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A New Approach for Documenting Architectural Cultural Heritage: The Case Study Of Asinou Church In Cyprus

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Abstract

The documentation of architectural cultural heritage sites has traditionally been labor-intensive. New innovative technologies provide an affordable, reliable and straightforward method of capturing cultural heritage sites, thereby providing a more efficient and sustainable approach to documentation of cultural heritage monuments and sites that architects, archeologists and cultural heritage experts can use for data acquisition, archive, process, share and visualize for documentation, restoration, preservation and rehabilitation purposes. This paper focuses on a new novel approach used in several EU Research projects, to document the UNESCO WHL site of Asinou Church in Cyprus (http://www.byzantinecyprus.com/) using various modern techniques, such as UAV, photogrammetry and 3D printing. Hundreds of images from the monument were taken using a UAV with an attached high resolution camera. The images were processed to generate an accurate digital 3D model and reproduced using a 3D printer. Such a methodology provides architects, archaeologists, civil engineers and cultural heritage experts an accurate, simple and cost-effective method of documenting cultural heritage sites and generating digital 3D models using novel techniques and innovative methods. This approach can also be used in urban or rural environments to document large scale sites which traditionally are time-consuming and labor-intensive.

Keywords: cultural heritage, architecture, documentation, 3D models

1. Introduction

UAVs have become a common tool in cultural heritage and archaeological research as they provide higher resolution images compared with satellite imagery. Research indicates that unmanned aerial vehicles (UAVs) can be used for low-altitude imaging and remote sensing of geospatial information [Colomina & Molina, 2014; Cho et al., 2013; Mayr, 2013; Petrie, 2013]. According to Burkart et al (2014), the emerging development of small versatile UAVs for use in remote sensing offers simple and affordable observation from the air. UAVs are being used for surveying cultural heritage sites due to their affordability, reliability and ease-of-use (Themistocleous et al, 2015a; Themistocleous et al, 2015, M. Lo Brutto et al., 2014). Remote sensing technologies on a UAV platform are extremely useful for the detection and monitoring of cultural heritage features (Themistocleous et al, 2014a; Themistocleous et al, 2014b; Themistocleous et al, 2014c; Agapiou et al, 2013). UAVs can be a efficient, non-evasive and low cost resource to document cultural heritage sites (Themistocleous et al, 2014a; Themistocleous et al, 2014b; Themistocleous et al, 2014c; Agapiou et al, 2013) and can be fitted with sensors which are able to produce an unprecedented volume of high-resolution, geo-tagged image-sets of cultural heritage sites from above (Themistocleous et al, 2014a; Themistocleous et al, 2014b; Kostrzewa et al, 2003; Ruffino & Moccia, 2005; Scholtz et al, 2011). Recent developments in photogrammetry technology provide a simple and cost-effective method of generating relatively accurate 3D models from 2D images (Ioannides et al, 2013; Themistocleous et al, 2015a; Themistocleous et al, 2015b; Themistocleous et al, 2014a; Themistocleous et al, 2015c). Researchers have used the combination of aerial imagery for 3D reconstruction of the cultural heritage site. These techniques provide a set of new tools for cultural heritage experts to capture, store, process, share, visualize and annotate 3D models in the field. According to Colomina and Molina (2014), the use of UAVs for surveying cultural heritage sites is becoming increasingly common, due to the ease of use and the quality of the processed measurements. Several cultural heritage researchers have used UAVs for archaeological sites in the Mediterranean (Rinaudo et al, 2012; Remondino et al, 2011) as well as in Germany, Cambodia and Hungary (Seitz & Altenbach, 2011; Meszaros, 2011). As well, researchers have used the combination of aerial imagery for 3D reconstruction of the cultural heritage site (Fiorillo et al, 2012; Eisenbeiss, 2009).

This paper focuses on the methodology used to document the cultural heritage site of Asinou Church in Cyprus using various state of the art techniques, such as UAV, photogrammetry and 3D printing. In this study, aerial surveying of Asinou church was conducted using a small quadcopter, equipped with a 12MP Camera. Hundreds of images of the Asinou Church were taken by the quadcopter with the attached high resolution, 12MP, low cost camera. These photographic images were then used to create a digital 3D model and a 3D printer was used to create a physical model of the church. Such a methodology provides archaeologists and cultural heritage experts a simple and cost-effective method to document and generate relatively accurate 3D models from 2D images of cultural heritage sites.

