Tutorial and Workshop Sessions (TU)

WORKSHOP "CALIBRATION AND ORIENTATION OF CAMERAS IN COMPUTER VISION"

Session TU-1 - **ISPRS Commission V and IEEE Computer Society, Technical Committee on Pattern Analysis and Machine Vision (PAMI)**
Sunday, August 2, 1992, 09:00-20:00
Tutorial Co-Chairmen: ***Prof. A. Gruen*** *(Switzerland) and* ***Prof. T. S. Huang*** (USA)

B. Wrobel (Germany) - **Minimum Solutions for Orientation**

Three key points were addressed: (1) Standard orientation tasks of photogrammetry and computer vision; (2) minimum solutions for orientation; and (3) number of solutions, instability, and undeterminability.

The speaker gave a classification of the standard orientation tasks of photogrammetry and computer vision (11 in all), the information from 2D images and 3D object space that they combine, and the corresponding information (points, lines, surfaces, digital picture functions) that they can utilize. He then regarded the three basic orientation procedures (space resection, relative and absolute orientation) in more detail, using point correspondences. He presented minimum solutions using corresponding points in image and object space for one representative orientation procedure for the three basic procedures with reference to direct closed-form and linear solutions. Further, he discussed (1) the number of solutions that exist within minimum solution procedures; (2) critical configurations of corresponding points and perspective centers with which the orientation is unstable or undeterminable and critical representations of the rotation matrices; and (3) configurations with which a stable and unique orientation can be obtained and at zero or minimum redundancy. Throughout his talk, the speaker gave an excellent overview of the research on these topics within photogrammetry and related disciplines from the 19th century up to present.

T. S. Huang (USA), R. Y. Tsai - **Uniqueness, Number of Solutions and Degeneracy in Determining Camera Orientations**

Three key points were addressed: (1) consideration of 3D-3D, 2D-3D, 2D-2D correspondence of points, lines, and corners for different orientation tasks; (2) problem formulation, efficient algorithms for solution, existence and uniqueness of solutions, and sensitivity of solutions to observation noise; and (3) implementation in different applications.

The speaker considered three categories of problems, depending upon the dimensionality of the features usedfor correspondence (3D-3D, 2D-3D, 2D-2D). Features considered include points, straight lines, curved lines, and corners. He presented different algorithms with emphasis on the existence, uniqueness, and number of solutions; degenerate cases; and sensitivity of solutions to noise in the observed data. The presented algorithms have been used in a variety of applications including (a) positioning and navigating 3D objects in a 3D world, (b) camera calibration, and (c) estimating motion and structure of moving objects relative to a camera.

W. Förstner (Germany) - **Robust Orientation Procedures with Minimum and Redundant Information**

Three key points were addressed: (1) Error handling in robust procedures with respect to different error types; (2) quantification of errors and the problem of defining tolerances, sensitivity of the results,and procedures to react to deficiencies; and (3) different levels of robustness and diagnostics.

The speaker first presented different types of errors (data, design/configuration, model errors) and proposed the use of tools from estimation theory (robustness and diagnostics) to attack these problems. He specifically handled three topics: (a) How small is small and the related problem of tolerances when evaluating the design; as a solution, he proposed the local description of instabilities by covariance matrices; (b) How sensitive are the results with respect to errors and the related subjects of determinability, detectability/controllability, and separability/localability; and (c) how to react to deficiencies. He described different robust procedures (complete search, FANSAC, clustering/Hough, M-estimates), their dependency on different parameters (availability of approximations, number and size of errors, number of observations and parameters, etc.), and their suitability for different cases.

D. Gennery (USA) - **Least-Squares Camera Calibration Including Lens Distortion and Automatic Editing of Calibration Points**

Three key points were addressed: (1) Least-squares camera calibration, (2) modelling of lens distortion, and (3) automatic editing of calibration points.

The speaker presented a calibration procedure developed at JPL. He presented the calibration testfield of JPL, the method to measure the pixel coordinates of the testfield points, the camera model of Yakimovsky and Cunningham and the lens distortion model, the derivation of approximations, the least-square solution using constraints, and a quality criterion to detect outliers and edit the points. Finally, he gave some calibration results with and without modeling the lens distortion.

C. Fraser (U.S.A.) - **Camera Component Calibration Techniques - Theory, Systems, Results**

Three key points were addressed: (1) Photogrammetric calibration approaches; (2) modeling of

departures from collinearly, and separability of interior and exterior orientation parameters; and (3) presentation of different calibration techniques.

