schmidt, Olaf Ronneberger, Hans Burkhardt, Taras Pasternak, Alexander Dovzhenko, Klaus Palmet: Fast Scalar and Vectorial Grayscale-Based Invariant Features for 3D Cell Nuclei Localization and Classification

Edgar Seemann, Bernt Schiele: Cross-Articulation Learning for Robust Detection of Pedestrians

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Self-calibration with Partially Known Rotations

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Abstract. Self-calibration methods allow estimating the intrinsic camera parameters without using a known calibration object. However, such methods are very sensitive to noise, even in the simple special case of a purely rotating camera. Suitable pan-tilt-units can be used to perform pure camera rotations. In this case, we can get partial knowledge of the rotations, e.g. by rotating twice about the same axis. We present extended self-calibration algorithms which use such knowledge. In systematic simulations, we show that our new algorithms are less sensitive to noise. Experiments on real data result in a systematic error caused by non-ideal hardware. However, our algorithms can reduce the systematic error. In the case of complete rotation knowledge, it can even be greatly reduced.

1 Introduction

For many computer vision tasks, the intrinsic camera parameters have to be known. Classic calibration uses a calibration pattern with known geometry and easily detectable features to establish correspondences between known 3D points and 2D image points. However, having to use such a pattern is not very convenient and sometimes impossible. Luckily, there are self-calibration methods, which estimate the intrinsic camera parameters from images taken by a moving camera *without* knowledge about the scene. For an overview, the reader is referred to the literature [1]. An important special case is self-calibration from a purely rotating camera as introduced by Hartley [2,1].

However, most self-calibration methods are very sensitive to noise [3,1]. They work well at low noise levels, but most often have serious problems at higher noise levels. On the other hand, in many practical situations, additional knowledge is available, which can be used to increase the robustness of self-calibration. De Agapito, Hayman and Reid [6] exploit a priori knowledge on the intrinsic parameters by using a MAP estimator. In this paper, we focus on rotation knowledge. Hartley [2] mentions the possibility to incorporate known rotation matrices into the nonlinear refinement step and reported greatly improved self-calibration results. Frahm and Koch [4,5] have presented a linear approach that uses known relative orientation provided by an external rotation sensor.

In practice, however, there are cases in between no and full rotation knowledge. For example, a pan-tilt-unit is often used to perform rotations about one of two physical rotation axes at a time. To the best of our knowledge, using such a priori information to improve self-calibration has not been systematically studied. In this paper, we give an overview of different kinds of partial rotation information with real pan-tilt-units in mind, and show how this knowledge can be incorporated into a nonlinear

F.A. Hamprecht, C. Schnörr, and B. Jähne (Eds.): DAGM 2007, LNCS 4713, pp. 1–10, 2007.

self-calibration procedure. We demonstrate the improvements gained by our new algorithms in systematic simulations and also in experiments with real hardware.

The paper is organized as follows: In Section 2 we give a repetition of self-calibration for a rotating camera. Section 3 describes how partial rotation information can be incorporated into the self-calibration procedure in various situations. Our new algorithms are evaluated in Section 4. Finally, we give conclusions in section 5.

2 Self-calibration of a Rotating Camera

2.1 Camera Model

First of all, we introduce the camera model and some notation. The pinhole camera model [1,7] is expressed by the equation $\lambda \boldsymbol{p} = \boldsymbol{K}\boldsymbol{p}_{\mathrm{C}}$, where $\boldsymbol{p}_{\mathrm{C}}$ is a 3D point in the camera coordinate system, $\boldsymbol{p} = (p_{\mathrm{x}}, p_{\mathrm{y}}, 1)^T$ is the imaged point in homogeneous 2D pixel coordinates, $\lambda \neq 0$ is a projective scale factor and $\boldsymbol{K} \stackrel{\text{def}}{=} ((f_{\mathrm{x}}, s, o_{\mathrm{x}}), (0, f_{\mathrm{y}}, o_{\mathrm{y}}), (0,0,1))^T$ is the camera calibration matrix, where f_{x} and f_{y} are the effective focal lengths, s is the skew parameter and $(o_{\mathrm{x}}, o_{\mathrm{y}})$ is the principal point. The relation between a 3D point in camera coordinates $\boldsymbol{p}_{\mathrm{C}}$ and the same point expressed in world coordinates $\boldsymbol{p}_{\mathrm{W}}$ is $\boldsymbol{p}_{\mathrm{C}} = \boldsymbol{R}_{\mathrm{o}}\boldsymbol{p}_{\mathrm{W}} + \boldsymbol{t}$, where $\boldsymbol{R}_{\mathrm{o}}$ is the orientation of the camera and $\boldsymbol{t}$ is the position of its optical center. Thus, $\boldsymbol{p}_{\mathrm{W}}$ is mapped to the image point $\boldsymbol{p}$ by the equation $\lambda \boldsymbol{p} = \boldsymbol{K}(\boldsymbol{R}_{\mathrm{o}}\boldsymbol{p}_{\mathrm{W}} + \boldsymbol{t})$.

