Available online at www.sciencedirect.com

ScienceDirect

IFAC-PapersOnLine 49-25 (2016) 170–175

Precise Multi-Sensor Georeferencing System for Micro UAVs

Petr Gabrlik * **Ales Jelinek** * **Premysl Janata** **

* *Department of Control and Instrumentation, Faculty of Electrical Engineering and Communication, Brno University of Technology, Brno, Czech Republic*
(e-mail: xgabrl00@stud.feec.vutbr.cz, xjelin08@stud.feec.vutbr.cz).
** *Department of Forest Management and Applied Geoinformatics , Faculty of Forestry and Wood Technology, Mendel University in Brno, Brno, Czech Republic (e-mail: premysl.janata@mendelu.cz)*

Abstract: The direct georeferencing technique in aerial photogrammetry using micro Unmanned Aerial Vehicles (UAV) is not commonly used against indirect approach due to high requirements of equipment and calibration. On the other hand this technique brings several advantages which can be beneficial in some applications. This paper deals with the development and testing of precise multi-sensor system for the direct georeferencing of aerial imagery. The system consist of dual-antenna Real Time Kinematic (RTK) Global Navigation Satellite System (GNSS) receiver with centimeter level accuracy and Inertial Navigation System (INS) which fuses inertial and position information to provide accurate navigation and orientation data in real time. Special attention is paid to the time synchronization of various sensor data and lever arm correction. 3D print technology was used to achieve low weight and high modularity of the system which can be easily modified and mounted to different types of UAVs. This paper also describes a test flight mission and the processing workflow from the data acquisition to the import of georeferenced orthophoto to a Geographic Information System (GIS).

Keywords: Direct georeferencing, photogrammetry, multisensor integration, navigation systems, UAV

1. INTRODUCTION

Unmanned Aerial Vehicles as a platform for aerial remote sensing and photogrammetry is more popular every year. The main reason for this progress are the availability and cost of a sensing equipment as GNSS receivers, INS units and digital cameras but also UAV platforms itself. The second reason of increasing popularity are new areas of use, which have not been feasible using manned aircrafts due to cost reasons or technical limitations. The one of the perspective areas is agriculture. UAVs can be used for the monitoring of a crop grow as describes Turner et al. (2014) or Haarbrink and Eisenbeiss (2008). Another example of use is close range archaeological site mapping. Saleri et al. (2013) present the workflow and results of Pompeii Theaters mapping and Verhoeven et al. (2012) deal with the benefits of this innovative approach. All these applications take advantage of UAV remote sensing which are mainly low cost, fast and safe operation. This work is also related to the development of multi-robot reconnaissance system which was previously described in Zalud et al. (2011) and Burian et al. (2014).

UAVs can be categorized by many parameters, but the most meaningful in most cases is classification according a takeoff weight. This parameter is typically directly related to the amount of equipment, which can be carried onboard. Arjomandi et al. (2006) classify UAVs into five categories according a takeoff weight. The most significant category in civilian sector are *Micro* (less than 5 kg) and *Light* (5 to 50 kg). This paper mainly deals with this kind of UAVs.

The typical products of aerial photogrammetry are orthophoto, point cloud or Digital Terrain Model (DTM). These products can be imported to a GIS or some classification software tool for subsequent processing, but typically, georeferenced data is required. There are two main approaches how to georeference image data. The first of them, indirect georeferencing technique, uses UAV as a platform for image data acquisition and onboard Position and Orientation System (POS) is used only for UAV stabilization and navigation. Image data is georeferenced indirectly using Ground Control Points (GCP), which are visible on images and which position is known (measured during land survey). The significant advantage of this approach is that a UAV does not have to be equipped by accurate POS, which is expensive and create extra payload. The second advantage is that the indirect approach estimates directly position and orientation of image (in photogrammetry called exterior orientation), respectively principal point and no extra position and orientation misalignment correction is needed. Relationship between image point and object point can be described by 7-parameters similarity (Helmert) transformation based on the central projection as shown in (1). In this equation, exterior orientation is represented by the position vector

2405-8963 © 2016, IFAC (International Federation of Automatic Control) Hosting by Elsevier Ltd. All rights reserved.
Peer review under responsibility of International Federation of Automatic Control.
10.1016/j.ifacol.2016.12.029

$[X_0(t), Y_0(t), Z_0(t)]_L^T$ and three attitude coordinates $\omega(t)$, $\phi(t)$, and $\kappa(t)$ (photogrammetry angles) as the parameters of rotation matrix. The last parameter of the transformation is scale $\lambda(t)$, which is different for every point. Using this equation a point with coordinates $\xi(t)$ and $\eta(t)$ in the image system can be transformed to a local system, where is described by the vector $[X(t), Y(t), Z(t)]_L^T$. Only time invariant parameter is the focal length c, which is one of a camera interior parameters. The projection is described in more detail in Cramer (2001) or Kraus (2007).

$$\begin{bmatrix} X(t) \\ Y(t) \\ Z(t) \end{bmatrix}_L = \begin{bmatrix} X_0(t) \\ Y_0(t) \\ Z_0(t) \end{bmatrix}_L + \lambda(t)\mathbf{R}_\mathbf{I}^\mathbf{L}(\omega(t), \phi(t), \kappa(t)) \begin{bmatrix} \xi(t) \\ \eta(t) \\ -c \end{bmatrix}_I \tag{1}$$

Indirect georeferencing brings accurate positioning results, which mainly depend on the accuracy of GCP position measurement. The need of land survey may be a disadvantage in some application.

