UAV SYSTEMS FOR DOCUMENTATION OF CULTURAL HERITAGE

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ABSTRACT

Architectural documentation is an activity which requires getting information from different sources for complete and comprehensive analysis. In the field of architectural documentation different innovative systems have been developed in survey like digital photogrammetry and Terrestrial Laser Scanning (TLS). One of these techniques Unmanned Aerial Vehicles (UAVs) equipped with a digital camera have become one of the most promising techniques in last years. It opens various new applications in large scale and close-range and so becoming progressively common due to the considerable potentials in terms of accuracy, costs and abilities. Their capability of data acquisition with high resolution allows texture mapping on DSM (Digital Surface Model), 3D models and orthophotos. It is also possible to create mosaics, maps and drawings which can be used for image interpretation. These data can be applied to several applications including 3D documentation of environment, cultural heritage, monitoring and recording landscape data and infrastructural assets for risk analysis and management process.

This paper discusses the potentials of UAVs in order to analyze, interpret and manage cultural heritage data through a case study (carried out before). It also presents the procedure of processing UAV data in order to create digital surface models and photo-realistic outputs for digital reconstruction models and visualization. The obtained results have been demonstrated with case study and general discussion has been made for evaluating potential of UAV technique for cultural heritage documentation.

Key words: : UAVs, Cultural Heritage Documentation, DSM, Orthoimage.

1. INTRODUCTION

Heritage documentation process involves huge multimedia data containing different information such as photographs, photographic panoramas, rectified photographs, orthophotos, technical drawings, different 3D models including point clouds and other kind of data such as videos, reports, pictures, texts etc. This process can be

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considered mainly in five main parts as (1) planning documentation, (2) data acquisition, (3) data processing, (4) data management and (5) dissemination of the data. All these steps involve diverse and intensive use of digital technologies. In this case, choosing the appropriate technology, procedure and workflow is always a challenging and depends on the size, complexity and the level of required accuracy of the project (Patias et al., 2008).

Even though traditional survey methods are still important and useful in some cases, technological possibilities have given opportunity to support traditional techniques in different ways. As hand measurement can provide dimensions and positions of objects and scenes of a few meters, sketches in small size, it is sometimes more impractical and not enough for larger objects. In this case, photogrammetry and terrestrial laser scanning could be more suitable by covering larger areas and enabling a large quantity of three-dimensional measurements to be collected (English Heritage, 2007). The studies have shown that photogrammetry has advantages for large amount of data, accurate data, possibility to texture in high resolution and detail, geo-reference data with stereo-viewing capability of the 3D data (Grussenmeyer et al., 2002, Patias, P., 2006). Similarly Terrestrial Laser Scanning technology has high performance in terms of data acquisition speed (Russo and Guidi, 2011) in different field of uses and has advantageous when used appropriately (English Heritage, 2007; Russo and Guidi, 2011). Even each technology has pros and cons., in most cases the combination of these technologies and related methodologies regarding their benefits may be the best solution (Russo and Guidi, 2011; Grussenmeyer et al., 2008; Patias, 2006.).

These both techniques has made it possible to obtain a high level of detail and accuracy and result to be very effective for small and medium-extension areas. However for large areas close range photogrammetry and terrestrial laser scanning are not always the most suitable techniques. Here, the information obtained from aerial or satellite images provide an overview of the study area to complete the documentation. Even they have been used for a long time; such images have some limitations linked to the geometric resolution, inadequate for detailed studies, to the periods of acquisition and to the cost (Lo Brutto et al., 2012). Besides, another challenge of these methods is the difficulty involved in acquiring reliable radiometric information of the complete surveyed area, which can easily be obtained by means of traditional aerial photogrammetry. However, the costs of aerial photogrammetry are usually too high in relation to the limited extension of the surveyed areas. Even the 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 it is rather difficult to obtain data at ground level, which can increase the performance of photogrammetry. But these surveys generally require working with large scales and high resolutions. As result, conventional aerial photogrammetric surveys can be unfeasible because of the limited site extent, the large scale required, the expected low flight height, speed of the aircraft and the relatively high cost of the technique (Mozas-Calvache et al., 2012). In this case the use of alternative techniques based on close range photogrammetry and laser scanning from light and low height platforms can be a solution for these problems.

