Quality of GPS/IMU data in a combined block adjustment of large scale images

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Abstract

The Dutch Survey Department of Rijkswaterstaat produces highly accurate Digital Elevation Models (DEMs) and Digital Topographic Databases (DTBs). This paper deals with airborne GPS/IMU integration during acquisition of aerial images with an image scale of 1:4000. These images are used for the production of DTBs. Since DTB objects meet accuracy requirements of 5 cm horizontally and 9 cm vertically, the exterior orientation parameters have to be known with high accuracy. Comparisons are made between conventional AT and GPS/IMU supported triangulation. Results show systematic effects in differences between direct and indirect sensor orientation. It can be concluded that using GPS/IMU and only 10 % of the number of GCP's, will lead to a small decrease of geometric accuracy. Besides data analysis, information analysis is carried out to find causes and solutions of remaining GPS/IMU problems.

1. Introduction

The Dutch Survey Department of Rijkswaterstaat produces highly accurate Digital Elevation Models (DEMs) and Digital Topographic Databases (DTBs). Along with the acquisition of these products the Survey Department has gathered a lot of experiences with airborne, ship borne and vehicle borne multi sensor integrated data for over five years.
Since DTB objects meet accuracy requirements of 5 cm horizontally and 9 cm vertically, the exterior orientation parameters have to be known with high accuracy. Currently, the aerial images (image scale 1:4000) are georeferenced using signalized ground control points (GCPs). Since maintaining GCPs is time-consuming and expensive the Survey Department tries to reduce the number of GCPs by using GPS/IMU [6].

In [1] it is explained that the integration of the GPS/inertial exterior orientations in a combined AT provides the most flexible approach. This combination allows the control of the whole process by increasing the reliability of the system. Besides this, it gives the possibility for self-calibration of the camera, which is inevitable for highest photogrammetric accuracy demands. Additionally, the misalignment between IMU and camera can be estimated for each image block optimally and long term errors caused by constant shifts in the GPS trajectory are detected and corrected in the adjustment.

In order to switch from a conventional aero triangulation (AT) process to a GPS/IMU supported process, the Survey Department has acquired a number of data sets with normal GCP configuration plus GPS/IMU data. Now it is possible to determine orientation parameters directly and indirectly. Differences between both solutions will be analysed with great care, because one cannot address those differences to GPS/IMU errors only. In earlier projects, it was shown that instead of reducing the number of GCPs, IMU data introduces errors that can only be corrected by a large number of GCPs [4]. The Survey Department decided to continue analyzing new data. Comparisons are made between conventional AT and GPS/IMU supported triangulation. Besides data analysis, information analysis is carried out to find causes and solutions of remaining GPS/IMU problems.

In chapter 2 the results of comparisons between conventional AT and GPS/IMU supported triangulation are shown, followed by a list of remaining GPS/IMU problems in chapter 3. In chapter 4 a near future perspective about applied GPS/IMU supported AT is given. In chapter 5 it is shown that quality is more than geometric accuracy. Conclusions can be found in chapter 6.

2. Practical results

National Park "Biesbosch" is a nature reserve, just south of Rotterdam, see figure 1. The Biesbosch project is suitable for describing the quality of the GPS/IMU data. This project contains 991 images, 20 strips and 430 GCPs.

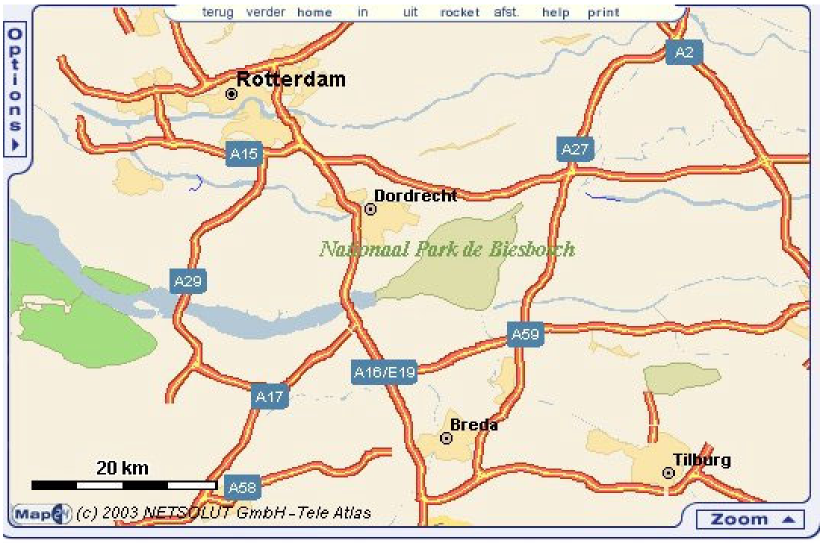


Figure 1: National Park Biesbosch.