The second approach is called direct georeferencing and it uses onboard sensors for image georeferencing. Exterior orientation is typically measured by GNSS receiver and INS unit which is mounted on an aircraft body. This approach requires higher payload capability, accurate sensors time synchronization and misalignment calibration. Transformation (1) has to be complemented by six time invariant parameters. Position vector $[X_I, Y_I, Z_I]_B^T$ called lever arm, which describes offset between GNSS antenna and image sensor (principal point) and three angles $\Delta\omega$, $\Delta\phi$, and $\Delta\kappa$ which form angular misalignment between INS unit and image sensor (boresight angles). Transformation has form (2) (in more detail in Cramer (2001))

$$\begin{aligned} \begin{bmatrix} X(t) \\ Y(t) \\ Z(t) \end{bmatrix}_L &= \begin{bmatrix} X_0(t) \\ Y_0(t) \\ Z_0(t) \end{bmatrix}_L + \mathbf{R}_\mathbf{B}^\mathbf{L}(\omega(t), \phi(t), \kappa(t)) \\ &\left(\begin{bmatrix} X_I \\ Y_I \\ Z_I \end{bmatrix}_B + \lambda(t)\mathbf{R}_\mathbf{I}^\mathbf{B}(\Delta\omega, \Delta\phi, \Delta\kappa) \begin{bmatrix} \xi(t) \\ \eta(t) \\ -c \end{bmatrix}_I \right) \end{aligned} \tag{2}$$

The accuracy of image georeferencing using direct approach depends on the accuracy of onboard POS, but because it is multisensor system, important is also time synchronization and lever arm / boresight angles calibration. Turner et al. (2014) present micro UAV multisensor system equipped with Differential Global Positioning System (DGPS) receiver which achieved mosaics spacial accuracy of ∼0,11 m. The significant advantage of this approach against indirect technique is that no terrestrial measurement is needed.

This paper deals with the development of multisensor system for *micro/light* UAVs. The system is designed for the direct georeferencing of aerial imagery but also laser scans. At first, used sensors and equipment is described. This part is also aimed at a time synchronization and data logging system. The second part describes system testing including a test flight and first results are presented. The paper also briefly shows the workflow from the flight data acquisition to data processing in a photogrammetry software and the import of georeferenced orthophoto to a GIS.

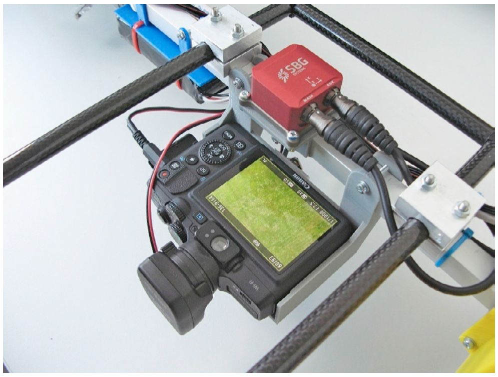

Fig. 1. Camera and INS (the red box) mounted in the middle of aluminum rail.

2. METHODS

2.1 Sensor system

For the UAV position measurement, RTK GNSS receiver Trimble BD982 is used. It is a single board embedded receiver which supports L1/L2/L5 GPS and L1/L2 GLONASS signals and provides dual-antenna input for true heading measurement. The receiver delivers centimeter level accurate position when a correction data is used and a tenth of a degree heading accuracy with 2 meters baseline. The maximum data output frequency is 50 Hz and it can be provided using several serial channels or ethernet. RTK correction are transmitted by a base station, which is located within a radio range of the UAV, via a 2.4 GHz transmitter in a real time.

The second part of onboard POS is a light-weight INS Ellipse-E manufactured by SBG Systems. This unit includes Inertial Measurement Unit (IMU) based on Micro-ElectroMechanical Systems (MEMS) technology and runs Extended Kalman Filter (EKF). The filter fuses inertial data and aiding data, which is GNSS position and heading information in this case, to provide accurate orientation and navigation data with a maximum output frequency of 200 Hz. The INS is shown on the Fig. 1.

The system is equipped with the small format digital camera Canon PowerShot G16 (Fig. 1) with a sensor resolution of 4000 × 3000 pixels (12 MP) and 6.1–30.5 mm (28–140 mm full frame equivalent) f/1.8–2.8 lens. Although this non-calibrated camera was designed for hobby purposes, it can be effectively used in low-altitude UAV photogrammetric applications. The camera meets basic requirements which is the support of the manual setting of shutter speed, aperture value, and focus distance and also it is equipped with a remote terminal for external triggering, and external flash connector for synchronization purposes. Another advantage is its low weight and size. Camera interior parameters, like focal length, principal point offset, and lens geometric distortion parameters can be estimated during image data processing in photogrammetric software (self-calibration based on bundle adjustment method) used e.g. in Gonzlez-Aguilera et al. (2012), or they can be obtained by a laboratory method as describe Ahmad and Samad (2010).