Camera Calibration for a Robust Omni-directional Photogrammetry System

Fuad Khan[1], Michael Chapman[2], Jonathan Li[3]

[1]Immersive Media Corporation Calgary, Alberta, Canada
[2]Ryerson University Toronto, Ontario, Canada
[3]University of Waterloo, Waterloo, Ontario, Canada.

Abstract

Immersive Media's Telemmersion® system is a multi-view imaging system that captures high-resolution full-motion 360o omni-directional images from synchronized cameras arranged in a dodecahedron.

This paper describes transformation of the resultant imagery from aesthetically pleasing blended mosaics to mathematically rigorous projections through camera calibration. Specifically, we describe our approach to camera calibration as it relates to panoramic image construction, stereo-photogrammetry, and augmentation of the immersive environment with 3D content.

Background

Immersive Media has been producing advanced omni-directional imaging systems based on a patented dodecahedral design since 1994. With twelve symmetrical pentagonal facets, the dodecahedron is the most natural geometric division of a sphere for immersive image capture. It offers symmetrical, standardized divisions of the sphere that utilize the most of the image produced by each lens, produce even resolution in every direction, and allow for better blending of the images. The camera system comprises a Dodeca camera and a dedicated base unit for camera control, image storage, and integration with GPS and GPS-aided inertial navigation systems. We have extended the immersive experience to include modeling and interaction with 3D environments and data by combining a rigorous approach to camera calibration with high accuracy direct camera pose determination.

Interior Orientation

Each of the 11 component cameras comprising the Dodeca camera (Figure 1) is calibrated to determine orientation parameters and relative pose. A calibration target array comprising 50 coded surveyed targets is used to generate calibration images. The calibration targets are arranged such that targets are simultaneously visible to adjacent sensors. Images are simultaneously collected on all sensors as the camera is rotated and translated through a calibration rig.

Intrinsic and extrinsic parameters are determined in two-stage least-squares self-calibrating bundle adjustments using a common set of images. Camera characteristics (principal point offsets and distortion parameters) are determined for each sensor independently in the first stage.

In the second stage, sets of adjacent images (captured simultaneously) are processed in a bundle adjustment to determine relative position and orientation. Image sets in the second stage are constrained by weight-constrained relative pose using the knowledge that they were acquired simultaneously in a geometrically rigid body.

Figure 1: Immersive Media Dodeca 2360 omni-directional camera

Camera Model

The multi-view Dodeca camera produces sets of synchronized images from component cameras which are combined into an omni-directional panoramic image. Camera calibration is conceptually divided into interior orientation and exterior orientation of the component sensors and a virtual camera abstracted from the view blending process that creates the panoramic image. The field of view for individual Dodeca lenses is significantly larger than that for cameras used in conventionally photogrammetry and machine vision applications. The wide constant angle curvature of these lenses presented a calibration challenge that required a non-standard camera model. Both generalized harmonic models and finite element models were found to be appropriate for camera characterization. A harmonic model was ultimately chosen based on re-projection accuracy and stability criteria. A high precision navigation system is employed to determine exterior orientation. However, an exterior calibration is required to align the camera reference frame to the vehicle reference frame and the individual camera elements to each other.

Panoramic Image Construction: Stitching

Panoramic images are constructed from individual sensor images though stitching. In essence, pixels from individual cameras are projected onto a 3D surface to construct a single panoramic image (see Figure 2). The final image is then re-projected into a flattened equi-rectangular image so that it can be stored in conventional media formats (e.g. JPEG, AVI, and Windows Media). A panoramic image viewer projects the flattened image onto a 3D mesh from which the viewer can interactively chose a particular field of view (see Figure 3). While a perfect panoramic imaging system would approximate a point source, in practice the inter-sensor spacing is non-zero. As a result, a parallax correction must be made in stitching to properly blend the images from adjacent sensors.

