Based Kinematic Acceleration Determination for Airborne Vector Gravimetry - Methods and Results -

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Abstract
The detailed structure of the earth's gravity field and its temporal variations is important for many scientific and economic applications (e.g. exploration purposes, geophysics, geoid determination). In order to guarantee this wide field of use a measurement system for the determination of this gravity data should be on the one hand accurate, reliable and with a high resolution on the other hand also efficient and independent of the area of operation. In comparison and in extension to satellite based and terrestrial methods the principle of airborne vector gravimetry seems to be an optimal solution to determine the significant regional gravity changes.

Because of their complementary error characteristics and consequent mutual aiding capabilities GNSS and INS are integrated primarily for applications in positioning and navigation. But also for airborne vector gravimetry the required observations can be done by these sensors. The method based directly on Newton second law of motion. The gravity vector along the aircraft trajectory can be computed directly by differencing the kinematic acceleration derived from GNSS observations and the specific forces measured by a high precision INS. In order to fulfil the requirements of the most users an accuracy of 1 mGal (0.00001 m/s²) with a spatial resolution of 1 km should be reached. In opposite to the navigation application in this case the primarily long term INS errors and the short term acceleration errors caused by white noise of the GNSS observations combine. Consequently, there is only a small frequency window within which the gravitational signal may be discerned.

Thus the paper investigates the possibilities to increase this spectral window using different sensor constellations, GNSS observations and post processing methods.

After a short summary about the general principles of airborne gravimetry in the first part the determination of the specific force by the inertial sensor is in the center of interest. Possible error sources of high precision strapdown INS like noise, biases and scale factor errors of accelerometers and gyros are described and investigated with regard to their spectral range of interest for gravity determination. Using typical data sets of airplane movement the effects of system dynamics on these errors can be studied. A realistic view on the expected accuracies of the specific force measurements are supported by practical tests in static mode, in a car navigation environment and also in a real observation situation for airborne gravimetry using data of a new flight test period. The paper demonstrates results of these specific force observations and compares different data rates and filtering techniques for INS data. The alignement problem and the stability of sensor orientation during the flight is investigated in a special manner, because it is an important limiting factor in vector gravimetry Corresponding to the specific force determination the main topic of the paper is the derivation of the kinematic acceleration using GNSS for purposes of airborne gravimetry. At the beginning of this chapter an error analysis of raw GNSS range and range rate observations and their derivations like double differenced values or special linear combinations are carried out on one hand in time domain on the other hand in frequency domain. In the following the three most important methods for deriving accelerations out of GNSS phase observations are described and compared to each other: double differencing of computed GNSS position, the direct calculation of body accelerations out of double differenced phase accelerations and the method of adapted Kalman-filtering using a second order dynamic model. Additionally in this theoretical part filtering techniques are mentioned allowing optimal results for the kinematic acceleration in the relevant spectral window of airborne gravimetry.

In the next part of the paper the described processing methods to derive acceleration information from GNSS data are tested using some data sets with different error characteristics (zero baseline, short/long baseline,

different multipath conditions, static/car dynamics/airplane dynamics, difference in height between reference and rover station). The different accelerations and their error behaviour are presented and compared between the used processing methods and observation conditions. If these results are evaluated in regard to the frequency area of airborne gravimetry on the one hand a statement concerning the best derivation method can be made on the other hand the influence of different GNSS observation errors like receiver noise or atmospheric errors are able to be estimated. Furthermore the required GNSS data rate is one aspect of this topic.

The integration of a multi-antenna GNSS receiver in the airplane gravimetry systems and the evaluation of its advantages for the acceleration determination is the subject of the next chapter. As it can be demonstrated by pre-tests the information of the known baseline lengths between the aircraft antennas are able to support both the phase ambiguity resolution which is required for some processing methods and it can be used as a pseudo-observation in an estimation process of aircraft accelerations. The paper demonstrates the sensor configuration as it is used in practical flight tests and approves the advantages for the acceleration determination.

Finally an overview of the whole data processing for airborne gravimetry is given including a description of an implemented Kalman filter model for the optimal estimation of gravity anomalies out of INS and GNSS sensor data and some possibilities to improve the system performance using special observation conditions like crossing point in the flight path or two way observations.

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