Assessment of Different GNSS and IMU Observation Weights on Photogrammetry Aerial Triangulation

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Key words: observation weight, direct georeferencing, aerial triangulation, block adjustment

SUMMARY

Nowadays, the Global Navigation Satellite System (GNSS) and Inertial Navigation System (INS) are playing a prominent character in high accuracy navigation applications. Beside camera calibration and tie points which are crucial, GNSS shift and drift errors, which caused by either unknown GNSS antenna-eccentricity, atmospheric effect, GNSS and INS observation qualities, unsolved datum correction between coordinate systems and far away GNSS reference stations from the project area, are important factors in bundle block adjustment ultimate accuracy. In this study, the influence of different a priori observation uncertainties of GNSS and Inertial Measurement Unit (IMU) using block- Aerial Triangulation (AT) method is examined. We investigate the effect of IMU and GNSS uncertainties on the final AT results using Trimble Inpho Match-AT software by evaluating the checkpoints RMS residual and employing a statistical t-test for determining the number of images with the gross error. In our study area, the most trustworthy observation uncertainties was 0.2, 0.2, 0.2 meter for East, North, and Height of the GNSS components respectively, and 0.007, 0.007, 0.009 for Omega, Phi, and Kappa for the IMU orientations, respectively.

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1. INTRODUCTION

The Exterior Orientation Parameters (EOPs) determination is the most crucial task within the photogrammetric processing sequence, but nowadays by technologies progression, sensor orientation is attainable in different alternatives. Not only the EOPs are attainable by traditional Aerial Triangulation (AT) which need ground control points but also the EOPs can be achieved directly by integrated Global Navigation Satellite Systems (GNSS) and Inertial Measurement Unit (IMU), known as Direct Georeferencing (DG) (Rizaldy and Firdaus, 2012). High-accurate EOPs would be achieved when the GNSS and IMU observation are integrated properly in order to remove some noises and errors using integration methods (Du et al., 2018). IMU itself has some errors therefore a low-pass filter is required for removing noises of accelerometers and a high-pass filter for removing the cumulative errors of the gyroscope (Jouybari et al., 2019).

Traditional AT will become out-of-date if the EOPs are obtained directly with sufficient accuracy and if there is no error in the calibration of the multi-sensor system (i.e. integration of GNSS, IMU and imaging sensor, Cramer 1999). The DG has three prominent privileges rather than applying the traditional AT: shorter time for data processing, mild workflow and lower-cost project at the same accuracy (Pfeifer et al., 2012).

With the progression of digital photogrammetry and the advent of commercial software, the AT becomes more and more automatic. The operator just needs to measure the GCPs and some tie points on the images, henceforth the EOPs calculate automatically. The measurement accuracy of tie points in an ideal situation can be between 0.15 and 0.2 of pixel sizes. The Automatic Aerial Triangulation (AAT) accuracy still depends on the forward and lateral overlap, distribution of GCPs, and the accuracy of EOPs for use in AAT process.

Generally, the GCPs distribution should be configured every third base length for horizontal control points and fifth base length for height control points in a block without GNSS observation with 60% and 20% forward and lateral overlaps, respectively. The more GCPs are used, the higher reliability of AT is achieved (i.e. AT is not feasible using just one GCP). Residuals uniformly distribute due to using GCPs in the corner of the block. If images overlap increase, the IMU measurements impact on AT decrease and block stability increase. However, the use of the GCPs can be eliminated by using more accurate IMU measurements in the AT process.

In this paper, the impact of various GNSS and IMU uncertainties, i.e. different weight matrix, on the AT calculation would be investigated. The GNSS shift and drift errors, which, is, consist of two constant (shift) and linear (drift) errors are evaluated by examining the checkpoints RMS of residuals in block-wise method and the number of image rejection by exerting a statistical hypothesis test. The number of rejected images, using the statistical test, show how suitable the assigned weights are.

