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# Development of a Mobile Mapping System for Multi-Purpose Applications Composed of a Low-Cost Inertial Measuring Unit, a GNSS-Receiver and a Close-Range LIDAR †

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**Abstract:** The research project "Development of a Mobile Mapping System for multi-purpose applications composed of a low-cost inertial measuring unit, a GNSS receiver and a close-range LIDAR" consists on considerations about the design of an aerial and a sensor platform, which can also be used separately. The aim of the project is the development of a measurement platform, which performs a direct scan of the Earth's surface by means of measurements with a laser scanner supported by several sensors to determine their position. The geo-referencing of the data will initially take place in post-processing.

**Keywords:** LIDAR; GNSS/INS data integration; Kalman Filter

## 1. Introduction

In the last twenty five years the demand for 3D-models is increasing for 3D city models; 3D models of the earth's surface for planning tasks; for the visualization of planning alternatives; in the sustainable urban development and many more. 3D models are generated mainly through methods such as LIDAR, photogrammetry, terrestrial laser scanning or Mobile Mapping. In recent years the close-range photogrammetry arises with the use of UAV's (Unmanned Aerial Vehicles). Since the close-range photogrammetry represent an indirect method of measurement, the developed "Mobile Mapping System for multi-purpose applications" take advantage of the LIDAR measurement using a direct method of measurements.

## 2. System Design

The original design for the system was developed at the beginning of 2015. This work was first presented at the conference "Oldenburger 3D Tage", Oldenburg, Germany in February 2015 [1] and at the "UAVg-2015" Conference in Toronto, Canada, September 2015 [2].

The first consideration for the sensor platform was to design a self-sufficient system, which should be mounted primarily on a multicopter. The system should also be installed on another platform without any changes. The first considerations were regarding the positioning of the system in space. Since under a multicopter the GNSS signal could be disturbed, the idea to equip the system with two antennas was born. An inertial measuring unit is also part of the system, as well as a laser scanner. The possibility of installing additional sensors should also be considered.

The system design is based on the following considerations:

Sensor selection and data recording, the sensor synchronization, the system calibration, the design of the kinematic model, the integration, fusion and geo-referencing and the quality control (accuracy and reliability) of the data.

## 3. Sensors

The required sensors are: an inertial measuring unit composed at least of accelerometers and gyroscopes, a GNSS-receiver with the required highly accuracy and a laser scanner with suitable range and accuracy.

### *3.1. Inertial Measuring Unit IMU*

The Inertial Measuring Unit STIM300 from Sensonor AS, Horten, Norway was selected for the system. The key for the choice of this IMU was the weight and the small dimension, the high quality of the components, the quality of the data and the 3-axis alignment of the unit. The STIM300 is a high-precision MEMS system (see Figure 1a).

### *3.2. GNSS Receiver*

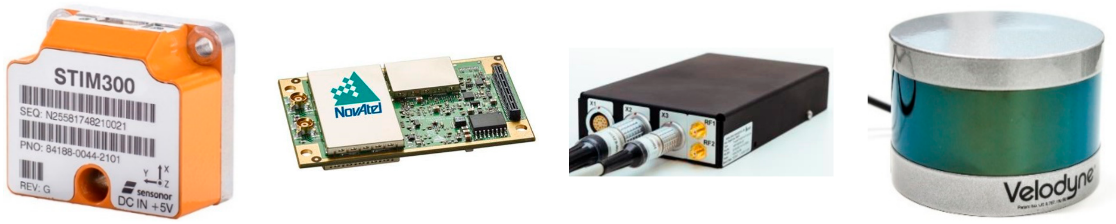
Because the system is conceived with a dual antenna for redundant position measurement, the GNSS receiver Novatel OEM7720 was choose. Novatel Inc., Calgary AB, Canada, is a leading GNSS company in the world, whose products are known for their high quality and great variety (see Figure 1b).

### *3.3. iMAT iNAT-M200-FLAT Inertial Navigation System (INS)*

The inertial navigation system iNAT-M200-FLAT from iMAR Navigation GmbH, St. Ingbert, Germany, combines fortunately the IMU-STIM300 with the GNSS receiver Novatel OEM7720. The whole sensor weighs only 550 g, including the housing. The system can perform up to 500 measurements per second (500 Hz), the receiver performs 1 measurement per second (1 Hz). The drift of the system is less than 0.5 °/h (see Figure 1c) [3]. The advantage of the iNAT-M200-FLAT INS is it, the synchronization is carried out internally and the data is recorded with the corresponding time stamp, the problem of the data synchronization is already solved.

### *3.4. Laser Scanner Velodyne VLP-16*

One of the new compact laser scanners on the market is the Velodyne Puck VLP-16 (see Figure 1d). The VLP-16 has 16 fixed measuring beams, which rotate around the vertical axis. The measuring accuracy is ±3 cm, the measurement range is ℂ 100 m and can measure up to 300 T points/second. The measurement method is the Time of Flight Method [4].




