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Feasibility of employing a smartphone as the payload in a photogrammetric UAV system

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A B S T R A C T

Smartphones can be operated in a 3G network environment at any time or location, and they also cost less than existing photogrammetric UAV systems, providing high-resolution images and 3D location and attitude data from a variety of built-in sensors. This study aims to assess the feasibility of using a smartphone as the payload for a photogrammetric UAV system. To carry out the assessment, a smartphone-based photogrammetric UAV system was developed and utilized to obtain image, location, and attitude data under both static and dynamic conditions. The accuracy of the location and attitude data obtained and sent by this system was then evaluated. The smartphone images were converted into ortho-images via image triangulation, which was carried out both with and without consideration of the interior orientation (IO) parameters determined by camera calibration. In the static experiment, when the IO parameters were taken into account, the triangulation results were less than 1.28 pixels (RMSE) for all smartphone types, an improvement of at least 47% compared with the case when IO parameters were not taken into account. In the dynamic experiment, on the other hand, the accuracy of smartphone image triangulation was not significantly improved by considering IO parameters. This was because the electronic rolling shutter within the complementary metal-oxide semiconductor (CMOS) sensor built into the smartphone and the actuator for the voice coil motor (VCM)-type auto-focusing affected by the vibration and the speed of the UAV, which is likely to have a negative effect on image-based digital elevation model (DEM) generation. However, considering that these results were obtained using a single smartphone, this suggests that a smartphone is not only feasible as the payload for a photogrammetric UAV system but it may also play a useful role when installed in existing UAV systems.

1. Introduction

Photogrammetric unmanned aerial vehicle (UAV) systems are used to remotely control cameras, other sensors, communication devices and other payloads for observational activities in a target area, as well as to enable the aircraft to self-pilot (Dalamagkidis et al., 2008). This technology combines aerial and terrestrial photogrammetry, and is commonly applied over short distances. Contrary to conventional aerial photogrammetry, such a system can be operated at a relatively low cost and applied on a real-time basis (Chiabrando et al., 2011). In addition, UAVs can provide continuous images of the terrain for photogrammetry, with a moderate degree of overlap at low altitudes (Eisenbeiss and Zhang, 2006; Lambers et al., 2007). Moreover, the images provided by UAVs may be used not only for high-resolution texture mapping of a digital surface model (DSM), but also for image rectification. The rectified images may be used for the interpretation of image mosaics, maps and drawings, and there have also been recent studies of the incorporation of images taken by UAVs and range data provided by laser scanning. Nagai et al. (2004, 2008, 2009) integrated a small low-cost laser scanner, a charge-coupled device (CCD) sensor, and a low-cost global positioning system and an inertial measurement unit (GPS/IMU) for the generation of DSMs and feature extraction. Jaakkola et al. (2010) introduced a novel low-cost mini-UAV-based laser scanning system and tested the quality and feasibility of the system for tree measurements. Choi and Lee (2011) developed a UAV-based close-range rapid aerial monitoring system, which

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made it possible to acquire high-resolution sensory data for a targeted area under emergency conditions requiring autonomous flight.

Since the first experiment in which a UAV was used in a photogrammetric application (Przybilla and Wester-Ebbinghaus, 1979), many new photogrammetric UAV systems using a variety of platforms have been introduced, such as balloons (Fotinopoulos, 2004; Mihajlović et al., 2008), kites (Aber et al., 2002; Bogacki et al., 2008), fixed-wing aircraft (Bendea et al., 2007; Haala et al., 2011; Yun et al., 2012), model helicopters (Remondino et al., 2009; Witayangkurn et al., 2011), and multicopters (Neitzel and Klonowski, 2011; Niethammer et al., 2010).

In the mid-1990s and early 2000s, extensive research into autonomous flying was performed (Chapuis et al., 1997; Eck, 2001; Eck et al., 2000, 2002). Since then, the trend in UAV photogrammetry has been toward the use of autonomous UAVs because manually controlled systems are highly sensitive to environmental conditions (Eisenbeiss, 2009). Micro-UAV systems such as microdrones could provide ideal remote-sensing platforms for various applications (Eisenbeiss, 2009; microdrones, 2012; Nebiker et al., 2008). These systems integrate a flight-control system, which autonomously stabilizes the platform and supports remote-controlled navigation. Additionally, micro UAVs can automatically provide DSM using high-resolution images acquired by the system (Dominici et al., 2012; Remondino et al., 2011).

A significant effort has been invested in autonomous micro air vehicles (MAVs) to tackle the challenges of miniaturization, autonomy, and control. Recently, the PIXHAWK system was developed by the Computer Vision and Geometry (CVG) group of ETH Zürich (Meier et al., 2012) to provide a flexible and computationally strong research platform for MAVs. The focus of this project is to use computer vision on the MAVs to enable autonomous action. This system can interface with stereo cameras to provide a depth map for obstacle detection.