2. METHODOLOGY

The purpose of this study is to declare which GNSS/IMU observation uncertainties are the best for aerial triangulation in the study area. Therefore, the statistical t-test is used for finding the gross error due to assigning optimistic or pessimistic observation uncertainties in the AT process. The t-test examines two estimates that are from the same component. The two estimates typically represent two different times (e.g. pre-processing and post-processing with an intervention between the two-time points). Generally, a t-test statistic can be written as follows:

$$t_{obs} = \left| \frac{\hat{\mathbf{L}} - \mathbf{L}}{u(\hat{\mathbf{L}} - \mathbf{L})} \right| \leq t_{n-1,\alpha/2} \tag{1}$$

where:

$$u(\hat{\mathbf{L}} - \mathbf{L}) = \sqrt{u^2(\hat{\mathbf{L}}) + u^2(\mathbf{L})} \tag{2}$$

In Eqs. (1) and (2), $\hat{\mathbf{L}}$ is the EOPs of images projection center after AT and $\mathbf{L}$ is the EOPs of images projection center before the AT (i.e. obtained from GNSS and IMU observations). Also $u(\hat{\mathbf{L}})$ and $u(\mathbf{L})$ are their corresponding uncertainties. It is assumed that the images projection center measured infinite times and one can assess that if any of the observations is not acceptable at α=5% significance level (risk level) with n-1 degrees of freedom. Thus, if $|t_{obs}| > 1.96$, there would be a gross error in each image projection center after the AT.

3. STUDY AREA AND DATA

The test data collected on July 8, 2018 over the test area Gothenburg, in southwest part of Sweden. The data collected by Lantmäteriet, the Swedish mapping, cadastral and land registration authority, in the form of a photogrammetry block of the large area with 0.25 m ground sample distance (GSD). The test field size is approximately 75 × 90 km² with 25 strips, 1198 images, 18 full control points, 28 vertical control points, 11 horizontal checkpoints, and 19 vertical checkpoints, which their accuracy is better than 5 cm (see Fig. 1). The aircraft was flown with 3700 meters altitude and had 60% and 25% forward overlap and lateral overlap, respectively.