In the last years relatively low-cost Unmanned Aerial Vehicles (UAVs) have become popular for rapid and accurate documentation of cultural heritage.
The aim of this research is to study the potentials of UAVs for documentation of cultural heritage and analyzing the data in detailed scale. Particularly this paper focuses on application of a UAV system for inaccessible and dangerous areas of cultural heritage. One old building built as hotel in 19 th century in Bad Harzburg, Germany was chosen as case study. The research consists of the steps of the project and final outputs of the project. The study also provides the definition of UAV, advantages of the systems, potential use fields of the systems in cultural heritage domain as well as in general.

2. UAV SYSTEMS

2.1. UAV Definition

As a simply definition, UAV is an aircraft without aircrew and replaced by a computer system and a radio-link. It mainly comprises
-a control station (CS) which holds the system operators and the interfaces between the operators and the rest of the system.
-an aircraft carrying the payload which may be in different types
-a system of communication between the CS transmitting control points inputs to the aircraft and returning to payload and other data from the aircraft to the CS.
-support equipment (may include maintenance and transport items) (Austin, 2010)

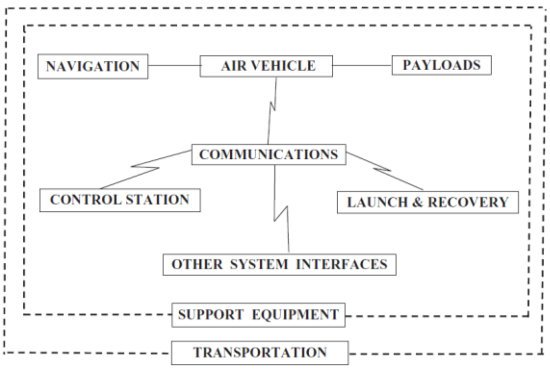

Figure 2. UAV system – functional structure (Austin, 2010)

These systems can be remotely controlled, semi-autonomous, autonomous or have a combination of them. They have a photogrammetric measurement platform with a measurement system including small or medium size still-video or camera, thermal or infrared camera systems, airborne LIDAR system or combination of them. This term was firstly used during 1970's and 1980's in United States Department of Defense and their most effective classification was done by the Unmanned Vehicle Systems International Association (International Unmanned Aerial System

Community) in 2008. Depending on this classification, they have mainly three categories based on their possible use which are; *tactic, strategic* and *special purpose* (Eisenbeiß, 2009).
UAVs have been used for different applications in many countries. They have diverse application fields mainly civilian and military ones. Beside their use in military in navy, army and air force, they have a great potential in observation, maintenance, surveillance, monitoring, remote sensing and security tasks (Eisenbeiss, 2004). Especially in environmental field they have been used for detection of environmental areas at risk, monitoring pollution, land, forestry, water course and level besides road traffic control, analysis of forecasting, power line inspection and pipe line security (Austin, 2010). Moreover, vegetation monitoring like coffee plantation and as an integral part of farm equipment in Japan, in road accident simulations and in many cases of forest fire monitoring, to monitor volcanoes and traffic fields are examples of UAVs use fields (Everaerts, 2008). As well as environmental tasks, they can also be deployed in surveillance applications against civilians, such as applications in policing (for missing persons, security and incident surveillance), border surveillance (Finn and Wright, 2012) and three-dimensional cadastral and transportation map updates, reconstructing mountain rock faces and calculating volumes of stock piles (Haarbrink and Eisenbeiss, 2008) and also in the last years for slope studies because of the reality in three-dimensional (3D) (Anuar et al., 2013).
However, the development of UAVs has been strongly motivated by military applications, during the World Wars balloons, pigeons and rockets were used for spying. Also after World War II, some nations were looking for aerial vehicles, which have the capability for surveillance, reconnaissance and penetration of hostile terrain without the deployment of human beings in areas of high risk (Eisenbeiss, 2004). The development of these systems have evolved with levels of technology of ever-higher performance and they have become a part of research field and opened new areas (Rinaudo et al., 2012). The first aerial photographs were taken by Gaspard Tournachon in 1858 from a manned balloon in Paris (Newhall, 1969). By the years, manned balloons and later model balloons were a part of this evolution. Wester-Ebbinghaus was the first to use a rotary wing UAV for photogrammetric purposes in 1980 (Eisenbeiss, 2009). But that time, these systems have several problems especially related to vibration because of wind and manual control which caused these system not to be acceptable as photogrammeric platform (Eisenbeiss, 2004). During the evolution of UAVs different kinds of balloons, kites, model helicopters and UAVs have showed high potential in process.

