DESIGN AND DEVELOPMENT OF A LOW–COST AERIAL MOBILE MAPPING SYSTEM FOR MULTI-PURPOSE APPLICATIONS

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ABSTRACT:

The research project with the working title "Design and development of a low-cost modular Aerial Mobile Mapping System" was formed during the last year as the result from numerous discussions and considerations with colleagues from the HafenCity University Hamburg, Department Geomatics. The aim of the project is to design a sensor platform which can be embedded preferentially on an UAV, but also can be integrated on any adaptable vehicle. The system should perform a direct scanning of surfaces with a laser scanner and supported through sensors for determining the position and attitude of the platform. The modular design allows his extension with other sensors such as multispectral cameras, digital cameras or multiple cameras systems.
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1. INTRODUCTION

The last twenty five years have shown an increasing demand on 3D models for a large number of applications: like 3D city models; 3D models of the earth's surface for planning tasks; in the visualization of planning alternatives; in the sustainable urban development; etc. (see group SIG 3D, www.sig3d.org). Today 3D models are created (generated) 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). We find this technology in a large number of applications, such as in "Disaster Research and Management" (Adams & Friedland, 2011); in "Rapid Aerial Monitoring for Emergency Responses" (Choi & Lee, 2011); in "Remote Sensing and Mapping" (Everaerts, 2008 and Eisenbeiss, 2011); in "3D Mapping" (Jutzi, Weinmann & Meidow, 2013); in "Mobile 3D Mapping for Surveying Earthwork" (Siebert & Teizer, 2013); in "Landslide Surveying" (Carvajal, Agüera & Pérez, 2011); in "Applications for the Coal Industry" (Riley & Crowe, 2006); in archaeology (Seitz & Altenbach, 2011); in "Three-Dimensional Building Reconstruction" (Wefelscheid, Hänsch, & Hellwich, 2011); in "Real-Time Monitoring" (Witayangkurn, Nagai, Honda, Dailey & Shibasaki, 2011) and many more.
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2. MOTIVATION

After a four years of testing an Octokopter from MikroKopter, Germany (see fig. 1 and 2), and the fact that a new acquisition should only be realized as part of a comprehensive concept, the idea of designing a new measuring system was born. After extensive research of the existing literature of recent years, it can be observed that almost the entire development in the UAV applications utilized a digital camera as the main sensor. The exceptions are two publications (Wallace, Lucieer & Watson, 2012 and Kuhnert & Kuhnert, 2013) which utilized a laser scanner as the main sensor. This acknowledgment plays an important role in the development of the new system.

Figure 1. Oktokoper take-off subsequent to the flight plan transfer

Figure 2. Images from a flight (HERICT-Project; Rhodes, Greece)

3. GENERAL DESIGN

The general concept for the developed system follows the proposed design and analysis from El Sheimy (1996).

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3.1 System design

- Data recording and sensor selection
For the data acquisition it is necessary to select sensors for the measurement and the position determination during the flight in a corresponding range and accuracy. These components are: Laser scanner for data acquisition; an inertial measurement unit (IMU) for detecting the pitch, roll and heading; and a GNSS receiver to determine the system position and trajectory.

- Sensor Synchronization
The synchronization of all components (laser scanner, IMU, GNSS receiver) is necessary in order to calculate the final data. A control unit starts the measurement and stores the collected data for post-processing.

- System Calibration
The system must be calibrated to evaluate the sensors interior orientation.

- Kinematic model
The kinematic model involves the estimation, modeling and interpretation of the system trajectory by means of measurements in a reference coordinates system.

- Data geo-referencing
After the calibration is known and the kinematic model is determined, the measured data can be geo-referenced.

- Integration and fusion of data
If several sensors are used, the geo-referenced data must be integrated and fused together.

- Quality Control
The accuracy and reliability of data needs to be verified and validated through reference measurements on a test field.