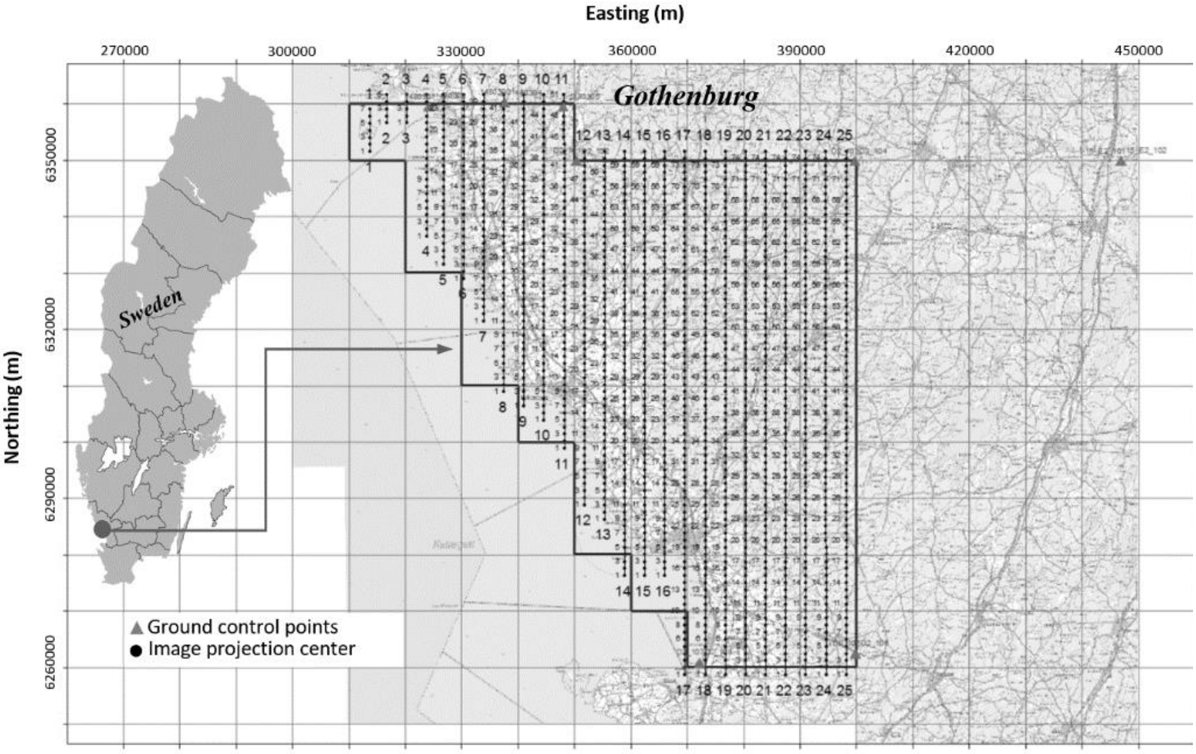

FIG. 1. A glimpse of test area with scale: 1:503000. Coordinates are in SWEREF99 TM reference system.

4. RESULT

The checkpoints Root Mean Square (RMS) of residual is calculated in a block-wise methods for GNSS shift and drift errors for various GNSS and IMU observation uncertainties using Trimble Inpho Match-AT software, Trimble (2015). We considered observation uncertainty of IMU and GNSS observations between 0.001° -0.009° with 0.001° interval for each step and between 0.04-0.36 m with 0.04 m interval for each step, respectively. Two scenarios built for testing the checkpoints RMS of residuals in height component for block-wise method. In the first scenario, the observation uncertainty of IMU data vary between 0.001° - 0.009° while the uncertainties of GNSS data are assumed constant according i.e. 0.2 m, 0.2 m, 0.2 m for E, N, and H, respectively. In the second scenario, the observation uncertainty of GNSS data vary between 0.04-0.36 m and while for IMU are assumed constant i.e. 0.003° , 0.003° , 0.007° and for ω, φ and κ respectively.

Here we use the statistical t-test that explained in Eqs. (1) and (2). Accordingly, in this step, the number of rejected images and RMS residual of checkpoints has been reviewed for all uncertainties in the block-wise method. Table 1 shows the most reliable, less reliable observation uncertainties in terms of RMS residual checkpoints and the number of image rejection using the statistical t-test. The results are also visualized in Fig. 1.

Table 1. The number of image rejection and checkpoints RMS of some best case, worst case for observation`s uncertainties.

Observation uncertainty			
GNSS (m)	**IMU (degree)**		
u(E), u(N), u(H)	***u(ω), u(φ), u(κ)***	**Total image rejection**	**RMS Residual check Points (m)**
0.2, 0.2, 0.2	0.007, 0.007, 0.009	1	0.157
0.2, 0.2, 0.2	0.006, 0.006, 0.008	2	0.158
0.2, 0.2, 0.2	0.008, 0.008, 0.002	538	0.151
0.2, 0.2, 0.2	0.003, 0.003, 0.007	95	0.168
0.2, 0.2, 0.2	0.001, 0.001, 0.001	2007	0.184
0.2, 0.2, 0.2	0.001, 0.001, 0.009	1195	0.192
0.08, 0.08, 0.08	0.003, 0.003, 0.007	75	0.157
0.04, 0.04, 0.04	0.003, 0.003, 0.007	80	0.157
0.12, 0.12, 0.12	0.003, 0.003, 0.007	85	0.160
0.2, 0.2, 0.2	0.003, 0.003, 0.007	95	0.168
0.36, 0.36,0.2	0.003, 0.003, 0.007	103	0.177
0.36, 0.36, 0.36	0.003, 0.003, 0.007	105	0.181
0.08, 0.08, 0.08	0.007, 0.007, 0.009	8	0.154

According to the presented outcomes in Table 1 and Fig. 2, the best observation weights are 0.2, 0.2, 0.2 m for GNSS observation uncertainty and 0.007°, 0.007°, 0.009° for IMU by considering two criteria i.e. the least RMS residual of checkpoints and minimum number of images with gross error i.e. with just one image rejection. However the 0.02, 0.02, 0.02 m for GNSS observation uncertainty and 0.006°, 0.006°, 0.008° for IMU observation uncertainty has approximately same accuracy.