Since most photogrammetric UAV systems are loaded with various types of sensors, the weight and dimensions of each sensor are restricted according to the overall payload. Such payload limitations necessitate the use of small, lightweight sensors, which often affects the accuracy of the data. However, owing to the recent development of micro-electro-mechanical systems (MEMS), sensors with the most advanced technologies have become much smaller and less expensive. UAVs are currently equipped with a number of sensors to provide high-quality images. A smartphone is an intelligent type of terminal that can be conceptualized as ubiquitous and capable of operation in a 3G environment at any time or location. In addition to the built-in camera (which provides relatively high-resolution images), it also has a variety of built-in MEMS sensors, such as GPS, accelerometer, and magnetometer (which can provide location and attitude information on an aircraft). Therefore, the data provided by the camera, GPS, and IMU included in current UAV systems can be obtained from one smartphone. And a single lightweight smartphone (weighing less than 110 g, 70 g or less without the liquid crystal display and battery) could be installed in any type of UAV without violating payload limitations.

Additionally, smartphone functions include the Internet, e-mail, SMS (short messaging service), MMS (multimedia messaging service), and IM (instant messaging) (Chang et al., 2009). Hence, the data provided by a photogrammetric UAV while in flight can be monitored on a real-time basis. Furthermore, anyone can develop a desired application, and many useful existing applications can be more easily employed.

Accordingly, the use of smartphones allows a photogrammetric UAV system to be established at much lower cost than existing systems. However, there has been no research on the use of smartphone technology in this context. This study is aimed at assessing the feasibility of using smartphones as payloads for photogrammetric UAV systems; the study's primary contributions can be summarized as follows:

1. The development of a photogrammetric UAV system to send and monitor images automatically taken by a smartphone loaded onto a UAV, as well as the data obtained from a variety of sensors built into the smartphone.
2. The camera lens built into a smartphone is subject to much greater distortion than the lenses generally used for photogrammetry. Therefore, camera calibration is performed to correct the lens distortion, and images obtained from the smartphone are processed taking the interior orientation (IO) parameters into account.
3. Static and dynamic experiments are conducted to assess the feasibility of using a smartphone as the payload for the photogrammetric UAV system. This feasibility study evaluated 3D position data, attitude data, and accuracy of image orientation, which were acquired by the application developed.
4. In the dynamic experiment, the smartphone image-based digital elevation models (DEMs) (hereafter DEM_i) are generated. These are compared with terrestrial laser scanning-based DEM (hereafter DEM_t). In addition, ortho-images are generated via a smartphone image block and only the DEM_t for the test area. A discussion and conclusions are presented in Sections 4 and 5, respectively.

2. Methodology

2.1. A smartphone-based photogrammetric UAV system

At the 20th ISPRS Congress held in Istanbul, Turkey, in 2004, a new ISPRS IC Working Group was initiated. The focus of this group was the automatic acquisition of high-resolution images via new technologies for autonomous vehicle navigation and UAVs. At the 21st ISPRS Congress, held in Beijing, China, in 2008, research was presented regarding the processing and application of images obtained from UAVs. These presentations were indicative of the current state of the art and the demand for research on UAVs in photogrammetry. Most recently, the first UAV-g 2011 conference was held, and many researchers in various areas, including photogrammetry, presented and discussed their outcomes to create synergies between research and application using UAVs in geomatics.

A photogrammetric UAV system generally consists of (a) an unmanned aircraft, (b) an onboard avionics system, (c) various sensors, and (d) a ground-station system. The ground-station system monitors the flight of a UAV and communicates with the onboard avionics system. As UAVs are capable of carrying only relatively small payloads, there are many limitations with respect to the onboard avionics system and other sensors. Such payload limitations necessitate the use of either lightweight sensors or lightweight navigation units, which often leads to reduced accuracy in the data provided by UAVs (Eisenbeiss, 2009).

Advancements in computer and IT technologies have led to many applications that consider and embed user convenience. Typical of these applications is the new generation of smartphones. A smartphone is a mobile communication terminal equipped with an open-type operating system. These devices have affected not only the technological aspects of life, but also the patterns and perceptions of their users. As the use of smartphones becomes more widespread, a variety of sensors and other devices are being incorporated into these units to create a more convenient interface for users. Numerous research projects are underway to study their diverse applications. Takeuchi and Kennelly (2010) and a research team at the University of California (CITRIS, 2011) evaluated the possibility of using a smartphone equipped with an accelerometer