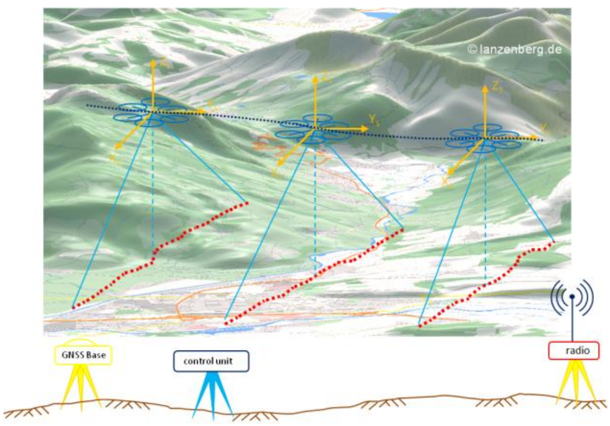

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Figure 3. Measurement process with base station and remote control unit

3.2 Flight platform

The system should be modular and independent. The flight and sensor platforms can work independently without using any performance from the other. The flight platform carries the sensor platform and follows the planned flight path. This concept allows the mounting of the sensor platform in different aerial or ground vehicles and could even be used manually.

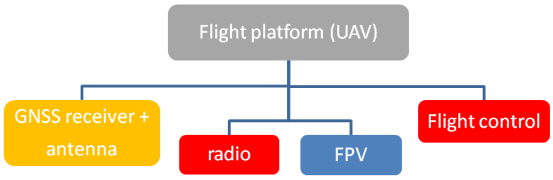

Figure 4. Standard design of a flight platform

Manufacturer	copterproject Hamburg
Type	CineStar 6HL Hexakopter
Navigation	MikroKopter flight control
Position	MikroKopter GPS V3
Engines	T-Motor MN 4012-11
Batteries	2 x LiPo 4500 mAh

Table 1: Hexakopter technical specifications

The Hexacopter CineStar 6HL from copterproject, Hamburg and a gimbal (FreeFly) has been selected as the flight platform (for technical specifications see Table 1 and also fig. 4 and 5).

Figure 5. Hexakopter CineStar 6 HL (© copterproject Hamburg)

3.3 Sensor platform design

The sensor platform comprises the control unit, the GNSS receiver and corresponding antenna, an inertial measurement unit, and a laser scanner (see fig. 6). All components are mounted on the gimbal underneath the UAV. The flight platform and the sensor platform are held in place by a quick lock (see fig. 6 and fig. 7).