Figure 2: Stitched panoramic image with lines connecting sensor focal points superimposed.
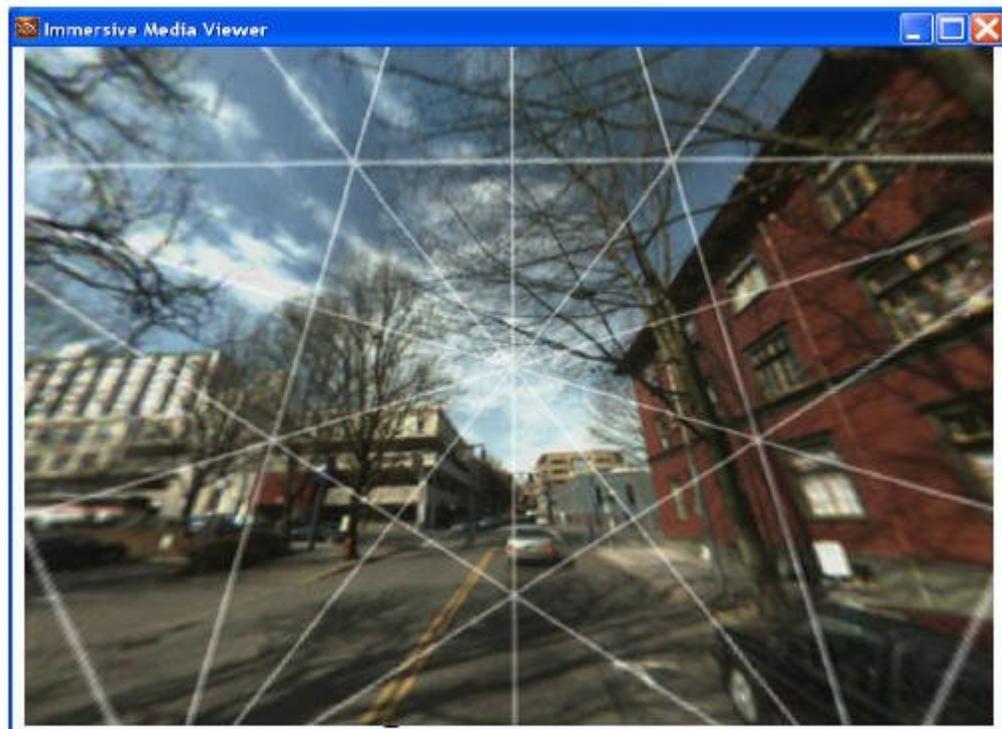

Figure 3: Panoramic Image Viewer

For aerial recording applications, a spherical convergence surface with a radius of approximately 6m is used. For terrestrial recording applications an ovoid surface is used to optimize parallax at relatively close range for objects near the ground and further at higher elevations (see Figure 4).
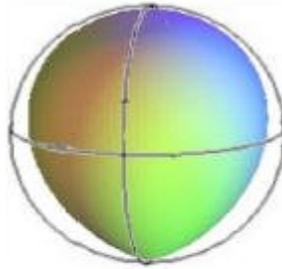
Figure 4: Ovoid convergence surface for stitching ground-level images

Exterior Orientation

Data collection vehicles are equipped with high-performance GPS-aided inertial navigation systems (see Figure 5) which enable direct determination of camera pose. The navigation system generates a tightly-coupled Kalman-filtered position and orientation solution by combining a GPS sensor, fiber-optic gyroscope and wheel rotation encoder. Exterior orientation parameters, consisting of a set of 3 lever arms and angular offsets, are determined through a bundle adjustment where vehicle position and orientation are fixed. An outdoor calibration field of 30 targets is used for exterior calibration.

Photogrammetry: Feature extraction and augmentation

Single-frame and stereo measurements from manual registration of features have been implemented. Images from individual sensors or stitched panoramic images can be used to construct stereo pairs. The high-performance navigation system produces sub-meter absolute accuracy and sub-centimeter relative accuracy. Highly accurate baselines allow a single camera to be used for stereo photogrammetry by utilizing temporal base pairs, rather than multiple cameras. Measurements across multiple sensors are possible because the sensors are synchronized and calibrated.
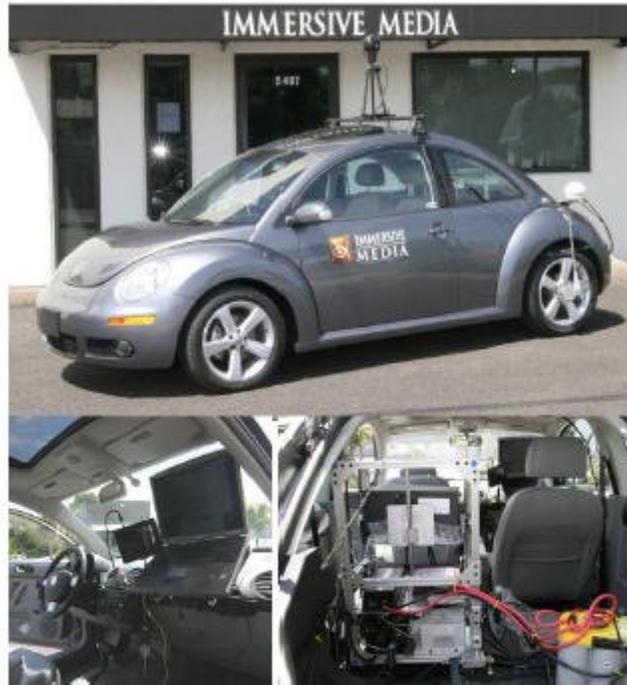
Figure 5: Telemmersion® data collection vehicle with Applanix POS/LV 200 navigation system

