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Robust and adaptive band-to-band image transform of UAS miniature multi-lens multispectral camera

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ABSTRACT

Utilizing miniature multispectral (MS) or hyperspectral (HS) cameras by mounting them on an Unmanned Aerial System (UAS) has the benefits of convenience and flexibility to collect remote sensing imagery for precision agriculture, vegetation monitoring, and environment investigation applications. Most miniature MS cameras adopt a multi-lens structure to record discrete MS bands of visible and invisible information. The differences in lens distortion, mounting positions, and viewing angles among lenses mean that the acquired original MS images have significant band misregistration errors. We have developed a Robust and Adaptive Band-to-Band Image Transform (RABBIT) method for dealing with the band co-registration of various types of miniature multi-lens multispectral cameras (Mini-MSCs) to obtain band co-registered MS imagery for remote sensing applications. The RABBIT utilizes modified projective transformation (MPT) to transfer the multiple image geometry of a multi-lens imaging system to one sensor geometry, and combines this with a robust and adaptive correction (RAC) procedure to correct several systematic errors and to obtain sub-pixel accuracy. This study applies three state-of-the-art Mini-MSCs to evaluate the RABBIT method's performance, specifically the Tetracam Miniature Multiple Camera Array (MiniMCA), Micasense RedEdge, and Parrot Sequoia. Six MS datasets acquired at different target distances and dates, and locations are also applied to prove its reliability and applicability. Results prove that RABBIT is feasible for different types of Mini-MSCs with accurate, robust, and rapid image processing efficiency.

1. Introduction

The use of Unmanned Aerial System (UAS) platforms for acquiring photogrammetric and remote sensing data has received increased attention from researchers, industries, and governments in recent years (Colomina and Molina, 2014). Compared with satellite and airborne platforms, UAS have the benefits of low manual operation risk, low cost, high efficiency, and the acquisition of high temporal and spatial resolution images (Toth and Jóźków, 2016). Multispectral (MS) and hyperspectral (HS) cameras are indispensable for acquiring visible (Red (RED), Green (GRE), and Blue (BLU)) and invisible (Rededge (REG) and Near Infrared (NIR)) imagery, thus enabling environmental monitoring, vegetation biomass estimation, and disaster investigation. The derived vegetation index from MS and HS imagery is the key to analyzing the health of plants, in which more than 70 vegetation indices can be obtained by a combination of broadband and narrowband spectral information in the range 400–1050 nm (Agapiou et al., 2012). Thus, mounting miniature MS/HS cameras on UAS platforms is the most effective solution for vegetation monitoring applications (Sankaran et al., 2015).

Recent developments in MS and HS cameras have made them smaller and lighter to meet the limited space and payload capacity of UAS platforms. According to the structure design, MS and HS cameras can be categorized as either single lens or multi-lens imaging systems. A single lens imaging system utilizes a single image sensor that has the ability to obtain multiple or even hundreds of spectral bands by respectively either modifying the sensor filter (Lebourgeois et al., 2008) or adopting the Fabry–Perot Interferometer (FPI) technique (Mäkeläinen et al., 2013). Unlike a single lens imaging system, multi-lens imaging systems have single or multiple camera bodies that utilize several image sensors to record discrete spectral bands using multiple lenses and filters. However, the original MS images of a multi-lens imaging system

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Fig. 1. The state-of-the-art miniature MS/HS cameras in the current UAS market. Left to right is the ADC, MiniMCA, RedEdge, Sequoia, Rikola, and a modified dual-camera multi-lens imaging system.

have significant band misregistration errors due to lens distortion and the differing positions and viewing angles of each lens. This results in geometric distortions and ghosting effects in the original MS images, which requires correction through band co-registration to obtain accurate spectral information for subsequent remote sensing analysis.

There are different types of miniature multi-lens multispectral cameras (Mini-MSCs) in the current UAS market that have different numbers of lenses, sizes, and spectral ranges. It is necessary to evaluate their band misregistration errors and determine a general solution for correcting the different types of systematic errors during band co-registration procedures. The objective in this study is to develop a general band co-registration method that is adaptive and robust to deal with the band co-registration issues of different Mini-MSCs. Section 2 includes reviews of miniature MS and HS cameras and the literature about related band co-registration methods. The proposed method and collected MS datasets from state-of-the-art Mini-MSCs for band co-registration performance analysis are introduced in Section 3. The results and conclusions are respectively analyzed and discussed in Sections 4 and 5.