2.2 Linear Self-calibration

We will give a very brief repetition of Hartley's linear self-calibration algorithm [2,1] for a purely rotating camera. In this situation, without loss of generality, we can assume $\boldsymbol{t} = 0$. Taking a second image $\boldsymbol{p}' = (p'_{\mathrm{x}}, p'_{\mathrm{y}}, 1)^T$ of the point $\boldsymbol{p}_{\mathrm{W}}$ with camera orientation $\boldsymbol{R}'_{\mathrm{o}}$ then results in $\lambda' \boldsymbol{p}' = \boldsymbol{K}\boldsymbol{R}'_{\mathrm{o}}\boldsymbol{p}_{\mathrm{W}}$, where $\lambda' \neq 0$ is another scale factor. The points $\boldsymbol{p}$ and $\boldsymbol{p}'$ *correspond*. By eliminating $\boldsymbol{p}_{\mathrm{W}}$, we get (cf. [1]):

$$\lambda'' \boldsymbol{p}' = \boldsymbol{K}\boldsymbol{R}\boldsymbol{K}^{-1}\boldsymbol{p} \quad \text{with} \quad \boldsymbol{R} \stackrel{\text{def}}{=} \boldsymbol{R}'_{\mathrm{o}}\boldsymbol{R}_{\mathrm{o}}^T \quad \text{and} \quad \lambda'' \stackrel{\text{def}}{=} \lambda'/\lambda \ . \tag{1}$$

In this formulation, $\boldsymbol{R}$ is the relative camera rotation. The transformation $\lambda''\boldsymbol{p}' = \boldsymbol{H}\boldsymbol{p}$ maps $\boldsymbol{p}$ to $\boldsymbol{p}'$, where $\boldsymbol{H} \stackrel{\text{def}}{=} \boldsymbol{K}\boldsymbol{R}\boldsymbol{K}^{-1}$ is the *infinite homography*. It is related to the *dual image of the absolute conic* $\boldsymbol{\omega}^* \stackrel{\text{def}}{=} \boldsymbol{K}\boldsymbol{K}^T$ by the equation $\boldsymbol{\omega}^* = \boldsymbol{H}\boldsymbol{\omega}^*\boldsymbol{H}^T$. Now, given $n \geq 2$ rotations of the camera (not all about the same axis), the self-calibration problem can be solved linearly by the following algorithm:

Input: A set of point correspondences $\{(\boldsymbol{p}_{i,j}, \boldsymbol{p}'_{i,j}) \mid 1 \leq i \leq n, 1 \leq j \leq m_i\}$, where $n \geq 2$ is the number of image pairs and m_i is the number of point correspondences for pair i. For numerical reasons [1,8], we normalize pixel coordinates throughout the paper to the range $[-1, 1]$ by applying a translation and an isotropic scaling.

1. For each image pair i, estimate the inter-image homography $\boldsymbol{H}'_i$ from the point correspondences of image pair i and enforce $\det(\boldsymbol{H}_i) = 1$ by setting $\boldsymbol{H}_i = \det(\boldsymbol{H}'_i)^{-\frac{1}{3}}\boldsymbol{H}'_i$.
2. Solve the set of equations $\{\boldsymbol{\omega}^* = \boldsymbol{H}_i\boldsymbol{\omega}^*\boldsymbol{H}_i^T \mid 1 \leq i \leq n\}$ for $\boldsymbol{\omega}^*$ (linear least squares).
3. Compute $\boldsymbol{K}$ from $\boldsymbol{\omega}^* = \boldsymbol{K}\boldsymbol{K}^T$, e.g. by Cholesky decomposition of $(\boldsymbol{\omega}^*)^{-1}$.

Note that Hartley and Zisserman [1] require the homographies $\boldsymbol{H}_i$ to be expressed with respect to a common reference image. It is obvious that this requirement is *not* necessary, as only the *relative* orientations $\boldsymbol{R}_i$ of pairs of views are required.