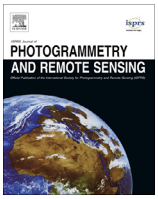
ISPRS Journal of Photogrammetry and Remote Sensing 123 (2017) 114–123

Contents lists available at ScienceDirect

ISPRS Journal of Photogrammetry and Remote Sensing

journal homepage: www.elsevier.com/locate/isprsjprs



# Time synchronization of consumer cameras on Micro Aerial Vehicles

M. Rehak [*], J. Skaloud

*EPFL TOPO, Station 18, 1015 Lausanne, Switzerland*

ARTICLE INFO

*Article history:*
Received 27 September 2016
Received in revised form 23 November 2016
Accepted 23 November 2016
Available online 9 December 2016

*Keywords:*
Time synchronization
Sensor orientation
MAV
BBA

ABSTRACT

This article discusses the problem of time registration between navigation and imaging components on Micro Aerial Vehicles (MAVs). Accurate mapping with MAVs is gaining importance in applications such as corridor mapping, road and pipeline inspections or mapping of large areas with homogeneous surface structure, e.g. forests or agricultural fields. Therefore, accurate aerial control plays a major role in efficient reconstruction of the terrain and artifact-free ortophoto generation. A key prerequisite is correct time stamping of images in global time frame as the sensor exterior orientation changes rapidly and its determination by navigation sensors influence the mapping accuracy on the ground. A majority of MAVs is equipped with consumer-grade, non-metric cameras for which the precise time registration with navigation components is not trivial to realize and its performance not easy to assess. In this paper, we study the problematic of synchronization by implementing and evaluating spatio-temporal observation models of aerial control to estimate residual delay of the imaging sensor. Such modeling is possible through inclusion of additional velocity and angular rate observations into the adjustment. This moves the optimization problem from 3D to 4D. The benefit of this approach is verified on real mapping projects using a custom build MAV and an off-the-shelf camera.

© 2016 International Society for Photogrammetry and Remote Sensing, Inc. (ISPRS). Published by Elsevier B.V. All rights reserved.

## 1. Introduction

Unmanned aerial vehicles (UAVs) have become an important tool for surveyors, constructions engineers and scientists worldwide. Thanks to their affordability and recent advances in guidance, autonomy and ease of use, they spread among wide public. The number of available systems is increasing rapidly (Colomina and Molina, 2014). This progress is accelerated by accompanied software bundled with the platforms that makes image processing as easy as never before. Despite this fast progress, the most popular mode of orientation is still via ground control points. Indeed, indirect sensor orientation is the most common method of georeferencing imagery collected by MAVs. On the other hand, we can witness a gradual increase of commercial platforms with embedded systems offering at least accurate aerial position control (Mavinci, 2016; senseFly, 2016a). Indeed, the recent advances in the field of miniaturization and mass production have made the geodetic-grade receivers with inertial measurement units (IMU) very affordable. Additionally, new and photogrammetry-dedicated imaging sensors appear in the research communities (Martin et al., 2014; Kraft et al., 2016), followed by the commercially available, state-of-the-art mapping sensors (senseFly, 2016b; Phase One, 2016).

### 1.1. Motivation

To benefit from on-board position and attitude determination in mapping, the camera events need to be registered to the same (global) time frame as satellite and possibly inertial data. The necessity of such precise time synchronization of measurement data from multiple sensors is widely recognized (Toth et al., 2008). Synchronization errors are common in navigation systems and they can either originate in hardware or software components. The presence of these errors worsen the accuracy of derived sensor exterior orientation parameters (Schwarz et al., 1993). In certain configurations, i.e. block structures with overlapping images and neighboring strips, the synchronization errors can be mitigated and their influence absorbed by position offset and drift parameters (Jacobsen and Schmitz, 1996; Cramer, 2003), while in corridors or configurations with low-number, low-quality tie- and control points, their impact on mapping accuracy is direct and significant (Jacobsen, 2002b; Skaloud, 2006).

In integrated sensor orientation (ISO) with camera self-calibration the influence of inaccurate time registration of images

---

[*] Corresponding author.
*E-mail addresses:* martin.rehak@epfl.ch (M. Rehak), jan.skaloud@epfl.ch (J. Skaloud).

http://dx.doi.org/10.1016/j.isprsjprs.2016.11.009
0924-2716/© 2016 International Society for Photogrammetry and Remote Sensing, Inc. (ISPRS). Published by Elsevier B.V. All rights reserved.

is often mitigated through absorptions by other calibrated parameters thanks to observation redundancy and geometric strength in block configurations. The synchronization errors do not manifest clearly in the check point (ChP) residuals when no ground control points (GCP) are used (Gerke and Przybilla, 2016). If a flight is designed with regular strips under constant flight speed, the absolute synchronization error translates to aerial position shifts with opposite signs according to flying directions which influence tends to “average out”. On the other hand, should the ground speed vary significantly with the flight speed direction, e.g. head vs. tail wind, such “averaging” will not have a zero mean. Also, in scenarios with greater requirements on aerial control, e.g. areas with low or badly distributed tie-points or in corridors, the systematic errors of that kind impact the ground accuracy.