3. UAVs for CULTURAL HERITAGE

Photogrammetry has a long history of successful achievements in 3D recording and documentation. Since the first steps of photogrammetry, unconventional documentation problems could be dialed with the help of remotely taken images for 3-dimensional mapping in high accuracy. From that time on, close-range photogrammetry developed innovative and novel tools, techniques, and best practices to handle special and extreme, in some cases, technical problems in 3D mapping. Inaccessibility of monuments, visibility problems, highly oblique images, low texture objects, restrictions in time and/or budget etc. made for a search for the new technologies. A major technology boost with the introduction of digital images and the universal use of laser scanning, along with the development of new digital image processing techniques, offered new solutions (Rinaudo et al., 2012).

Following the developments in image capturing and processing, Unmanned Aerial Vehicles (UAVs) have become an alternative in cultural heritage domain and have been started to be successfully used in different projects. Since they have the ability to perform in high risk situations without any danger for researcher and they can reach the places where men cannot, they have become standard platforms in cultural heritage sector. Their cost-effectiveness, less economic limits, real time data capability, fast data acquisition and small-size features have made them as a strong alternative in heritage documentation projects. In cultural heritage area their applications are mainly focused on documentation, observation, monitoring, mapping, 3D modelling and 3D reconstruction (Remondino et al., 2011) as well as digital maps, digital orthophoto, digital elevation model (DEM) and digital surface models (DSM) (Patias et al., 2008).

In documentation and modelling of buildings, images are generally taken from the ground level for façade information and to detect the features on façades. However in many cases, it is difficult to get the photos of the roof of the buildings and to get an overview from the top with the building surrounding. In this sense UAVs enable to capture the images from the roof and to see the surrounding of the building in larger view. Additionally, with the help of oblique images, it is possible and easier to get information and observe also building façades with these systems. Oblique images make possible to record of historical objects with a vertical direction and they may be used for 3D photorealistic model production and façade views which also give opportunity to make analysis and determination of materials. Here, high accuracy recording should be considered so the details have to be recognized. In addition to such details, with the help of oblique cameras, it is possible systematically to take photos of the cities and then to arrange them in high quality and to share (Höhle, 2013). When needed, their combination with infrared and thermography cameras can be preferred for special purposes. Infrared and thermography cameras have valuable information for further data interpretation and object analysis in cultural heritage field in terms of spatial and spectral information. The applications with the integration of UAVs with such systems are considered as successful practices in cultural heritage study areas (Patias et al., 2013).

Archaeological documentation is other research and application field in which UAVs have been effectively used in cultural heritage domain. In 1970 Whittlesey reported on the use of a tethered balloon for archaeological documentations in the first time, which he actually started in 1967 (Eisenbeiß, 2009). After this experience, during the history, many systems like kites, balloons etc. have been used for archaeological area documentation. In parallel to this evolution, in last years, increasing particular attention has been especially paid to archaeological areas in cultural heritage field in order to obtain complete documentation. In addition to terrestrial laser scanning and photogrammetry, UAVs applications has shown considerable progress in the field of aerial photography, laser scanning technology and thermal and ultraviolet imagery. In this sense generated RGB orthophotos, DEMs and 3D models have started to be used for observation of archaeological areas (Brumana et al., 2011; Rinaudo et al., 2012) and documentation of archaeological excavations (Eisenbeiss and Sauerbier, 2011; Brumana et al., 2013; Anuar et al., 2013), several ancient Greece sites (Skarlatos et al., 2004), for burial mounds (Hendrickx et al.2012), combination of UAVs and terrestrial systems for monuments (Püschel et al., 2008; Eisenbeiss et al., 2005; Lambers et al., 2007) and to document architectural remains (Zischinsky et al., 2000) and for modelling archaeological cultural heritage (Verhoeven, 2009).

4. CASE STUDY

4.1. Site Description

Harzburger Hof is an old Hotel in Bad Harzburg, Germany. It was built as Deluxe Hotel with casino on 1874 and unfortunately was destroyed by a fire in May, 2014. The building is planned to be renovated and reused as hotel in the future. The fire started on the roof of the building so we made a survey to check the situation of the roof with UAV.

(a)

(b)

(c)

Figure 3: (a): Harzburger Hof Hotel (www.panoramio.com) (b) The fire from the top (www.beobachter-online.de) (c) After the fire (www.goslarsche.de)

The application of UAV system aimed to document the building after the fire and to merge the data from laser scanner with UAV data. The interest was more focused on the roof.. In the field survey, 11 ground control points were measured with total station and terrestrial laser scanner survey was carried out. Two kinds of UAVs were used: the first one equipped with laser scanner and the other one with SLR camera. This study presents the first results of this experience.