Figure 1. Asinou Church

The study area is the church of Panagia Phorbiotissa, better known as Asinou Church (fig. 1), located in the north foothills of the Troodos Mountains of Cyprus, which is a UNESCO World Heritage Site (Themistocleous et al, 2015c). The modest structure boasts a common church design of the 12th Century. It is made up of a rectangular nave covered by a barrel vaulted dome. The structure was built with mud mortar and has experienced frequent collapses and reconstructions (www.byzantinecyprus.com).

2. Methodology

In the study, a small quadcopter with a compact 12MP camera was used to conduct the aerial 3-D survey. Over 1,000 images were taken at Asinou Church, which were post-processed using Agisoft Photoscan Professional to create a 3D model, which was then printed in 3D (fig. 2).

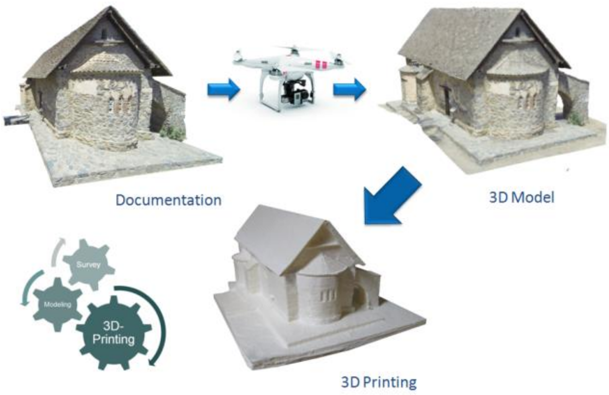

Figure 2. Methodology of 3D documentation of Asinou Church using UAV aerial imaging

2.1 Quadcopter with 12MP Camera

In this study, a small quadcopter (DJI Phantom 2) with an added gimble, telemetry and GoPro HERO3+ camera was used to acquire the images (figure 3). The Phantom 2 Quadcopter has a compact and highly integrated design combined with FPV flying and aerial photography (fig. 3) (Themistocleous et al, 2014c). The GoPro HERO3+ camera features 4K video capture at 15 fps, 2.7K capture at 30 fps, 60 fps in Full HD 1080p, and can also take up to 12MP still photos (Themistocleous et al, 2014c). A small quadcopter was used due to its maneuverability, which was needed to take images above and around the church.

Figure 3. Phantom 2 Quadcopter with GoPro Hero 3 Camera at Asinou Church

A gimble was added to the camera to provide high precision 3-axis camera stabilization system that allows for smooth aerial photography. The integrated GPS system included position holding, altitude lock and stable hovering to provide constant stability in flight. The copter was flown in manual mode to ensure that all the images necessary for image processing are taken and to avoid any obstacles around the church, especially trees (fig. 4). During the flight, two operators were required for the aerial survey; one operator controlled the flight path of the UAV while the other operator monitored the UAV telemetry data (fig. 4). The telemetry information was transmitted to the operator on a monitor in order to verify the position, distance, height and battery life of the quadcopter. This was necessary to guarantee the overlap and correct position of each image.

Figure 4. Phantom 2 Quadcopter with GoPro HERO3+ Camera during flight with two operators

2.2 Photogrammetry Software

Agisoft PhotoScan Pro photogrammetry software was used to conduct the image processing. Agisoft PhotoScan is capable of interpolating digital images in order to create high resolution, scaled and georeferenced 3-D models from them. Agisoft PhotoScan Professional's set of functions include aerial triangulation, polygonal model generation (plain/textured), setting coordinate system, georeferenced DTM generation and georeferenced orthomosaic generation (Themistocleous et al, 2014a). To complete the georeferencing task, the program requires either GPS coordinates associated with cameras, provided in an EXIF/ plain text file or in this case by ACPs generated by the autopilot, or GCP coordinates that can be used to achieve higher accuracy (up to 1 cm). Camera calibration data can be calculated by the program (and exported if needed) or imported from an external source. Agisoft PhotoScan Professional supports a range of input formats including JPEG, TIFF, PNG. A wide range of output formats (GeoTiff, xyz, Google KML, Wavefront OBJ, VRML, COLLADA, PDF) ensures easy import to any GIS system for future photogrammetric analysis (Themistocleous et al, 2014a).