A comparison has been made between results of a conventional AT and GPS/IMU supported triangulation using software package Bingo. For every tie point, GCP and projection centre, this comparison shows a certain displacement. Differences should be handled with care, because these differences are only partly caused GPS/IMU errors. Other error sources can be:

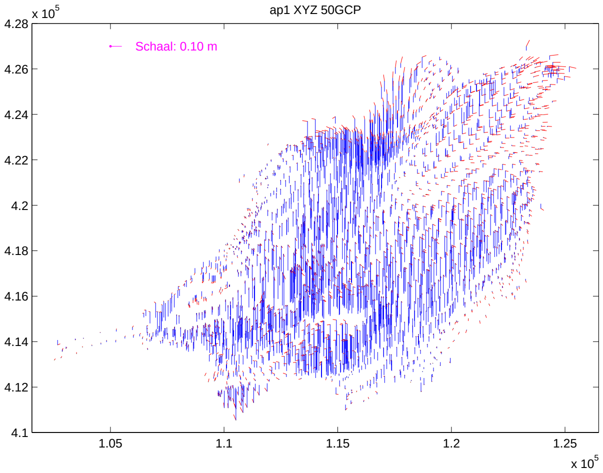
- Lens distortion; estimation of lens distortion parameters depend on input measurements.
- Triangulation accuracy; configuration and measurements of tie points and GCPs.
- Datum parameters; in 2000, the cadastre of the Netherlands introduced a correction grid in order to compensate for discrepancies between the ETRS datum and the local RD datum. Corrections up to 20 cm can occur. Some international flight companies are not familiar with this correction tool, introducing systematic errors in trajectory information when transforming to the local system.
- Model noise (or errors) in software.

Focus is the quality (reliability and accuracy) of the triangulation results, using GPS/IMU plus a certain number of GCPs. In this paper the results are shown for cases using only 10% of the normal number of GCPs, lying near the edges of the block.

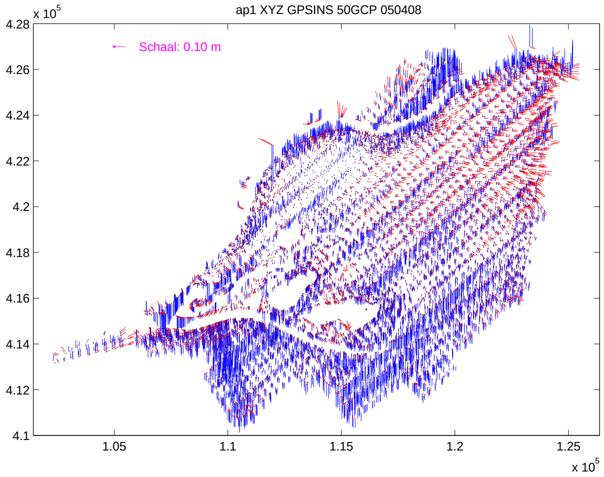
To be able to qualify the GPS/IMU data, a number of datasets of adjusted tie points has been determined by an AT with Bingo:
Set 1: conventional AT results including all GCPs and tie points, without using GPS/IMU.
Set 2: conventional AT performed with only 10% of all GCPs, and all tie points.
Set 3: 10 % of GCPs, all tie points and GPS/IMU data.
Set 4: same as set 3, twice as large a-priori standard deviations of GPS and IMU data.

In the conventional AT it became clear that lens distortions appeared in all images. Normally, these kinds of distortions are calibrated and eliminated by the flight company. Note that this kind of distortion can only be eliminated by the flight company in a calibration procedure, or by estimating these distortions (as additional parameters) using a huge number of GCPs. For the Survey Department, only the latter option could be performed. Lens distortion parameters are estimated in a conventional AT (set 1). Subsequently these parameters have been applied in all triangulations.