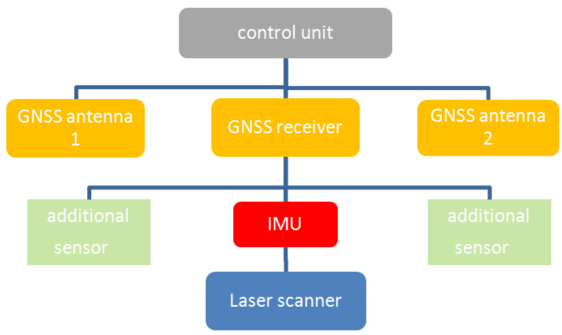

Figure 6. Sensor platform design

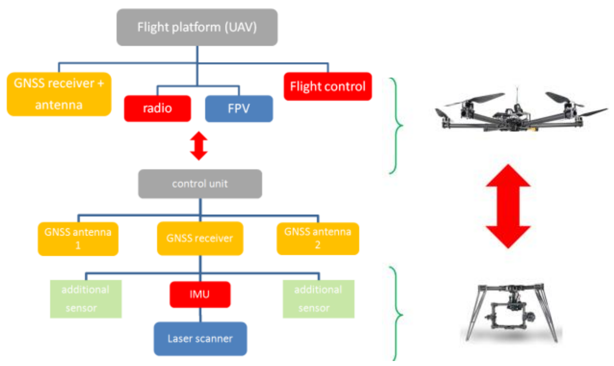

Figure 7. General concept of the flight and sensor platform

The position and trajectory of the sensor platform is determined by a GNSS receiver with the corresponding antenna. To avoid multipath and interferences, we placed a second GNSS antenna eccentrically on a carbon bar (each in the end of the bar) which is controlled by a dual GNSS receiver with the corresponding input for two antennas. This configuration is supported on the ground by a GNSS base station. An inertial measurement unit is firmly attached to the sensor platform. The advantage of this configuration is that the trajectory can better be evaluated. The measured base length is compared with the calibrated distance between the GNSS antennas to sort out possible outliers (see fig. 8).

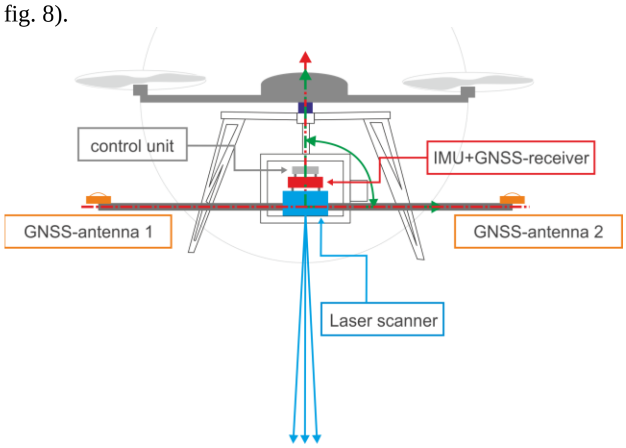

Figure 8. Side view with the measuring system

The gimbal compensates the movements of the flight platform and keeps the sensor platform in an approximate horizontal position during the data collecting and the IMU detects every movement in a sufficient accuracy (see Fig. 9).

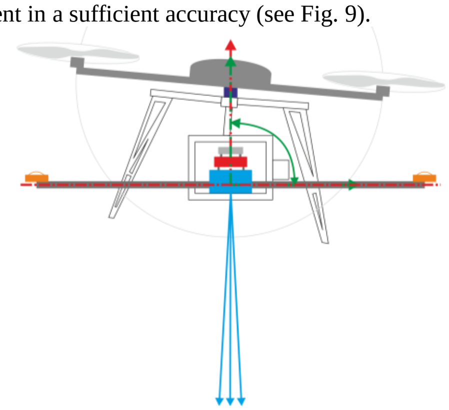

Fig. 9: The measuring system with the gimbal underneath the UAV

4. STATUS QUO AND DEVELOPMENT

The first investigations and the practical implementation of the measurement system has recently been performed in a master thesis at the HafenCity University. The concept was first implemented with the existing resources of the Department of Geomatics.

4.1 Components

The laser scanner Sick LMS 151, a Xsens inertial measurement unit and a simple GPS receiver with PPS-output have been first tested. The Raspberry Pi Model B has been selected as controller, (see fig. 10 and fig. 11; tables 2, 3, 4 and 5). The technical specifications of the components are:

Fig. 10: SICK Scanner LMS 151, IMU - Xsens MTI-28A33G15, GPS receiver Navilock

Manufacturer/Type	SICK LMS 151
Range	50 m
Scan angle	max. 270 °
Angle resolution	0,5 ° / 0,25 °
Scan rate	50 Hz / 25 Hz
Error	Statistical: 12 mm Systematic: ±30 mm Temperature drift: max. 0,32 mm/°C
Laser	Laser class 1 (905 nm) Beam divergence: 15 mrad (R15mm/m) Beam diameter at outlet: 8 mm
Weight	1,1 kg