Based on the latest multi-view 3D reconstruction technology, it operates with arbitrary images and is efficient in both controlled and uncontrolled conditions (Remondino et al, 2011) Photos can be taken from any position, providing that the object to be reconstructed is visible on at least two photos. Both image alignment and 3D model reconstruction are fully automated. Agisoft PhotoScan allows the building of 3D models and DSM with different resolutions. In addition, the software has an automatic tool of texture projection, which makes automatic projection from the color directly on the surfaces possible (Meszaros, 2011).

The first step in the program's procedure is called Structure from Motion (SFM). At this stage the software analyses the dataset, detecting geometrical patterns in order to reconstruct the virtual positions of the cameras that were used. The second step involves the creation of a complete geometry of the scene using a dense multi-view stereo reconstruction. At this stage the dataset of images are employed to produce a high-resolution geometry of the surface. This step successfully creates a 3D model, also known as a Digital Surface Model (DSM).

The processing began with the ortho-mosaic production from multiple images, that was then used for DTM production from which a contour map can be generated. All photos can be included in processing or it is possible to select a sub-set of images on key sites with the study area for more detailed analysis ensuring sufficient overlap and GCPs allow for this.

3. Results

Over 1,000 images were taken at Asinou Church, which were post-processed by removing the lens distortion and then processed using the Agisoft Photoscan Professional software (fig. 5).

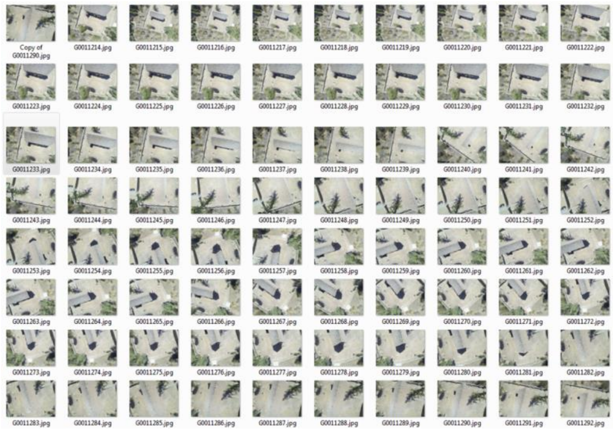

Figure 5. Images Processed with Agisoft Photoscan

Since the GoPro HERO3+ camera used a wide-angle lens, lens distortion removal was required by calibrating the camera and removing the distortion using the appropriate distortion filter (fig. 6).

Figure 6. Post-processing lens distortion removal

The Agisoft PhotoScan and a Cyprus University of Technology developed software package was used to conduct the image processing, where the images were entered into the software (fig. 5). Both software packages allow the generation of high resolution georeferenced orthomosaic, detailed DTMs and textured polygonal models through the use of the image overlay 9. The processing began with the ortho-mosaic production from these multiple images, which was used for the 3D model (fig. 7, 8). All images can be included in processing or it is possible to select a sub-set of images on key sites with the study area for more detailed analysis ensuring sufficient overlap and ground control points (GCPs) allow for this.