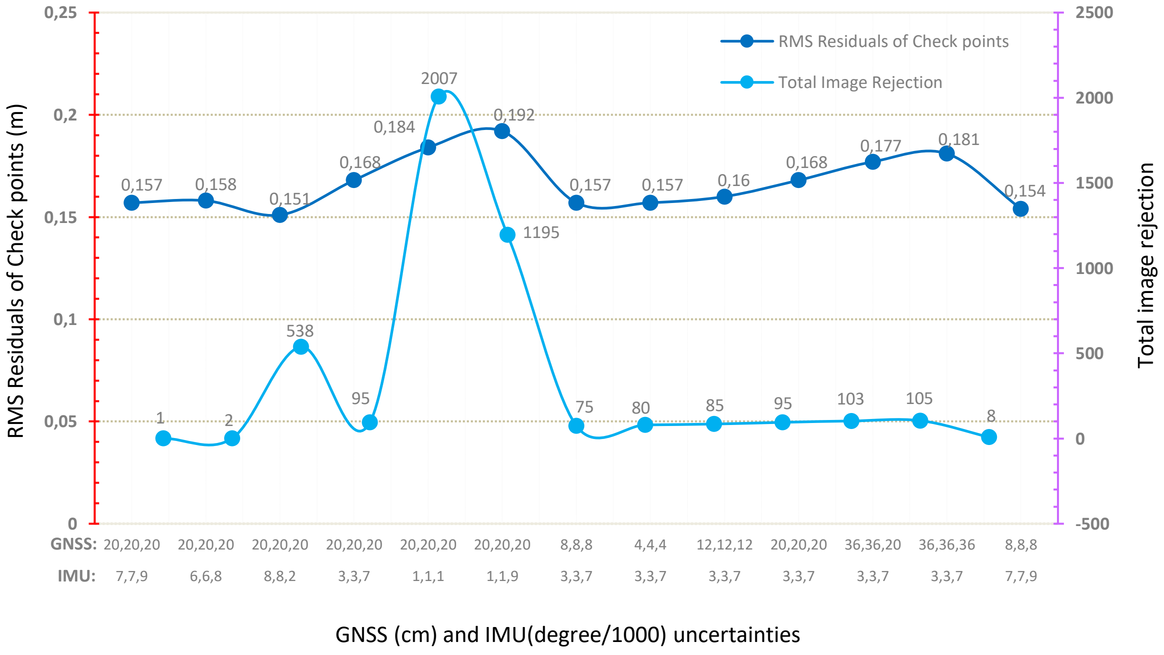

Fig. 2. RMS residuals of check points and the total image rejection for each GNSS and IMU uncertainties

5. CONCLUSION

In this paper different GNSS and IMU observation weights on photogrammetry AT assessed. Furthermore, statistical t-test on different observation uncertainties explicates that 0.2, 0.2, and 0.2 m for E, N, and H and 0.007, 0.007, and 0.009 for ω and φ and κ, respectively are the best observation weight values for calculating AT, via fewer number of rejected images and smaller RMS residual of checkpoints.

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BIOGRAPHICAL NOTES

Arash Jouybari has graduated with a M.Sc. in geomantic engineering in the field of Geodesy-Hydrography from University of Tehran, Iran in 2017; M. Sc. Thesis was "Field calibration of GPS/INS navigation systems". In addition, he has B.Sc. in Geomatics Engineering. He had been an instructor at the University of Applied Science and Technology, Tehran from 2015 to 2017. He is currently a Ph.D. student in University of Gävle.

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