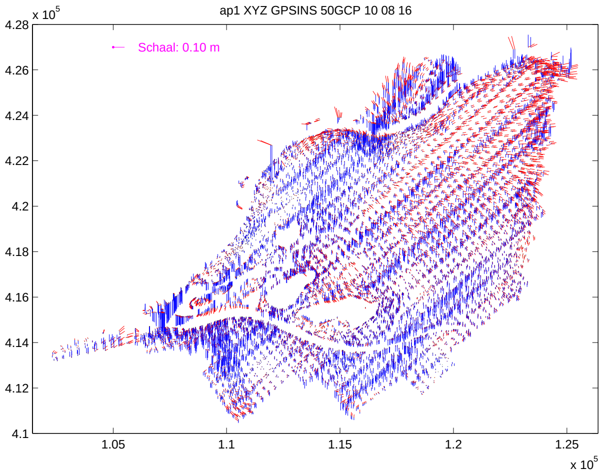
Defining set 1 as being reference dataset, differences in object space (GCPs and tie points) have been determined between reference dataset and the other three sets, see figure 2.
Comparing figure 2a and 2b (or c) show obviously that GPS/IMU data improves the results on areas where no GCPs are used. Still, it can be seen that the GPS/IMU data seems to be in conflict with indirectly measured parameters. In some of the strips in the Southeast area some long term systematic effects exists, probably caused by GPS/IMU effects. Results of set 4 show that these systematic effects are minimized if a-priori standard deviations of the GPS and IMU data are set twice as large as realistic: 10 cm for GPS (x,y,z) and 8 mgon for φ and ω, 16 mgon for κ.



2a: Differences between set 1 en set 2.



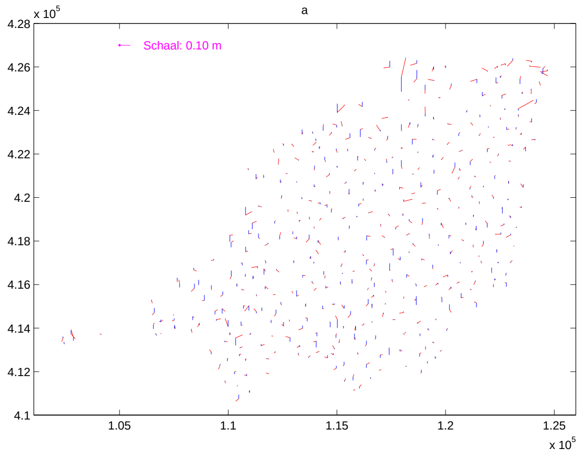
2b: Differences between set 1 en set 3.



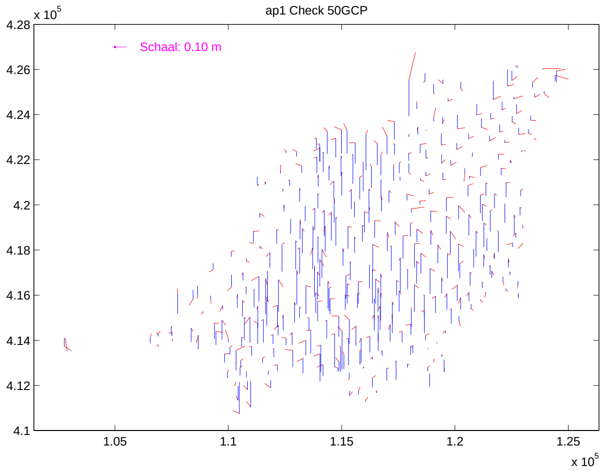
2c: Differences between set 1 en set 4.

Figure 2: Differences at tie points.

