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Method for photogrammetric surveying of archaeological sites with light aerial platforms

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ABSTRACT

In this paper, we describe a complete methodology for performing photogrammetric surveying of archaeological sites using light aerial platforms or unmanned aerial vehicle (UAV) systems. Traditionally, the main problem with using these platforms is the irregular geometry of the photographs obtained. These irregular image block patterns are occasioned by uncontrolled circumstances (e. g. effect of wind, lack of flight control, etc.) which generate high imprecision in the positioning of camera stations. The method proposed here allows the execution of the photogrammetric flight following the predicted parameters determined in mission planning (camera focal length, photo scale, ground sample distance -GSD-, overlaps, etc.) so we can obtain regular flight geometries. Our method allows the use of conventional photogrammetric data reduction methods based on the use of stereoscopic photogrammetric workstations. Although flights with irregular patterns can allow the formation of stereo pairs within certain limits, conventional photogrammetric procedures often have great difficulty in processing these irregular image blocks. For this reason this system raises the staking out of the camera positions by using a robotized total station and a mini prism situated on the platform. This method is applied to a real photogrammetric survey of an archaeological site of the Tartessic epoch in Southern Spain. The results obtained, confirmed by a quality control of the photogrammetric flight, have demonstrated the viability of this methodology even when moderate wind effects appear.

1. Introduction

In any archaeological study a cartographic survey of the site is essential. The terms of this survey will depend on the final output of cartographic products (topographic maps, digital elevation models -DEM's-, orthoimages, VRML models, etc.) and the technical specifications needed to obtain them (working and output product scales, accuracies, available instruments, data acquisition and reduction methods, economical costs, etc.). Photogrammetry, both aerial and terrestrial, has largely been employed in this type of survey (Fryer et al., 2007). In fact, architectural and archaeological photogrammetry is nearly as old as photography, and the first archaeological photogrammetric recordings began at the end of the XIXth century (Patias et al., 2008).

Aerial techniques can be an optimal solution in the case of medium-sized and large sites, since the possibility of raising sensors and capturing the information, in many cases rather difficult to obtain at ground level, can increase the performance of photogrammetry. But a photogrammetric flight must fit as far as possible to a mission plan for an adequate fulfillment of the survey objectives. Thus, appropriate photogrammetric block geometry facilitates the stereoscopic image analysis but also minimizes the economical cost of data acquisition and processing. In the general case of photogrammetry (vertical stereo photographs), mission planning must tightly constrain many different parameters: sensor, field of view or camera focal length, photo scale or ground sample distance −GSD-, overlaps, base-height ratio, tilt tolerances, etc. Usually in conventional aerial photogrammetry the project requirements are given by technical specifications defined by governments and agencies. There are also some standards, such as DIN 18740-1:2001-11 and 18740-4:2007, which establish the requirements for the different photogrammetric parameters in aerial projects with both analogical and digital cameras. So aerial photogrammetric projects are usually planned and carried out according to those requirements, which implies the making of image blocks organized in parallel strips to ensure stereoscopic coverage with multiple stereo pairs. Each photograph overlaps with the next photograph along the same flight-line with 60–70% forward overlap (endlap), while adjacent strips overlap 20–30% (sidelap).

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Any conventional photogrammetric project must fit to that block geometry even in the case of cartographic surveys at limited archaeological sites. But these surveys generally require working with large scales and high resolutions. As a result, conventional airborne photogrammetric surveys can be unfeasible because of the limited site extent, the large scale required, the expected low flight height and speed of the aircraft and the relatively high cost of the technique. The use of alternative techniques based on close range photogrammetry from light and low height platforms can solve this problem. The last decade has seen extensive use of these light aerial platforms or unmanned aerial vehicles (UAV) combined with digital non metric cameras (both compact and reflex). The important developments in image resolution, dropping prices, improvements in camera calibration capabilities, commercialization of helium and hot air devices and radio controlled model airplanes, helicopters and drones capable of carrying enough instruments for a payload, the miniaturization of global positioning systems and inertial motion units (GPS/INS), etc. are the main factors responsible for the increased attraction of using these instrumentations. These techniques comprise the so-called small format aerial photography (SFAT) and they use different UAV systems such as kites, helikites, balloons, blimps, radio controlled model airplanes and helicopters (Warner et al., 1996; Verhoeven, 2009; Aber et al., 2010; Chiabrando et al., 2011). Powered paragliders and ultralights can also be effectively used in archaeological surveys carried out under SFAT (Faustmann and Palmer, 2005).

The simplest low height aerial platforms are tall tripods and telescopic masts which can raise the camera up to 10–15 m (Georgopoulos et al., 1999). The photogrammetric network can be easily planned and surveyed and the camera remains static during exposition. But there are difficulties in making vertical photographs, so variations in scale will occur, and in any case the camera height is limited. Other light and economical UAV platforms are related to the use of kites and helikites – a hybrid system combining kites and balloons – to minimize the wind effect (Verhoeven et al., 2009; Verhoeven, 2009; Aber et al., 2010). These depend largely on the wind conditions and it becomes rather complicated to maintain regular image block geometries, so their use is not very extensive.