4.2. Data Acquisition and Processing

Before starting to survey, 11 ground control points (GCP) were arranged a part of the area and 4 targets were put on a part of the building. RIEGL VZ-1000 Terrestrial Laser Scanner and Leica TS09 Total Station was used for the measurements.

The UAV system is a prototype Quadcopter based on a DJI F450 frame produced by GRAVIONIC[1]. The system is equipped with Canon IXUS 220HS 12MP camera calibrated before.

Figure 4: Quadrocopter

Figure 5: Flight path in Mission Planner 1.3.7.

Figure 6: Riegl VZ- 1000 TLS

Figure 7: Leica Total Station

Figure 8: A4 targets as GCP

The system overall weight is 1,5 kg with the dimension 50x50x40 with propellers. It is able to fly up to 45 minutes depending on payload. The electronic equipment includes APM2.6 autopilot with external GPS and magnetometer. In our case study the flight was about 9 minutes from 45 meters high and image overlap was 86%. For the flight, Mission Planner 1.3.7. software was used for managing flight path. Orientation of the images and orthophoto creation were prepared in Photoscan software.

[1] GRAVIONIC- German Geo Services- was founded in 2007 as a spin off of the Institute of Flight Guidance and Control (IFF) of the Technical University of Braunschweig, Germany. http://www.gravionic.com/

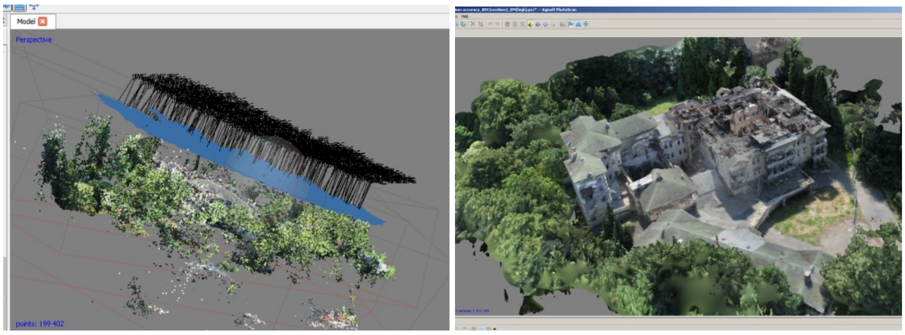

Figure 9: (a) Photo Alignment (b) Dense Point Cloud

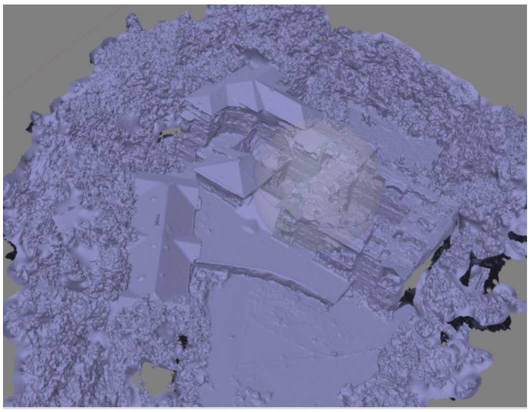

Figure 10: (a) Mesh Model

(a)

(b)

Figure 11: (a-b) Details from textured model from the roof Figure 12: Orthophoto

5. CONCLUSION

The use of UAVs in cultural heritage domain has showed increasing interest in last years. They have been started to use in many applications including archaeological areas, historic sites and cultural heritage buildings. They have become preferred platforms for documentation, modelling, mapping and monitoring purposes. Related to costs, flexibility, high resolution data and point density potentials they have become a strong alternative for geodetic surveys, risky surveys and dangerous and inaccessible places.

The case study presented in this paper is only the first results of the documentation of a historical building. It was a kind of experience to see the potentials of UAVs in order to get detailed documentation for especially inaccessible areas or dangerous/risky places. The use of UAV platforms can be an optimal solution for these kinds of places. Besides, they can be efficiently used to generate orthophotos and 3D models with or without texture. In some cases, the use of other techniques in order to support UAVs could have better results for a complete documentation. In similar cases to this building, it would be better to get also vertical images for façades details. It gives more opportunity for analyzing and observing the façades. Related to this study, the next step will be to combine UAV data with terrestrial data for complete documentation.

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