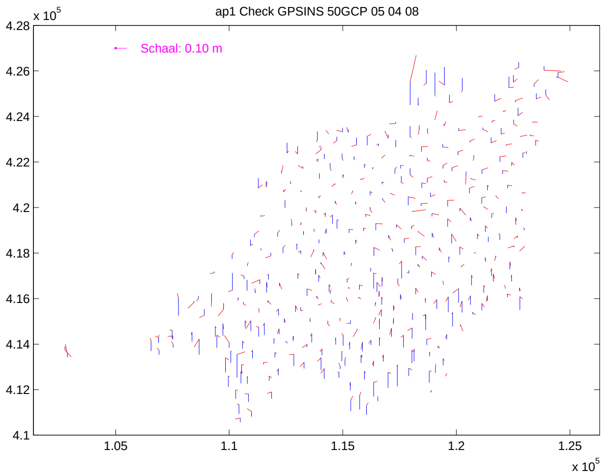
More objective results can be achieved by checking at independent control points. So additionally, differences at check points are plotted in figure 3. Since only 10 % of the available GCPs were used in set 2, 3 and 4, the other 90 % could be used as independent checkpoints. Note that figure 3a shows the residuals at all GCPs used in the AT, leaving no independent checkpoints. Statistical information of these differences is summarized in table 1. It can be concluded that using only 10 % of the number of GCP's (set 2), will lead to a large decrease of height accuracy. Adding GPS/IMU data (set 3 and 4) will improve the results significantly. There is a systematic mean difference in height of about 2 centimeters. In horizontal direction mean differences are less than 1 centimeter. Compared with the normal dataset, RMS values are increased from 2-3 centimeter to 3-5 centimeters. Interpretation of these results should be handled with care, because in both sets the same tie points have been used. Systematic errors in tie point coordinates, for example caused by lens distortion, may falsely be accused to errors in GPS/IMU data. Future data analysis is needed to find out which errors may be part of this RMS value.



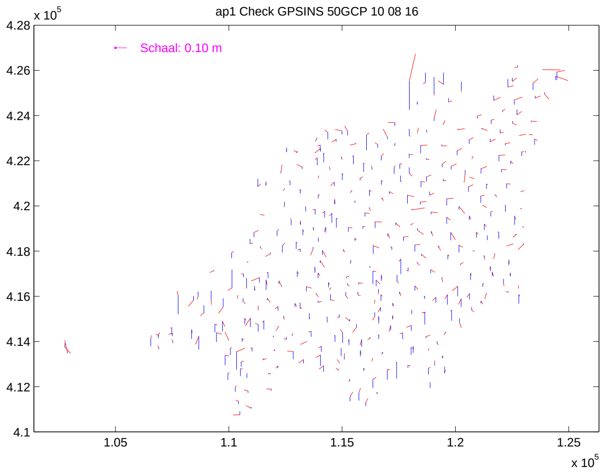
3a: Residuals of set 1.



3b: Results of set 2.



3c: Results of set 3.



3d: Results of set 4.

Figure 3: Differences at check points.

	mean dx(m)	mean dy(m)	mean dz(m)	rms dx (m)	rms dy (m)	rms dz (m)
Set 1	0.000	0.000	0.000	0.023	0.021	0.026
Set 2	0.007	-0.005	-0.097	0.032	0.030	0.107
Set 3	0.008	-0.009	-0.026	0.029	0.028	0.054
Set 4	0.007	-0.007	-0.021	0.030	0.028	0.045

Table 1: Results at checkpoints, mean and RMS.

3. Inventory of the bottle necks

In previous projects it was shown that for our purposes still a huge number of GCPs is needed in order to correct for systematic and stochastic errors in the IMU data in an integrated block adjustment [4]. In the precious chapter it was shown that is some parts of the block systematic errors occur.
It is better to avoid these systematic effects, rather than to eliminate them afterwards. Therefore, information analysis is carried out to find weak places in the acquisition of GPS/IMU data, and its quality description (accuracy and reliability). In cooperation with Delft University of Technology the theoretical and optimal acquisition of GPS/IMU data has been compared with the practical data acquisition. In the following, discrimination has been made in weak points in acquisition stage and weak points in software.

3.1. Weak points in acquisition stage

Compared to laser data acquisition, the flight schedule of image acquisition is more difficult to predict because of more severe weather condition limitations. That is why flight companies have logistic problems setting up and maintaining ground stations.

In order for RTK DGPS methods to be effective under most situations, including a high level of ionospheric acitvitiy, the distance between the rover and the closest reference station must not exceed about 20 km [2]. As the receiver separation increases, the problem of accounting for distance-dependent biases increases. The atmospheric induced biases are the major error sources in this case. The success of precise GPS positioning over long baselines depends on the ability of resolving the integer phase ambiguities when short observation time spans are required, which is especially relevant to RTK applications. The use of multi reference stations network in GPS navigation may significantly increase the distance, by a factor 2 to 3 [5] over which kinematic carrier-phase ambiguity resolution can be performed. This can be achieved by imposing the geometry conditions based on fixed location of the base stations, and through the use of the base station data to estimate the measurement errors that can be used to evaluate corresponding errors at the rover location [7]. In our case this means that if a network solution is used, the distance between ground station and rover can increase to 40-60 km.