### *1.2. Paper structure*

In the following section we first discuss the problem of realizing the correct time stamping of consumer market cameras, assessing its performance as well as its influence on mapping accuracy in the context of MAV operation. Next, we present the spatio-temporal observations models together with their stochastic models that allow self-calibration of the constant time offset. The fourth section concentrates on performance analysis in real scenarios. There, a MAV platform and its sensor payload are presented. The test data characterization is then followed by calibration and practical evaluation. This section describes in detail the results and reveals different strategies of determining the synchronization errors. The influence of the estimated synchronization error is tested during an independent mapping project. Finally, the last part draws conclusions from the conducted research.

## 2. Methods of time registration and related error propagation

### *2.1. Methods of synchronization*

The task of synchronization is fundamentally common in electronic systems, and as such, it is assessed in almost any navigation or communication field. Mapping from MAVs is somewhat similar to close-range photogrammetry with the use of non-metric cameras for purposes of multisensory systems (Perry et al., 2009). For this, it is necessary to precisely establish the time registration of imagery with other navigation components such as GNSS/IMU or with other cameras constituting a camera array (Ding et al., 2008).

With MAVs, the first common method of image synchronization with the exterior orientation parameters is through the correlation between the image acquisition time stored in image metadata file and the GNSS log or other trajectory files. This method is sufficient for the indirect approach to the sensor orientation where the sensor positions and orientations enter only during the image preselection and/or as an initial approximation for the bundle block adjustment (BBA). To use the exterior orientation (EO) parameters as weighted observations as required in direct or integrated sensor orientation, a considerably more accurate method of synchronization has to be employed.

The second method is based on time-stamping of the trigger pulse that is sent by an autopilot to an imaging device. In this case, the precise time stamping is affected by camera’s internal electronic. The camera delay, or so-called shutter lag, is a feature which affects all consumer-grade cameras and has a significant influence on the precision of synchronization. When the shutter button is actuated locally or remotely via a triggering signal, the camera may seem to take a photo instantly. However, there is a certain delay before a photo is actually taken (Jon et al., 2013). There are several ways of reducing this delay, e.g. by using manual rather than automatic camera settings, or from the hardware modification by implementing electronic trigger instead of infra-red remote trigger. Employing manual settings makes the residual delay not only smaller but also more stable, which is an important prerequisite for its elimination. This method is sometimes sufficient for slow flying platforms such as multirotors, but not sufficiently precise for fixed-wing platforms. Despite its limitations, this method is widely used among UAV users as it is relatively easy to implement and results in much higher geotagging accuracy than the previously mentioned approach.

One possibility of estimating the camera lag is by taking an image of an “optical clock”. An example of such a method is presented for a consumer-grade Sony NEX-5R camera (Sony, 2016). A dedicated optical clock sends a trigger signal to the camera at an optional interval, e.g. every two seconds, and at the same time it runs graphical time counters with a resolution of one millisecond (Fig. 1). The camera takes images of these counters and an automatic evaluation based on image processing determines their values. Table 1 shows a statistical evaluation of such calibration. The residual variation >10 ms is too large to be of benefit for accurate aerial control (e.g. cm-level positioning accuracy). The relatively large delay has its origin in the shutter construction, whereas the infra-red activation is responsible for its variance. Hence, without a feedback mechanism, precise time stamping of images from a camera is an intractable problem.

Several options are viable in terms of modification of the triggering system or signalization of the shutter opening to minimize the effect of camera internal electronic on the quality of time registration. The commonly used method on off-the-shelf, non-metric cameras is based on the processing of the camera flash signal. Such signal is sent by the camera at a certain instance of exposure and can be time-tagged in further processing.

This signal is brought to the event input of a GNSS receiver. This is a well established form of synchronizing imaging sensors to the GNSS time base. This method usually requires only minor hardware and software modifications of the existing components. However, as the flash pulse is likely not sent at the exact moment of the mid-exposure, a residual error can persist. Contrary to the second method, this approach provides time registration that is considerably more precise. Indeed, using flash in photography requires good synchronization, and such capability is well integrated into the camera’s electronics.

Probably the most precise method of synchronization of a mechanical shutter is performed by recording the signals of shutter curtains directly from the camera circuitry. Such signals correspond to the real exposure in the millisecond level while being independent from the camera settings. The considerable drawback

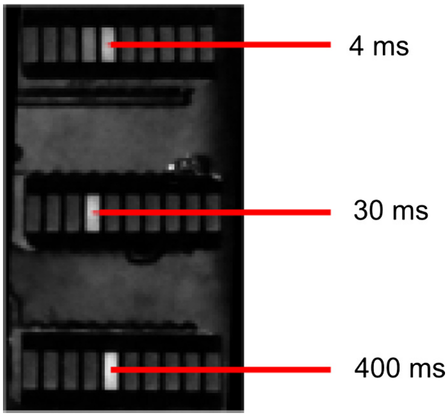


**Fig. 1.** Determination of a camera lag using LED bar-graphs.

Download English Version:

https://daneshyari.com/en/article/4973003

Download Persian Version:

https://daneshyari.com/article/4973003

Daneshyari.com