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Original article

An UAS-assisted multi-sensor approach for 3D modeling and reconstruction of cultural heritage site

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ABSTRACT

Unmanned Aerial System (UAS) has been widely used to produce highly-precise orthomosaics, Digital Surface Models (DSMs), Digital Terrain Models (DTMs) and 3D models in many applications. UAS is also utilized to document cultural heritage sites using low-cost photogrammetric approach. Particularly, possibility of multi-sensor acquisition provides substantial information about both geometric features and material classification. In this study, a novel methodology using multi-sensor data acquisition is proposed in order to extract and to distinguish material features from UAS-based photogrammetry for the cultural heritages. Sensors which are able to collect visible, thermal and infrared radiations of the electromagnetic spectrum were employed to produce 3D model information of Assus Ancient Theater located in Behramkale Village, Canakkale, Turkey. The results showed that the accuracies of the 3D models were obtained as ±2–3 cm, ±10–15 cm and ±5–7 cm for the digital, thermal and multi-spectral camera systems, respectively. Beside the given high-accurate geometric model, the classification outcomes as a result of the spectral analysis revealed material features in an affordable and efficient way.

1. Research aim

The purpose of this study is developing a method to generate UAS-assisted digital, thermal, and multi-spectral 3D point clouds and orthomosaics in the cultural heritage site. The article discusses the findings of the thin sections and the material classification using the reflectance of the surface of the material. The advantage of feature extraction using multi-sensor imagery is shown, and the concluded procedure can be clearly adapted to different archeological fields against general aging and other destructive factors.

2. Introduction

Ancient sites are important symbols of the cultural heritage. It is vital to model and to reconstruct them for protection against general aging and destructive factors such as earthquakes, landslides, atmospheric cycle and flooding. Photogrammetry is the science of making measurements using central projection imaging from sensors, particularly for recovering the three dimensional positions of surface points. Digital photogrammetry techniques have long been used to produce high-accurate photo-realistic 3D models of archeological sites and structures [1,2]. Furthermore the use of easy acquisition and low-cost software improves and simplifies the production of geometric data in digital format [3].

Modern photogrammetry and remote sensing identified the potential of UAS-sourced imagery in the last decade. The photogrammetric survey has developed its own traditional acquisition and processing method with the assist of advanced UAS technology [4,5]. The orthomosaic generation was expressed for the archeological ruin in Hungary using a digital camera integrated to a fixed-wing UAS [6]. As a further study, a quadcopter which is equipped high-resolution digital camera was used to obtain orthophoto and 3D point clouds in Germany and Cambodia [7]. The use of an hexacopter equipped with a digital camera was first explained to generate the DSM and orthophoto of a Roman villa archeological site located in Aquileia (Italy), a well-known UNESCO WHL site [8].

The development and improvement of various types of sensors, data processing methodologies and multi-resolution 3D representations contribute considerably to the material identification as well as documentation, conservation and presentation of archeological information in the cultural heritage site. The multidisciplinary approach in cooperating multi- and hyper-spectral imagery was defined in order to assess exposed and known buried archeological remains [9]. Furthermore, the integrated optical and electronic components were presented to achieve the sensor fusion in the cultural heritage applications [10]. A system which employed multi-sensor surveillance technologies, using optical and infrared

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Fig. 1. (a) Studying area in NW Turkey, (b) the location of Ancient Theater, (c) a snapshot from the fieldwork in the study area.

cameras, wireless sensor networks was also proposed to setup a warning system for monitoring archeological and cultural sites [11]. Moreover, the reliable non-destructive techniques based on thermal camera imagery were introduced for the historical sites [12]. In addition, a suitable group of sensors was selected and fused for indoor 3D documentation applications using a low-cost Inertial Measurement Unit (IMU) digital cameras, and 3D cameras [13].

Many other similar works arise in different domains. For example, a new augmented reality system of the patient's infrared tissue temperature maps was proposed for directly visualizing myocardial ischemia during cardiac surgery [14]. Furthermore, thermal imaging was used on smartphone attachable thermal devices in medical applications [15]. In addition, a method was presented for automatically generating 3D spatio-thermal models to quickly represent 3D heat distribution for their existing buildings by leveraging recent image-based 3D modeling approaches as well as depth cameras and thermal imaging [16–18]. Multi-spectral data of the plant surface was successfully used to determine the location of sick leaves on the 3D model [19]. Multi-spectral data on 3D objects was captured to produce visual images with high quality in computer graphics [20]. Furthermore, many examples can be extended to culture heritage and biomedical imaging etc. [21,22].

Although the UAS photogrammetry has been widely used in the 3D documentation of the cultural heritage sites, the UAS-assisted new light-weight and low-cost sensors which are capable of collecting the reflection of electromagnetic radiation at different ranges, provide more detailed information about the material of the ruins at the sites. In this study, the uses of three band multi-spectral camera covering the Near Infra-Red (NIR), Red Green (RG) (spectral range: 0.52–0.92 μm), thermal camera forming an image using infrared radiation (spectral range 7.5–13 μm) and typical digital camera producing an image in the visible spectrum (spectral range: 0.4–0.7 μm) are proposed to generate 3D geometric modeling and to discriminate the material features at the historical site.

The paper (a) presents an UAS-assisted photogrammetric procedure to generate high-accurate digital, thermal, and multi-spectral 3D point clouds and orthomosaics; (b) analyzes the findings of the thin sections prepared for examination with a microscope; (c) investigates the material classification, based on the results in (b), using the reflectance of the surface of the material; (d) proposes the feature extraction from the digital and thermal orthomosaics to detect the surface shapes and characteristics.

The rest of the paper is organized as follows: Section 3 explains the study area. Section 4 describes the methodology used in this study. Section 5 provides the results of the photogrammetric process of the images obtained from digital, thermal and multi-spectral sensors. Section 6 gives information about the findings from the petrographic studies. Section 7 includes the results of

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