Since early 2003 a nation wide commercial (RTK-) GPS network, called '06-GPS', is active in the Netherlands. Mean distance between two neighbouring ground stations is about 70 kilometers. According to [5] this is slightly too large to use for precise trajectory determination as needed for our DTB.

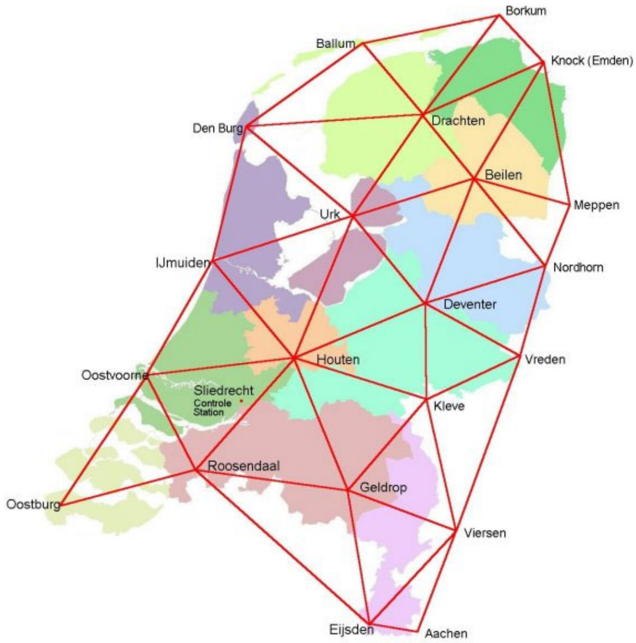


Figure 4: 06 -GPS Netwerk (source: www.06-gps.nl).

A conclusion of the information analysis is that Flanders (northern part of Belgium) has got a GPS network solution that is better than the Dutch system, called FLEPOS. FLEPOS is a governmental initiative to integrate a dense GPS network in the geo-information infrastructure. Mean distance between two neighbouring ground stations is about 25 kilometres. Besides good geometric properties, FLEPOS is financially interesting for flight companies: the use of its dGPS corrections and raw GPS data is free of charge.

When using less GCPs, proper system calibration becomes an issue of major importance. System calibration means determination of the spatial and rotational offsets between the sensor components, i.e. the misalignment between IMU and camera frame, and the interior orientation of the camera [1].

3.2. Weak points in integration software

Integration of GPS and IMU data has been done in either Applanix or IGI software. The working of the integration, including cycle slip detection and other Kalman filter specifications, is a black box procedure to the users (flight companies). The Survey Department also recognize this problem in vehicle and ship born trajectory determination. Another, even more important, weak point is the lack of quality information of the results after integration. Position and attitude parameters are determined and given without being accompanied by any accuracy estimation. This problem has also been mentioned in the analysis of the results of an OEEPE test [3] in which several companies compared results of direct georeferencing and integrated sensor orientation.

4. Near future perspective

In the near future the Survey Department will start a project in which existing topographical information will be used to improve the reliability of the integrated sensor orientation. This is done in two steps.

4.1. Step 1: Integrated sensor orientation

In a first step all images are connected by tie points in an automatic triangulation. Tie points are selected automatically in an image matching algorithm. In this step GPS/IMU data is being used to speed up the image matching, because of the good approximate values to set up a stereo model. Small changes in our software are necessary to import IMU data to the matching algorithm.

The reliability of the results remains a weak point of integrated sensor orientation due to a lack of redundancy in absolute orientation. Systematic errors in the GPS/IMU measurements or changes in the system calibration parameters between calibration and actual flight may go unnoticed, because they cannot be detected without the introduction of GCP coordinates [3].

4.2. Step 2: DTB referencing

To overcome the lack of reliability, 3D information features will be used, extracted from existing DTB data. Although this information does not have the same point accuracy as signalized GCPs, the redundancy will compensate for that. Features include object points and lines. In figure 5 an example of DTB data is shown. A major condition is that extracted objects have to be stable, in order to minimize the number of error sources.