The speaker first presented the current capabilities of modern photogrammetric systems, stressing that calibration is an essential limiting factor of the accuracy. He gave a short description of the collinearity equations and DLT and presented correction models for departures from collinearity due to radial lens distortion, decentering distortion, focal plane unflatness, in-plane image distortion, and change of the interior orientation elements, also presenting examples. He presented configurations for decorrelating the interior and exterior orientation parameters. Finally, he presented a general photogrammetric model and different calibration procedures using a 3D control field, scale bars, and plumblines.

S. Shafer (U.S.A.) - **Camera Calibration for High-Precision Machine Vision**

Three key points were addressed: (1) Cameras with multiple degrees of freedom (focal length, focus distance, aperture, color band, camera position and orientation, etc.), (2) high-precision imaging in a calibration lab, and (3) camera calibration models.

The speaker first proposed to improve the quality of image data by using camera systems with variable parameters (focal length, focus distance, aperture, color band, camera position and orientation, exposure time, and sensor gain) with specific reference to range from focus and color image analysis. Models for different degrees of freedom were presented. He presented CMU's calibration imaging lab, and the problems of defining and locating the image center. He then presented a very general and complicated camera model and compared it to the simplified, idealized model that is used. He presented the different assumptions to go from the general to the idealized model and proposed that the calibration needs to determine also the form of the model, not just the parameters, and that it should start with the simplest model and generalize it as the data force us to.

A. Gruen (Switzerland) - **System Calibration Through Self-Calibration**

Three key points were addressed: (1) Self-calibration model, (2) treatment and determinability of additional parameters, and (3) accuracy test.

The speaker first presented the mathematical model of self-calibration and the least-squares estimation procedure, stressing its generality and flexibility to handle different tasks. He presented the systematic error compensation by additional parameters and problems related to the determinability of these parameters and to what extent they are influenced by the geometry and network design. Finally, the results of a system test were presented in order to demonstrate the accuracy potential of CCD-camera based systems.

O. D. Faugeras (France) - **Automatic Calibration of a Stereo Rig**

Three key points were addressed: (1) Epipolar transformation and constraints on camera calibration, (2) parametrization and representation of camera calibration by algebraic curves, and (3) combination of different viewpoints.

The speaker showed the connection between camera calibration and epipolar transformations and that the latter impose constraints on the camera calibration. He presented two cases of calibration using two and three epipolar transformations respectively. For each case, he presented the parametrization of the camera calibration by algebraic curves, giving a representation of these curves and the number and order of their singular points. He explained his approach for relative reconstruction of points, the approach to combine different viewpoints, and gave some experimental results.

TUTORIAL "FUNDAMENTALS OF REAL-TIME PHOTOGRAMMETRY"

Session TU-2 - **ISPRS Commission V**
Saturday, August 8, 1992, 09:00-17:30
Sessions Reporter: D. Fritsch
Morning Session Lectures: ***Dr. E. Baltsavias and Dr. H. Beyer***
Afternoon Session Lectures: ***Dr. D. Fritsch and Dr. R. Lenz***

In the morning session three key points were addressed: (1) The introduction to software aspects of digital photogrammetry, (2) linear system theory -- low level image data processing; and (3) medium level image data processing.

The second part of the tutorial dealt with algorithms and software aspects of digital photogrammetry. In particular, linear filtering, image restoration and enhancement, image matching, and object reconstruction was demonstrated.

TUTORIAL "MODERN TREND IN PHOTOGRAMMETRY" The Giovanna Togliatti Memorial Tutorial

Session TU-3 - **Intercommission Working Group III/VI**
Sunday, August 9, 1992, 08:30-17:00
Chairman: ***Dr. Luigi Mussio***

Luigi Mussio (Italy) - **Opening**

After addressing the participants of this last tutorial of the Intercommission WG III/VI, devoted to the memory of Prof. Giovanna Togliatti, Prof. Mussio summarized the work carried out by the WG members during the period 1988-1992.

Three different tutorials took place in the past years. In 1988, the a tutorial was organized in Pisa (Italy) where some basic math topics were discussed. In 1990, a second tutorial took place in Rhodes (Greece) where special math topics were presented; among these were estimation and prediction problems and optimization. The most recent tutorial, organized before the XVII Congress, took place in Milano (Italy) in 1991. All the tutorials were successful from the scientific point of view and were attended by high profiled participants.

Gottfried Konecny (Germany) - **Space Photogrammetry**

Three key points were addressed: (1) The late Prof. Giovanna Togliatti gave significant contributions to the field of photogrammetry and to the ISPRS, (2) space photogrammetry offers imagery suitable for mapping applications, and (3) the precision of these data are just sufficient for mapping.

Giovanna Togliatti's Memorial Tutorial opened with a description of her life and work in photogrammetric research.

