Linear Approach for Initial Recovery of the Exterior Orientation Parameters of Randomly Captured Images by Low-Cost Mobile Mapping Systems

F. He [a], * , A. Habib [a]

[a] Department of Geomatics Engineering
University of Calgary,2500 University Drive NW,
Calgary, AB T2N 1N4, Canada – (hef, ahabib)@ucalgary.ca

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ABSTRACT:

Nowadays, 3D modeling of objects can be achieved using either passive or active remote sensing systems. Active sensors, such as laser scanners, are able to directly provide precise and reliable 3D information of scanned objects. However, the derived point cloud usually lacks spectral information (especially when dealing with collected data by mobile platforms). On the other hand, passive sensors, which commonly use digital frame cameras, can be incorporated for 3D reconstruction while providing spectral information of the derived coordinates. Compared to active sensors, the spectral information from passive sensors would allow for the derivation of better and more reliable semantic information pertaining to the reconstructed objects (e.g., the type and condition of mapped objects could be easily derived from the resulting 3D models). Therefore, passive-sensor-based reconstruction still remains the most complete, economical, flexible, and widely-used 3D modelling option in many areas (Remondino and El-Hakim, 2006).

3D reconstruction from digital images captured by passive sensors requires the knowledge of the Interior Orientation Parameters (IOP) of the utilized camera, the Exterior Orientation Parameters (EOP) of the involved images, and the corresponding points/features in the set of overlapping images. The IOP of the utilized camera can be derived from a camera calibration process. The EOP of the involved imagery can be either derived through an indirect geo-referencing procedure using tie and control points or a direct geo-referencing process through the implementation of a GNSS/INS unit onboard the mapping platform. While the latter approach provides practical convenience in terms of simplifying the geo-referencing process, it requires significant initial investment for the acquisition of the GNSS/INS Position and Orientation System (POS) – especially, when seeking high level of reconstruction accuracy. Therefore, significant research efforts have been exerted towards the development of automated procedures for 3D reconstruction and derivation of the geo-referencing parameters of the involved imagery in the absence of a GNSS/INS unit or in the presence of less accurate POS information from consumer-grade GNSS/MEMS units.

As far as the 3D reconstruction is concerned, one of two approaches could be adopted. In the first approach, a two-step procedure is adopted for the 3D reconstruction assuming the availability of prior knowledge regarding the EOP of the involved images. In the first step, corresponding features are identified in the set of available images (i.e., the matching problem). In the second step, the 3D positions of the matched points are derived using a simple intersection procedure that incorporates their image coordinates, IOP of the utilized camera, and the EOP of the involved images (Kraus, 2007). The main drawback of this procedure is the reliance on the availability of highly accurate EOP, which could be only available through the utilization of high-end POS unit. The second approach for 3D reconstruction, which was mainly initiated by the computer vision research community, the feature matching and EOP recovery are simultaneously established. A commonly used procedure in this approach is known as Structure from Motion (SFM), which is based on 3-step strategy. In the first step, the relative orientation parameters relating stero-images or image triplets are initially estimated using automatically identified point and/or line features. Then, a reference coordinate system is established and utilized to define the position and orientation parameters for the involved imagery using the derived relative orientation parameters in the first step as well as 3D coordinates of the matched points. Finally, a bundle adjustment procedure is usually implemented to refine the derived information in the second step (Triggs et al., 2000). Compared to the first approach for 3D reconstruction, SFM is more advantageous since it allows for 3D mapping in the presence or absence of GNSS/INS units.

