CALIBRATION OF MULTI-CAMERA PHOTOGRAMMETRIC SYSTEMS

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ABSTRACT:

Photogrammetric reconstruction systems often include multiple cameras. Having a correct system calibration is essential for accurate object point determination. This is especially crucial for direct sensor orientation in mobile mapping applications, dense image matching for full surface/object reconstruction, long-term infrastructure monitoring, biomedical and motion-capture metric applications.

The calibration parameters for a multi-camera photogrammetric system include the interior orientation parameters (IOPs) and the mounting parameters for each involved camera relative to a body frame or a reference camera. The IOPs should ideally be estimated prior to any data collection campaigns. However, in the case when a system consists of many cameras and/or disassembling them from the platform is not desirable, the IOP estimation must be done in-situ or on-the-job. The challenge of such an IOP calibration approach is to guarantee adequate network geometry. For example, multi-station convergent images with a good base-to-depth ratio and sufficient tie points which are distributed evenly within the image format. This network configuration can be simulated by translating and rotating a portable test field, while keeping the camera system in place. Assuming that the mounting parameters are defined to be relative to a reference camera, they consist of the lever arm/spatial, r, and the boresight/rotational, R, offsets between the different cameras and the reference one. There exist two-step and one-step procedures for estimating the mounting parameters.

The two-step procedure first estimates the exterior orientation parameters (EOPs) for the different cameras through a conventional bundle block adjustment based on the collinearity equations (see equation (1)). The mounting parameters are then derived from the EOPs using equations (2) and (3). At the end, the resultant time-dependant mounting parameters can be averaged, and their standard deviations can be computed.

$$r_I^m = r_{c_k}^m(t) + \lambda R_{c_k}^m(t) r_i^{c_k}(t) \tag{1}$$

$$r_{c_k}^{c_r}(t) = (R_{c_r}^m(t))^{-1}(r_{c_k}^m(t) - r_{c_r}^m(t)) \tag{2}$$

$$R_{c_k}^{c_r}(t) = (R_{c_r}^m(t))^{-1} R_{c_k}^m(t) \tag{3}$$

The one step procedure is usually based on constrained equations, which enforce an invariant geometrical relationship between the cameras at different observation epochs. For example, if the number of cameras involved in the system is n_k, and the number of observation epochs is n_t, then the total number of EOPs is $6n_k n_t$. Assuming that the lever arm and boresight components are not changing over time, the number of constraints that can be introduced is $6(n_k - 1)(n_t - 1)$. Thus the number of independent parameters that define the EOPs of the different cameras at all the observation epochs is $6(n_k - 1) + 6n_t$. The downside of using such relative orientation constraints is that the complexity of the implementation procedure intensifies with the increase of the number of cameras in the system and the number of observation epochs. In this paper, a single-step procedure is utilized which directly incorporates the relative orientation constraints among all cameras and the body frame/reference camera in the collinearity equations. (see in equation (4)).

$$r_I^m = r_{c_r}^m(t) + R_{c_r}^m(t) r_{c_k}^{c_r} + \lambda R_{c_r}^m(t) R_{c_k}^{c_r} r_i^{c_k}(t) \tag{4}$$

The mounting parameters, $r_{c_k}^{c_r}$ and $R_{c_k}^{c_r}$, are now time-independent, and the EOPs of the reference camera, $r_{c_r}^m(t)$ and $R_{c_r}^m(t)$, now represent the EOPs of the system platform. This model preserves its simplicity regardless of the number of cameras or the number of observation epochs. It should be noted that instead of solving for $6n_k n_t$ EOP unknowns, the adjustment will solve for $6n_t$ EOPs for the reference camera in addition to $6(n_k - 1)$ mounting parameters for the rest of the cameras with respect to the reference camera.

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This is equivalent to the total number of independent parameters that are needed to represent the EOPs of the different cameras at all the data acquisition epochs. The reduction in the number of parameters in the adjustment will also reduce any possible high correlations between the many system calibration parameters. The difference in the bundle adjustment mathematical models described in equations (1) and (4) is visually summarized in Figure 1.