The calibrated panoramic environment can be readily augmented with geo-referenced content since the problem of rendering 3D objects into a panoramic scene requires the same data as photogrammetry but is much less complicated. Figure 6 illustrates insertion of traditional GIS data into calibrated GeoImmersive imagery captured at street level. Large-scale calibrated, georeferenced Immersive environments provide unique opportunities in photogrammetry, interactivity, and fusion of data from 2D and 3D sources. Immersive Media and its partners are actively leveraging and extending conventional photogrammetry tools to develop novel applications in a number of areas, including asset management, situational awareness, and mobile mapping.

Figure 6: An augmented immersive image. The fire plug is a virtual geo-referenced object inserted into the scene.

Conclusions

The development of multi-use sensors will increase the versatility of the mobile mapping platforms. An omni-directional camera that has undergone a rigorous camera calibration offers the possibility of a compact imaging system that has the capabilities of other more space-consuming systems. Through the integration of a high-precision geo-referencing system, the system is capable of producing high accuracy 3D coordinates of features along with their attributes. The use of real-time digital signal processing hardware facilitates the display of rectified and geo-referenced imagery to the user during data capture. The immersive characteristics of this system make it particularly attractive for asset management and surveillance applications as well as those associated with traditional mobile mapping. The fusion of this data source with other sensor data, such as airborne data, suggests many other possibilities.

Bibliography

Bakstein, H. and Pajdla, T. (2002) .Panoramic Mosaicing with a 180 degree Field of View Lens., Proc. IEEE Workshop on Omni-directional Vision, pp. 60-67.

Claus, D. and Fitzgibbon, A. W. (2005) A rational function lens distortion model for general cameras., Proc. CVPR, pp. 213-219.

Kannala, J. and Brandt, S. (2004) *A generic camera calibration method for fish-eye lenses.* In: proceedings 17th International Conference on Pattern Recognition (ICPR 2004), pp. 10-13.

Kumler, J.J., Bauer, M. (2000) *Fisheye lens designs and their relative performance.* In: Proceedings of the Lens and Optical System Design and Engineering Conference of the SPIE Annual Meeting.

Micusik, B. and Pajdla, T. (2003) Estimation of omnidirectional camera model from epipolar geometry. Proc. CVPR, pp. 485-490.

Schneider, D., Schwalbe, E. (2005*) Design and testing of mathematical models for a full-spherical camera on the basis of a rotating linear array sensor and a fisheye lens.* In: proceedings of 'Optical 3D Measurement Techniques VII', Eds.: Grün, A.; Kahmen, H., Vol.1, pp. 245-254.

Schwalbe, E. (2005) *Geometric modelling and calibration of fisheye lens camera systems.* Proceedings 2nd Panoramic Photogrammetry Workshop, Int. Archives of Photogrammetry and Remote Sensing, Vol. 36, Part 5/W8.

Shah, S. and Aggarwal, J. (1996) Intrinsic parameter calibration procedure for a (high-distortion) fish-eye lens camera with distortion model and accuracy estimation., Pattern Recognition, 29(11), pp.1775-1788.

Thirthala, S. and Pollefeys, M. (2005) Multi-view geometry of 1D radial cameras and its application to omni-directional camera calibration., Proc. ICCV, pp. 1539-1546.

Zhang, Z. (2000) A Flexible new technique for camera calibration. TPAMI, 22(11), pp. 1330- 1334.