In a second part, an overview was given of the technological advances in space photogrammetry, of its applications in the field of mapping, and of the positioning precisions which can be reached.

F. Rocca (Italy) - **Applications of SAR Interferometry to Digital Terrain Modelling**

Synthetic Aperture Radar can measure differential travel times as well as backscatter. It can be used for telemetry. A DTM obtained with a sensitivity of about 5 m with a spatial resolution of 20 by 20 m is shown. Using successive lenses, we demonstrate the sensitivity to 1-cm (0.01-m) differential terrain motion.

SAR interferometry using the ERS-1 satellite could become a powerful and cheap instrument for digital terrain maps. Land use and differential terrain motion for volcanoes, upwelling landslides, and tectonic plate motion analyses.

Valery Moskalenko (United Nations) - **Teaching Photogrammetry in Developing Countries**

The key points addressed were (1) the United Nations renders its assistance to developing countries in teaching photogrammetry and remote sensing through (a) seminars and courses, (b) scholarships and fellowships, and (c) dissemination of information; and (2) the United Nations considers studies in the situation with respect to education and training in imaging and mapping in the world (including photogrammetry and remote sensing). Though there is a specialized unit in the U.N. system completely devoted to education and training in the field of photogrammetry and remote sensing, education and training in the field of imaging and mapping, including photogrammetry and remote sensing, have always been an important part of the United Nations Activity.

Luigi Mussio (Italy), A. de Haan - **Mathematical Aspects of Digital Photogrammetry**

Three key points were addressed: (1) Digital photogrammetry: description of object (shape, color, meaning) from digital images; (2) the relatively simple image-to-image matching techniques only use part of the information in the image; and (3) more complete modeling involves models for camera, object shape, object reflectance, and illumination.

In digital photogrammetry, the pixel light intensity counts are directly available to the computer for automatic or operator assisted elaborations. This opens the way for the development of mathematical models that directly link the pixel intensity values to the object description. Such models should include a description of the camera, the object shape, object reflectance, and illumination.

H. Ebner (Germany), C. Heipke - **Digital Photogrammetric Work-Stations**

Three key points were addressed: (1) Digital photogrammetry, (2) performance of digital photogrammetric workstations today; and (3) potential of digital photogrammetric workstations.

Digital photogrammetry has become a focus of research. The tools for handling digital data are called digital photogrammetric workstations (DPWS). These are on the verge of replacing analytical plotters. The state-of-the-art of these DPWS is presented, its and components are listed. In addition to a practical example for working with DPWS, a classification of these workstations is given.

Armin Gruen (Switzerland) - **Digital Close-Range Photogrammetry**

Three key points were addressed: (1) Digital close-range photogrammetry has to be seen in the context of a robot vision system ("multi-eye measurement robot"); (2) with standard hardware components, an accuracy of 1:50,000 can be achieved under operational conditions; and (3) algorithmic advancements are needed in order to promote digital photogrammetry further in the case of non-targeted object applications.

System aspects: A digital close-range system consists of a variety of components for image acquisition, preprocessing, recognition/localization, positioning, and information extraction. The performance of the system depends on its weakest component. Therefore, a good adjustment and balancing of its components is crucial.

Data acquisition: In addition to "industrial" CCD cameras, regular TV-cameras and still video cameras are of great interest; they come with a viewfinder and local storage devices.

The "multi-eye measurement robot": A new and necessary approach to digital close-range systems and tasks. Emphasis is on dynamic data acquisition (image sequences), processing of more than two frames

simultaneously, and use of a general concept, including object tracking, egomotion, object reconstruction, etc.

Current accuracy of CCD-based systems with off-the-shelf components: 1:50,000, but needs sophisticated systematic error modeling. Not all sources for systematic errors are fully explored yet. Further improvement in accuracy is possible, in particular, through the use of longer CCD chips or chip arrays.

Algorithmic advancements: Multi-photo, geometrically constrained matching has proved very successfully. Extension/modifications of this technique towards the high accuracy measurement of material (non-targeted) object features are being developed. First results with an edge measurement approach are very encouraging.

Pilot projects/typical applications: Measurement of turbulent flow, surface reconstruction of cars and airplane patches, 3D trajectories of a walking person, crash car measurement, and architectural photogrammetry.

Conclusions: Digital photogrammetric techniques and systems are available, and their successful utilization has been shown. Their use will increase dramatically in the near future. New application fields will be added. For the external user (non-photogrammetrists), more robust systems with sophisticated user-interfaces are needed. Research should focus on algorithmic advancement with the aim to be able to process less structured images. Object oriented techniques, e.g., supported by CAD models, are crucial.

Future concepts should be based on an image sequence approach, considering the dynamic nature of data acquisition.