(**a**) (**b**) (**c**) (**d**)

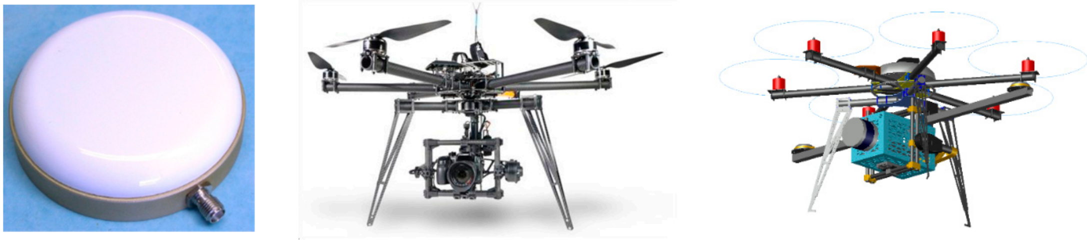
**Figure 1.** Sensors: (**a**) STIM 300 (© Sensonor AS, Horten, Norway); (**b**) Novatel OEM7720 GNSS dual receiver (© Novatel Inc., Calgary AB, Canada); (**c**) iMAR-M200-FLAT INS; (**d**) Velodyne LiDAR PUCK.

GNSS Antenna G5Ant-2AMNS1

Two G5 active antenna L1/L2 GLONASS + GPS + OmniStar/TerraStar (Antcom: G5Ant-2AMNS1) were integrated in the system (see Figure 2a).

### 3.5. Flying Platform Hexacopter CineStar 6 HL

The Hexacopter CineStar 6HL (modified version from copterproject©, Hamburg, Germany) with a gimbal (Movi, FreeFly) has been selected as the flight platform (see Figure 2b).



(**a**) (**b**) (**c**)

**Figure 2.** (**a**) GNSS Antenna (G5Ant-2AMNS1); (**b**) Hexacopter CineStar 6HL; (**c**) Sensor box Prototype.

### 3.6. Assembly of the Components

All components are mounted on the gimbal underneath the UAV in a specially designed box as a prototype, later with a carbon fibre box (see Figure 2c). The flight platform and the sensor platform are held in place by a quick lock. This configuration is supported on the ground by a GNSS base station. The advantage of this configuration is that the trajectory can be better evaluated. The measured base length is compared with the calibrated distance between the GNSS antennas to sort out possible outliers. The gimbal compensates the movements of the flight platform and keeps the sensor platform in an approximate horizontal position during the data collecting, the IMU detects every movement with high accuracy and stores the data.

## 4. GNSS/INS Data Integration

An integrated navigation system combines several sensors and navigation methods. The disadvantage from one sensor or method can be respectively compensated from the other because the complementary properties of the data sources (see: Attributes of GNSS and INS Systems [5]). The new integrated navigation system shows a higher performance compares with the characteristics of each subsystem [6].

The output of an inertial navigation system is basically a position, which errors depends on the quality of the used sensors and earth models. The advantages of an inertial navigation system is the high rate of data output and their small short-term position errors. These errors drifted over time without bounds. To compensate this disadvantage, the system is complement with a GNSS receiver providing long term position accuracy [7].

### 4.1. System Architectures: Loosely Coupled Integration

For data integration of an INS and a GNSS receiver are used almost exclusively Kalman filters. Based on the used additional information, there are several integration architectures. A loosely coupled integration was chosen for the data integration. The incoming signals from the GNSS-antenna provides estimate range and range rate, between the vehicle and the satellite. To resolve the vehicle position, their velocity, the receiver clock bias and the receiver drift rate, are needed four satellites signals. Receivers of higher quality used Kalman filtering (polynomial KF) to estimate the position, velocity, acceleration, clock bias and clock drift rate. In an INS system the raw accelerometer and the gyroscopes data will be compensated (e.g., through calibration and alignment mode). After integration of the corrected angular rate, the output is the vehicle attitude in a reference coordinate system (ECEF coordinate system). The velocity increments are now rotated in this coordinate system and then integrated. The output is the position and velocity of the vehicle [5].

### 4.2. GNSS Position

The positions are improved by differential GNSS evaluations. The raw data of the trajectory of the GNSS measurements are calculated in RTKLIB open source software and combined using the coordinates of the reference measurement [8]. The calculated coordinates shows in test a standard deviations below one centimeter, which confirms the manufacturer's specification of the receiver.

### 4.3. The Kinematic Model

The Extended Kalman Filter follows a solution approach that combines the GNSS measurements with the inertial data [9]. The core of the EKF is the kinematic model and describes the prediction of the state vector. In order to set up the kinematic model, the acceleration equation is applied to a linear motion. This yields the system matrix, which can be represented by a Jacobi matrix.

## 5. Conclusions

The design of a mobile mapping system (from the sensors choice to the calculation of the trajectory) was reported in this work. The developed kinematic model and the applied Extended Kalman Filter show an accurate and plausible trajectory determination. Also is showed, that the Kalman Filter is able to optimally combine the proposed sensors. The inertial measuring unit in conjunction with the GNSS receivers increases the accuracy of the system position and attitude.

**Conflicts of Interest:** The authors declare no conflict of interest

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