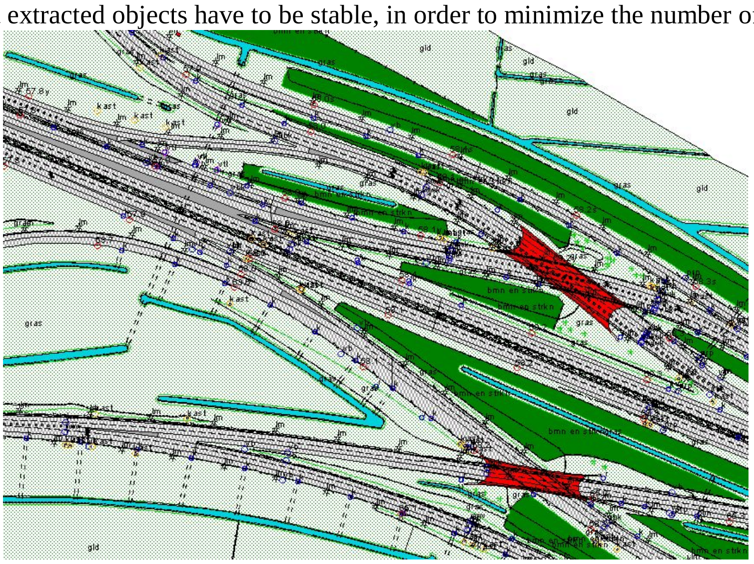


Figure 5: DTB objects will be used to extract ground control.

If no existing topographical data is available, but necessary after detection of systematic GPS/IMU errors, extra ground control can be acquired afterwards, by measuring natural ground control points. Because the measurement of a single natural point is less accurate than a signalized control point, more natural points will be determined. It is to be expected that this option is quicker and cheaper than the conventional triangulation procedure.

4.3. Problem area's

Cases that are critical for matching during aerial triangulation (in step 1), in our products (highways and rivers), are steep slopes, area's with no texture and large water bodies. Besides this, another problem arises in step 2: in most of these area's no useful existing DTB data is available. However, the impact of these two problems is rather small. Without giving solutions, these problems are put in perspective:

- Looking at the end product (DTB) it can be concluded that in the problem area's there are only few objects to acquire, let alone objects who need highest precision.
- Accuracy of conventional AT in problem area's is also weaker than in other area's: the orientation parameters in problem area's are determined indirectly by connecting weak tie points and a small number of GCPs.

5. Quality is more than geometric accuracy

In data analysis, most attention is paid to the geometric accuracy of the data. In the DTB production proces three aspects are important: costs, time and accuracy. The task of the Survey Department is to find an optimal solution between costs and time profits and geometric accuracy. The Survey Department described a short cost analysis in [6], in which it was shown that the use of GPS/IMU data is cost effictive because of the reduction of tie points. In [4] is has been shown that GCP reduction saves time in the pre-flight period and in the AT step.
In this chapter a light is shown on the life time of geometric accuracy. Often, the quality of the end product is subject to dynamic processes, so the value of precision parameters decreases in time. DTB objects are extracted from aerial images. In a conventional AT, the time between image acquisition and delivering DTB data to the user is about one year. The use of GPS/IMU data will decrease this period with a few months. DTB data will be used between 1 and 6 years (or: the next revision update) after image acquisition. During this time, dynamic processes may influence the earth surface. Dynamic processes can be abrupt (human intervention etc) or smooth (land subsidence etc). Although the time profits of GPS/IMU will not fully compensate for less accurate results, some users may attach more value to time and costs benefits than geometric accuracy. Future work includes setting up a look-up-table connecting costs, time and accuracy.

6. Conclusions

Differences should be handled with care, because these differences are only partly caused GPS/IMU errors. It can be concluded that using GPS/IMU and only 10 % of the number of GCP's, will lead to a small decrease of geometric accuracy. There is a systematic mean difference in height of about 2 centimeters. Compared with the normal dataset, RMS values are increased from 2-3 centimeter to 3-5 centimeters. Interpretation of these results should be handled with care, because in both sets the same tie points have been used. Systematic errors in tie point coordinates, for example caused by lens distortion, may falsely be accused to errors in GPS/IMU data. Future data analysis is needed to find out which errors may be part of this RMS value. Visually, systematic patterns can better be seen at tie points than at GCPs, because of the higher point density.
Mean distance between two neighbouring ground stations of the Dutch RTK-DGPS network is about 70 kilometres, which is slightly too large to use for precise trajectory determination as needed for our DTB. Another weak point is the lack of quality information of the results after integration. Position and attitude parameters are determined and given without being accompanied by any accuracy estimation.
In the near future the Survey Department will start a project in which existing topographical information will be used to improve the reliability of the integrated sensor orientation.

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