Table 2: Laser scanner technical specifications

Manufacturer/Type	Xsens MTI-28A33G15
Static accuracy	Roll/Pitch: <0,5 ° Heading: <1 °
Dynamic accuracy	2 ° RMS
Angle resolution	0,05 °
Time accuracy	10 ppm
Dynamic range	Pitch: ±90 ° Pitch/Heading: ±180 °
Max. update rate	Onboard: 256 Hz External: 512 Hz
Dimension (Size)	58×58×22 mm
Weight	50 g

Table 3: IMU technical specifications

Manufacturer	Navilock
Chip set	SiRF Star 3 High Sensitive
Frequency	L1, 1575,42 MHz
C/A Code	1.023 MHZ Chip rate
Channels	Max. 20
Position update rate	5 Hz
Position accuracy	10 m 5 m with WAAS / EGNOS
Speed accuracy	0,1 m /sec
Time accuracy	1 µs (synchronized to GPS time)

Table 4: GPS receiver technical specifications

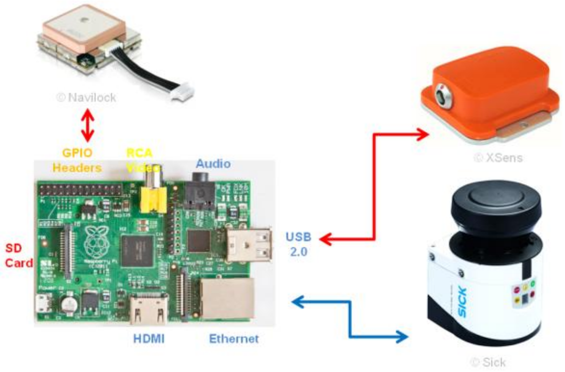

Fig. 10: Rapsberry Pi, Model B and sensors

Manufacturer/Type	Raspberry Pi, Model B
Chip	Broadcom BCM2835
CPU	700MHz ARM1176JZF-S
GPU	Broadcom VideoCore IV
Main memory	512MB SDRAM
Interface	2 x USB 2.0 10/100Mbit Ethernet GPIO
Power consumption	3,5 W
Dimension (Size)	9,3cm × 6,4cm × 2,0cm
Operating system	Linux
Weight	40 g

Table 5: Technical specifications Raspberry Pi

The Rapsberry Pi runs on a C++ program, which controls the GPS receiver (GPIO interface), the IMU (USB interface), the laser scanner (Ethernet interface) and also the data storage.

4.2 Data processing

The trajectory determination and the fusion with the laser scanner data was performed in MATLAB, by synchronizing the GPS time-stamp from the receiver (see fig. 11).

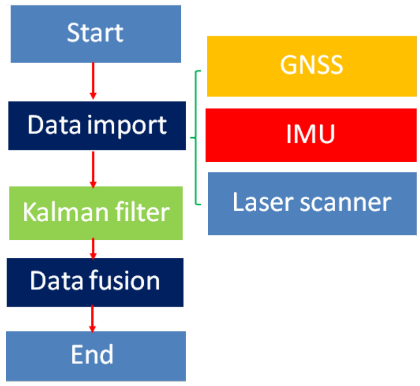

Fig. 11: Data processing

5. CONCLUSIONS AND OUTLOOK

The tests has shown that the conceiving system can be implemented as previously planned. The new system will be equipped with a new laser scanner (range up to 150m), an IMU with higher accuracy (roll/pitch/heading: 0,015°/0,015°/0,080°) and a GNSS (L1/L2) receiver. Currently we are working on the trajectory determination by a Kalman filter (Nøkland, 2011) and on the geo-referencing of the data. The future applications for the presented system are:
Topographical survey of the earth's surface (DTM), updating 3D city models, monitoring of landslides, 3D-recording of industrial facilities, evaluation of earthworks, documentation of archaeological excavations, etc. Further the following investigations are planned: system implementation with new sensors, validating the system on a test field, mapping the earth surface in real-time, obstacle detection during the flight, flight automation, data recording simultaneously with other measuring systems (ground or aerial), and the implementation of new measuring sensors.

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