SfM 3D reconstruction approaches usually use either a sequential or hierarchical approach to initially estimate the EOP of the involved images – the focus of the second step of the above mentioned 3-step strategy – in an incremental manner. For example, Snavely et al. (2006) proposed an incremental SfM procedure, in which images are added one by one into the reference frame. In their method, the reference frame is established from a single pair of images that has a large number of matched points/features and a long baseline. Then, new image is incrementally augmented to the reference frame. The EOPs of the augmented image are estimated using the reconstructed 3D points from the first pair through a Direct Linear Transformation (DLT) procedure. Fitzgibbon and Zisserman (1998) developed a hierarchical approach to recover the EOPs for either closed or open set of acquired images. In this method, trifocal tensors are estimated for all consecutive image triplets. Then, a hierarchical approach is applied to gradually integrate the image triplets to subsets. Finally, these subsets are augmented into a single block. For either the sequential and hierarchical approaches, intermediate bundle adjustment – which is time consuming – is implemented to ensure successful

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[*] Corresponding author. This is useful to know for communication with the appropriate person in cases with more than one author.

augmentation of the individual images into the final image block. Other than the expensive intermediate bundle adjustment, current incremental SfM methods suffer from severe error propagation during the sequential image augmentation process. Therefore, some global methods have been developed to simultaneously establish the EOPs for all the available images. Martinec and Pajdla (2007) developed a two-step global method to solve for the EOPs of the images. First, they determine the rotational component of the EOPs of the images. Then, the spatial component of the EOPs is estimated in the second step. However, this two-step approach cannot deal with images that have been captured from an almost linear trajectory – those images will be denoted here forth as linear-trajectory images. Jiang et al. (2013) proposed another two-step global linear method for the estimation of EOPs of available images. To handle linear-trajectory images, they use the baseline/depth ratios from neighboring stereo-pairs for the image augmentation process. However, the estimated baseline/depth ratios may not be accurate.

In this paper, we present an alternative incremental approach for initial recovery of the EOPs of the involved imagery, which have been captured by a calibrated camera – i.e, a camera with known IOP. The proposed method has the following characteristics:

1. It is based on a linear approach for the estimation of the relative orientation parameters among the available stereo-pairs as well as the sequential estimation of the rotational and positional components of the EOPs for the images during the incremental augmentation process,
2. The sequential augmentation is based on augmenting images that exhibit the best compatibility with previously referenced images,
3. It can handle a set of randomly collected image set (i.e., it does not assume any prior knowledge regarding the sequence of the image collection procedure). This would be advantageous in dealing with images that have been captured from different campaigns,
4. It can handle images which have been captured in a block or linear trajectory configuration, and
5. A built-in mechanism is implemented to exclude images with erroneously estimated relative orientation parameters.

The proposed procedure is conducted according to the following sequence:

1. For the given images, we establish the relative orientation parameters (ROPs) for all the stereo-pairs using the SIFT operator for the identification of corresponding points in these images (Lowe, 2004). The ROPs are derived first using a linear approach that establish the essential matrix relating the overlapping images (Nistér, 2004) and then refined through the coplanarity constraint (Mikhail et al., 2001).
2. A reference frame is established using an image triplet that satisfies both good geometric configuration and a large number of matched points. These conditions are evaluated through a score value, which has been developed by He and Habib, 2014.
3. The rotational component of the EOPs for the remaining images are estimated using a quaternion-based linear approach similar to the one suggested by Martinec and Pajdla, 2007. Rather than randomly selecting an image for the augmentation process, the image that exhibit the highest compatibility with previously referenced imagery is selected from the available images through a reverse-tree-graph-based approach (Martinec and Pajdla, 2007).
4. The positional component of the EOPs for the remaining images is estimated using a linear approach. Similar to the previous step, the image that exhibit the highest compatibility with previously referenced imagery is selected from the available images through a reverse-tree-graph-based approach. This step is designed to handle images captured either in a block or linear trajectory configuration.
5. Throughout the above steps, an outlier removal procedure is implemented to exclude images with erroneously estimated relative orientation parameters, which might occur due to the presence of repetitive structure within these images and/or poor texture.

Preliminary Results:

To illustrate the feasibility of the proposed procedure, we conducted several tests on real datasets that have been captured in different configurations. Figure 1 illustrates sample images of an image block that have been captured by a low-cost amateur UAV, which is shown in Figure 2.