2. Miniature MS/HS cameras and band co-registration methods

Several types of miniature MS and HS cameras have been manufactured for remote sensing image acquisition over the last decade. As some MS cameras utilize a multi-lens structure, researchers have proposed various solutions to deal with related band co-registration issues. However, none can offer a general solution that suits all types of Mini-MSCs. Details of miniature MS and HS cameras and the proposed band co-registration methods are introduced in this section.

2.1. Miniature MS and HS cameras

Fig. 1 and Table 1 show the appearance and specifications of state-of-the-art miniature MS/HS cameras available in the current UAS market, such as the Tetracam Agricultural Digital Camera[1] (ADC), Tetracam Miniature Multiple Camera Array[8] (MiniMCA), Micasense RedEdge,[2] Parrot Sequoia,[3] Rikola,[4] and a modified dual-camera multi-lens imaging system. The cameras' structure, sensor geometry, body size, and acquired spectral information differ from one another. We categorize those cameras based on their number of lenses into single lens and multi-lens imaging systems and discuss them in detail in the following sections.

2.1.1. Single lens imaging system

As depicted in Table 1, single lens imaging systems include the ADC MS camera and Rikola HS camera. The ADC was introduced in 1994 and has proven its capabilities in UAS agricultural applications (Petrie, 2003). It has a 3.2 megapixel (2048 × 1536) resolution Complementary Metal–Oxide Semiconductor (CMOS) sensor, which is divided into a mosaic of tiny optical filters, each of which allows a separate RED, GRE, or NIR band of wavelengths to pass while blocking others. This technology creates MS imagery that includes one invisible and two visible bands with spectral information approximately equal to the bands of the Landsat Thematic Mapper (i.e. TM2, TM3, and TM4). It has advantages such as its low cost and light weight, but its applications are limited by the low image quality and it cannot get precise radiometric information, as it has adopted a broadband filter (Huang et al., 2010). Nevertheless, it has been mounted on an unmanned helicopter and used for rice crop yield biomass estimation (Swain et al., 2010) and soil salinization investigation (Tamás and Lénárt, 2006). Similar single lens cameras can utilize RED-blocking to replace the internal NIR-blocking filter of a consumer-grade camera sensor, which has higher image resolution that can also obtain MS imagery with BLU, GRE, and NIR (Hunt et al., 2011; Lehmann et al., 2015). There is no band co-registration issue as only one lens is adopted.

The Rikola HS camera also utilizes a single lens structure, but it could obtain hundreds of spectral bands. It was first introduced in 2011 as a frame-based megapixel (1010 × 1010) HS camera that adopts the FPI technique to acquire HS information. When the light is collimated through the FPI, the transmitted spectral bands are a function of the interferometer air gap. It is thus possible to get different sets of visible-to-NIR (VNIR) or short-wave infrared (SWIR) light by changing the air gap. A HS cube can thus be constructed through a sequence of images captured with different air gaps. There is no band co-registration issue if the imaging status is in a static environment. However, since each set of spectral bands was acquired at a different time, it is necessary to perform band co-registration, especially when mounted on a moving UAS platform (Honkavaara et al., 2017; Vakalopoulou and Karantzalos, 2014). With the advantages of its light weight and perspective projection geometry, it is well suited for mounting on a small UAS for precision agriculture applications and for utilizing the latest UAV image processing software to create a digital surface model (DSM) and HS ortho-images. For instance, Honkavaara et al. (2016) utilized both FPI-based VNIR and SWIR cameras to investigate the performance and thus generate a DSM and measure the surface moisture of a peat production area.

2.1.2. Multi-lens imaging system

A multi-lens imaging system can be further divided into single camera or multi-camera structures. The single camera structure adopts one imaging system with multiple lenses that acquires multiple images simultaneously. Such systems have been utilized for large area aerial mapping, 3D city modeling, and MS images acquisition, i.e. Z/I DMC, Microsoft Ultram Osprey, and Leica RCD30 (Petrie and Walker, 2007). The multi-lens structure of Mini-MSCs enables users to obtain discrete narrowband spectral information when utilizing separate lenses with specific band-pass filters, such as the MiniMCA, RedEdge, and Sequoia MS cameras.

As listed in Table 1, the MiniMCA includes three camera models with 4 (MiniMCA-4), 6 (MiniMCA-6), or 12 (MiniMCA-12) lenses. The user-configurable spectral bands allow a user to collect specific

[1] http://www.tetracam.com/.
[2] https://www.micasense.com/.
[3] https://www.parrot.com/.
[4] http://www.rikola.fi/.