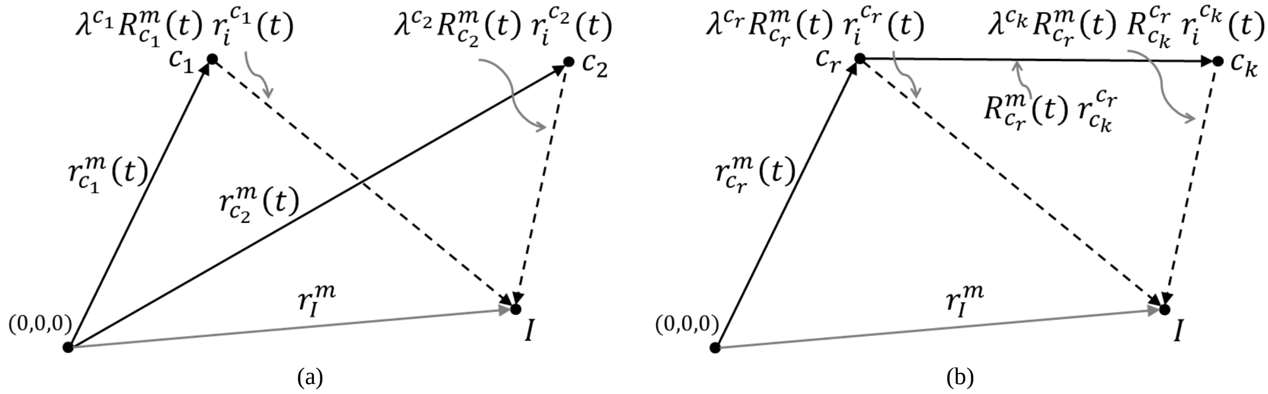

Figure 1: Mathematical model for multi-camera calibration using separate EOPs for each camera station (a) versus using EOPs for a reference camera and ROPs for the rest of the cameras (b)

In order to test the proposed method for system calibration, a close-range multi-camera photogrammetric system (see Figure 2) was set up and will be calibrated in the following manner:

a) Two-step mounting parameter estimation as shown in equations (1), (2) and (3);
b) One-step mounting parameter estimation as shown in equation (4),

where both approaches will be tested with and without prior knowledge of the camera IOPs. The findings from these tests and any recommendations for calibrating multi-camera systems will be reported in the full paper submission.

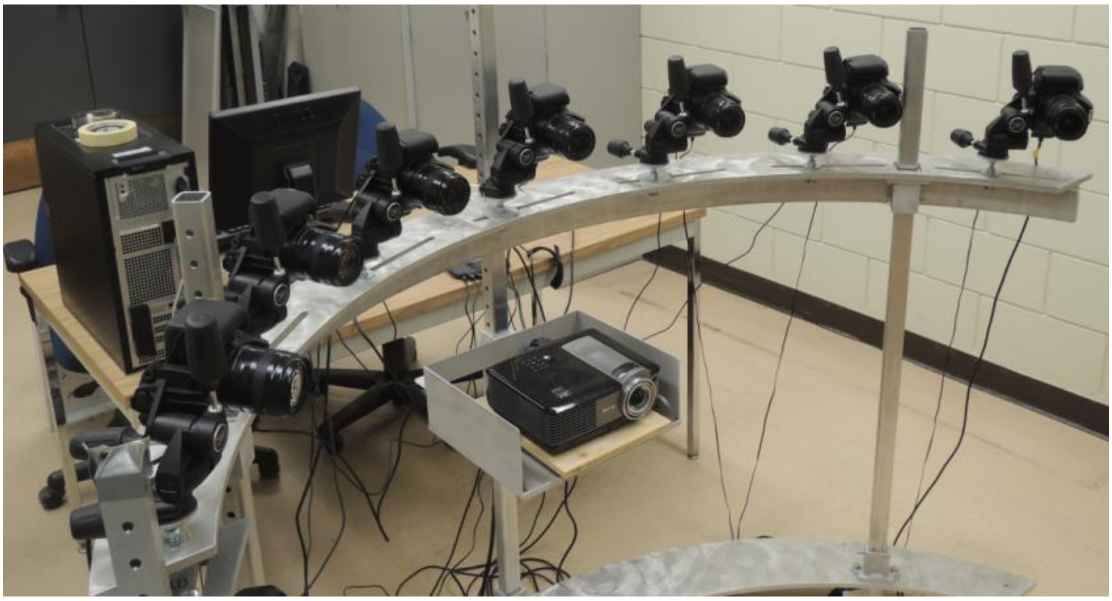

Figure 2: A close-range multi-camera photogrammetric system