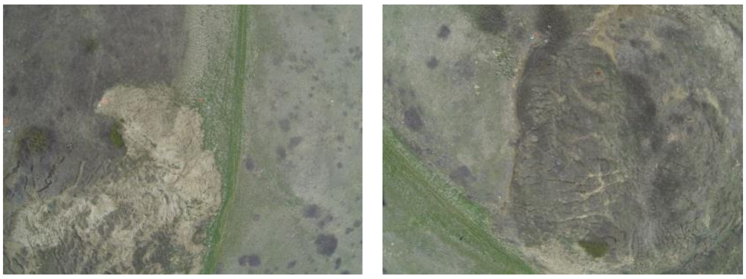

Figure 1. Sample images of the image block

Figure 2. The small DJI Phantom 2 UAV drone with GoPro camera mounted

The outcome of the proposed methodology reveals that it can provide accurate and robust estimation of the image orientation parameters. Figure 3 shows both the position and orientation of the diffferent images together with the derived points, which have been used for the relative orientation and scene reconstruction.

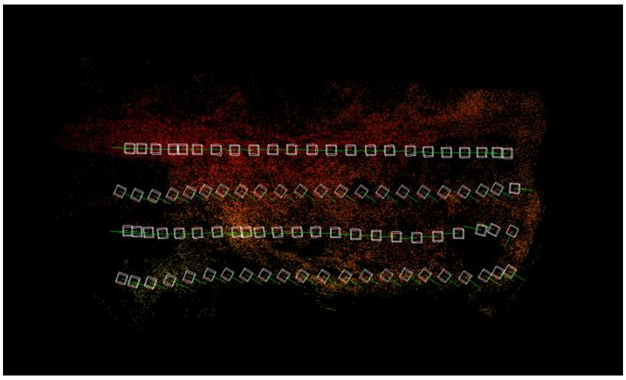

Figure 3. Sparse point cloud and image position/orientation for the different images within the block that has been captured by the UAV in Figure 1

References

Fitzgibbon, A.W., Zisserman, A., 1998. Automatic camera recovery for closed or open image sequences, in: Computer Vision—ECCV’98. Springer, pp. 311–326.

He, F., Habib, A., 2014. Automatic orientation estimation of multiple images with respect to laser data. Presented at the ASPRS 2014 Annual Conference, Louisville, USA.

Jiang, N., Cui, Z., Tan, P., 2013. A Global Linear Method for Camera Pose Registration, in: Computer Vision (ICCV), 2013 IEEE International Conference on. IEEE, pp. 481–488.

Kraus, K., 2007. Photogrammetry: geometry from images and laser scans. Walter de Gruyter.

Lowe, D.G., 2004. Distinctive image features from scale-invariant keypoints. Int. J. Comput. Vis. 60, 91–110.

Martinec, D., Pajdla, T., 2007. Robust rotation and translation estimation in multiview reconstruction, in: Computer Vision and Pattern Recognition, 2007. CVPR’07. IEEE Conference on. IEEE, pp. 1–8.

Mikhail, E.M., Bethel, J.S., McGlone, J.C., 2001. Introduction to modern photogrammetry. John Wiley & Sons Inc.

Nistér, D., 2004. An efficient solution to the five-point relative pose problem. Pattern Anal. Mach. Intell. IEEE Trans. On 26, 756–770.

Remondino, F., El-Hakim, S., 2006. Image-based 3D Modelling: A Review. Photogramm. Rec. 21, 269–291.

Snavely, N., Seitz, S.M., Szeliski, R., 2006. Photo tourism: exploring photo collections in 3D. ACM Trans. Graph. TOG 25, 835–846.

Triggs, B., McLauchlan, P.F., Hartley, R.I., Fitzgibbon, A.W., 2000. Bundle adjustment—a modern synthesis, in: Vision Algorithms: Theory and Practice. Springer, pp. 298–372.