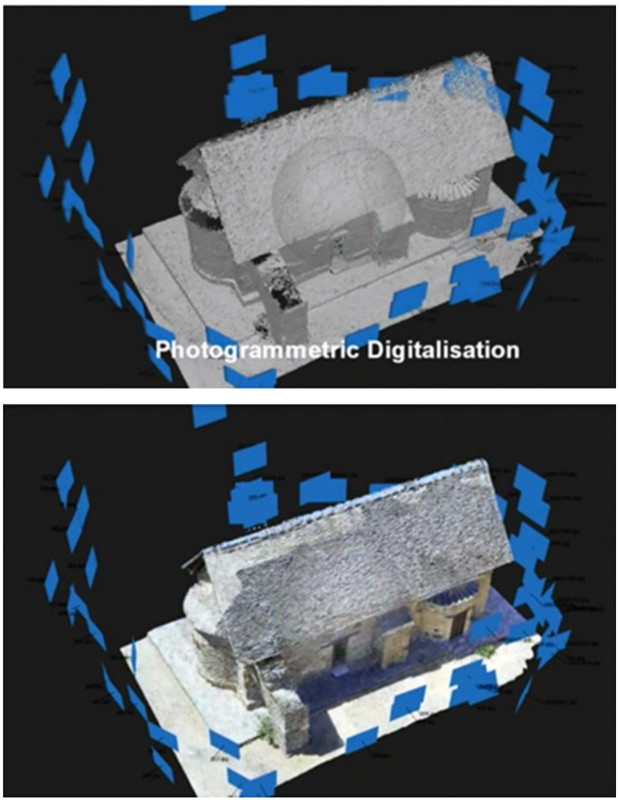

Figure 7. Ortho-mosaic production

Following the ortho-mosaic production, a high resolution 3D mesh model of the church was generated and exported to a surface model. The surface model was imported into Autodesk 3DS Max in order to clean up, fix and optimize the mesh. Any unnecessary noise or busy surroundings were cleaned up and large mesh issues, such as particles, holes, spikes and tunnels were fixed. The mesh was then prepared for printing, by exporting the corrected model into a .stl file, where a 3D printer was used to generate a 3D model. The model was printed using a Makerbot Replicator 3D printer with PLA filament and layer resolution of 100 microns, which provided an accurate representation of the church (figure 8).

Figure 8. 3D model of Asinou Church

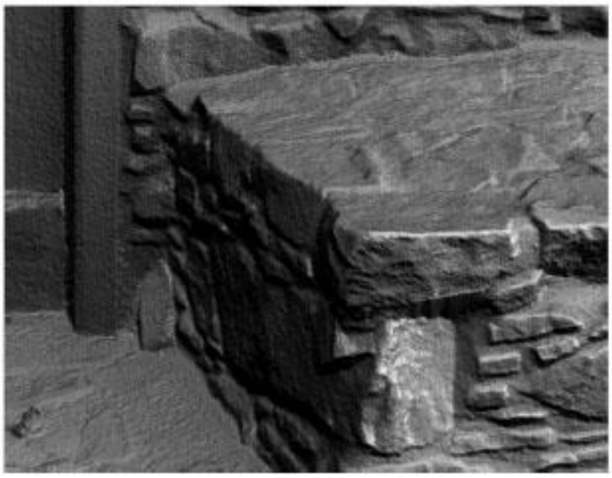

Figure 9: High resolution detailed Point Cloud Structure (1mm) generated by the CUT Software package

4. Conclusions

UAVs are becoming an extremely important tool for archaeologists, architects and cultural heritage documentation specialists to document and analyse cultural heritage sites as they provide a cost-effective and efficient manner to acquire high spatial resolution data with high temporal frequencies, especially in areas that have limited coverage and are inaccessible to humans. The study highlighted the ability of UAVs with on-board cameras to provide high resolution data of a cultural heritage site using a non-invasive technology and a specified number of ground control points.

In this paper, the DJI Phantom 2 with GoPro HERO3+ camera was used to survey the Asinou Church in high resolution. The aerial imagery obtained from the UAVs was imported a) into the Agisoft software, b) to the newly developed 3D Reconstruction software platform at the Digital Heritage Research Lab to create rapid and automated generation of ortho-mosaics and 3D digital surface models. The study highlighted the ability of UAVs with on-board cameras to accurately document a cultural site using non-invasive technology. The technologies employed were very useful in obtaining a 3D model of the Church, in high resolution and accuracy, which could then be reproduced using a simple 3D printer.

The methodology of using UAVs for documenting cultural heritage buildings can also be usedin the built environment to conduct tectonic building analysis and forensics by using different sensors such as infrared and thermal cameras. This method also provides and accurate, reliable and quick approach to document and analyze buildings in the exterior building envelope. As well, this method can also be used to survey larger areas in urban settings.

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