In recent years radio controlled aerial UAV's (drones) have been increasingly used for applications in cultural heritage surveys including: pre-Columbian sites in Peru (Eisenbeiss, 2005); Landenberg castle in Switzerland (Püschel et al., 2008); several ancient Greece sites (Skarlatos et al., 2004); and the Augusta Bagiennorum archaeological site in Italy (Bendea et al., 2007). Most of these drones (airplanes and helicopters) use GPS/INS systems which facilitate the planning, execution and processing of the photogrammetric flight. However these types of UAV's have some problems such as: vibrations (although there are some anti-vibration platforms); raising dust at very low flight heights; the need for well trained operators for air navigation; safety precautions in urban areas, where according to some countries' laws UAV's cannot be used; and, of course, the high cost. This cost is higher in those cases where the UAV have large payloads because of the need to lift heavier reflex cameras (metrically more stable than the smaller zoom compact cameras). UAV's without GPS/INS navigation systems make irregular image block geometries, even in the case of using video transmitter systems (Skarlatos et al., 2004). Several studies have shown that the UAV's with GPS/INS can obtain a relative accuracy in the trajectory of around 0.5 m (Eisenbeiss, 2004). In this sense, Sauerbier and Eisenbeiss, 2010 present the results obtained in several studies (using different UAVs) where they analyze and compare the flight trajectory obtained with respect to the flight plan. A more complete study of UAVs can be found in Eisenbeiss, 2009.

Other systems include balloons and blimps, which are more economical and solve some of the UAV's problems in relation to vibrations, raising dust, safety precautions in urban areas and the need for trained operators for flight operations. Cameras are mounted on platforms balanced by pendulum or mainly by Picavet suspension (Picavet, 1912). The camera cradle can be radio controlled, allowing camera orientation and exposition from the ground. TV systems and digital viewfinders connected to the camera allow the operator to follow the mission plan. As with other UAV's, ample references can be found with respect to balloons (both helium and hot air) and blimps for surveying archaeological sites (Karras et al., 1999; Celikoyan et al., 2003; Bitelli et al., 2003; Bitelli and Girelli, 2004; Altan et al., 2004; Fotinopoulos, 2004; Mihajlovic et al., 2008; Gómez-Lahoz and González-Aguilera, 2009). But these aerial platforms also have problems during flight control, since they are very sensitive to winds (large problems arise with wind speeds higher than 10 km/h). Also poor image block geometry often appears because of irregular image coverage due to inadequate flight control and lack of knowledge about the actual camera position with respect to the planned trajectory.

The use of these platforms presents advantages and disadvantages (e.g. wind conditions, space requirements, cost, restrictive rules, obstacles, etc.). The particular conditions of the project with the available instruments (UAV, cameras, navigation systems, etc.) and costs will define the best option to choose.

In this context, the present paper describes a methodology for the use of tethered UAV's in photogrammetric surveying of archaeological sites. This methodology aims at improving the operational procedures in order to fit the image block geometry to a previously designed mission plan, independent from the platform used. This method allows the use of conventional photogrammetric data reduction methods based on the use of conventional mapping stereoscopic photogrammetric workstations (DPW). Although flights with irregular patterns can allow the formation of stereo pairs within certain limits (poor overlaps, inadequate convergence or divergence of camera optical axes, etc.), a conventional DPW may have difficulties in processing these irregular image blocks. Thus, we have developed an example using a balloon for applying the proposed methodology in order to demonstrate the viability of this system for planning, controlling and guiding.

2. Methodology

As mentioned above, proper flight geometry during image acquisition is essential to conventional aerial photogrammetric methods. These procedures minimize the number of photographs, make the average photo-scale and overlaps homogeneous, avoid areas without stereoscopic coverage and facilitate the stereoscopic image analysis. Mission planning analyses all these parameters. At this stage a digital elevation model (DEM) can help to predict scale and overlap changes due to large relief variations in some areas of the site. This is an important matter because the usual large working scales in archaeology can imply significant height differences near vertical walls, ditches, pits, graves, etc. This implies scale changes and the presence of occluded areas. These problems can be predicted and solved by increasing the overlap percentage only on those critical areas. Other flat areas are covered with the usual overlaps without increasing unnecessarily the number of images. But most light aerial platforms do not allow proper block geometries, it being rather difficult to obtain regular patterns.

The methodology developed in this work has been checked in an archaeological survey carried out with a tethered helium balloon (2.5 m diameter). This kind of platform is very unstable and sensitive to wind conditions, but with the proposed method the results have been optimum with respect to the flight pattern