The Documentation of Ecclesiastical Cultural Heritage Sites in Cyprus

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ABSTRACT

Innovative digital applications are invaluable for the documentation and conservation of cultural heritage monuments. Digital techniques can provide data on cultural heritage sites to enhance understanding of their changes over time. Due to the age and conditions of cultural heritage monuments in Cyprus, especially churches, there is a great demand to develop a methodology that is capable of digitizing both the internal and external church using a variety of non-invasive techniques as a means of storing and managing documentation data and metadata for providing comprehensive culturally digital and documentation evidence. In this paper, the integration of various technologies was used to document the 12th century St. Efstathios Chapel in Kolossi, Cyprus. The methodologies included data acquired by close-range images from Unmanned Aerial Vehicles (UAVs) and hand-held cameras, coordinates from ground control points using Total Stations etc., to document both the internal and external facades and relics of selected religious monuments. Thousands of images from the monument were taken using a UAV with a high-resolution camera. The images were processed using photogrammetry to provide a digital model of the church. The use of the HSV color model was used to examine potential anomalies in the structure. The combination of the technologies will provide a 3D model to document and identify ecclesiastical cultural heritage sites, which can be incorporated into a dynamic database and valuable resource to better understand the cultural heritage monument. In this way, the end-users will be able to access the information from the digital platform at any time. This research is supported by the project entitled: "Navigators of Cultural Heritage Digitization of Churches of Cyprus and Crete" referred as "Digital unblocking of holy islands" and is co-funded by the European Regional Development Fund (ERDF)and by national funds of Greece and Cyprus, under the Cooperation Programme "INTERREG V-A Greece-Cyprus 2014-2020".

Keywords: Cultural Heritage, photogrammetry, HSV, color models, UAV, ecclesiastical monuments

1. INTRODUCTION

Digital techniques using UAV and photogrammetry can document and provide data on cultural heritage sites to enhance understanding of their changes over time [1]. In this paper, the authors attempt to find different techniques for analyzing the model and images acquired from UAVs and generated by photogrammetry in order to provide a better understanding by analyzing the images with the Hue-Saturation-Value (HSV) color model. The documentation of cultural heritage using UAVs and photogrammetry is becoming a common method to digitize and document cultural heritage monuments, as compared to traditional methods of acquiring 3D models such as laser scanning and LIDAR. Photogrammetry using UAV images provides continuous covering of the object in a high-resolution context, producing a highly dense and textured 3D point cloud model [2-3].

This paper provides the methodology that was used to document the 12th century Agios Efstathios Church. The church was documented using a UAV for the exterior of the church and a RGB camera for the interior of the church, whose images were then processed through SfM photogrammetry. The objective of this paper is to use an alternative color model, such as HSV color model, to further investigate the cultural heritage monument for any anomalies that can relate to building pathologies such as water damage, material degradation and structural anomalies. This might be considered as an additional method for visual inspections using remote sensing techniques. Photogrammetry, combined with HSV color models, can provide detailed information for diagnosis and inspection of cultural heritage monuments and sites, as it is a fast and accurate tool.

Innovative digital applications in the field of protection and enhancement of cultural heritage, as well as the threats to archaeological and cultural remnants of the past, create important, innovative requirements and challenges of protecting cultural wealth of a country. The project "Digital unblocking of holy islands" aiming to acquire 3D digital datasets of mass historic religious monuments and artefacts in the areas of the Archdiocese of Crete in Greece and the Holy Bishopric of Limassol in Cyprus. The purpose of this project is to develop an information hub for the management and promotion of ecclesiastical cultural heritage. In this way, the end-users will be able to access the information from the digital platform at any time.

2. STUDY AREA AND DOCUMENTATION

2.1 Study area

The Agios Efstathios Church, also known as Saint Efstathios Church, (figure 1) is located near the Kolossi Castle in Kolossi Village, which is within the Limassol district of Cyprus. The church of Agios Efstathios was built in the 12th century, although important repairs and conversions have been done to it during the middle of the 15th century. The Church is of a vaulted, cruciform, and square shape, 9.60 X 9.60 meters without the chancel. Inside it has three vaulted arches, the two standing in the north and south side with a width of 3.85 meters and a height of 2.90 meters, while the third is in the east side having a height of 3.10 meters and a width of 2.70 meters. Noteworthy frescos from the 15th century are in the dome. The peak of the dome consists of a fresco of Jesus Christ, while the Evangelists Apostles John, Matthew, Luke, and Mark are portrayed in the spherical triangles that support the dome. As well, there is a large fresco that was also created in the 15th century and depicts Saint Efstathios on horseback, bearing a shield on his left hand and a spear in his right hand, while his cloak flaps in the air. A deer with the cross between its horns can be seen on the lower right part of the fresco. The fresco of Saint Efstathios has sustained extensive damage over the years. It is believed that the church was used by the knights of the Order of St. John of Jerusalem (Knights Hospitallers), who were owners of the castle nearby, since the coat of arms of their Grand Commander, Louis-de-Magnac, was still upon the arch of the church until 1930. The same coat of arms exists on various point of the castle. Indeed, it is probable that the same knights -because of the military status of the saint and his Latin descent -gave the name of St. Efstathios to the Byzantine church that pre-existed.

Figure 1: Agios Efstathios Church in Kolossi, Cyprus

2.2 Documentation process and methodology

The documentation process includes a survey of the Agios Efstathios Church, beginning with the placement of ground control points (GCPs) inside and outside of the church. The GCPs were used to achieve centimeter accuracy of the model, in order to geo-reference the 3D models, so that they can be overlaid and provide a detailed model of the church using the point clouds generated from RGB and multispectral imagery. A DJI Mavic 2 Pro UAV with a 20MP.Hasselblad L1D-20c camera was used to generate images of the exterior of the church. A hand-held RGB Canon EOSM3 camera with 24.2 MP CMOS (APS-C) sensor and an EF-M22mm f/2 STM lens was used in a time-lapse function to document the church in the interior in order to create a complete point cloud of the entire structure. For the interior images, multiple portable lighting sources with diffused lighting was used in order to illuminate the interior of the church. As well, the camera was held by a 3D axis hand-held gimbal in order to stabilize the camera and avoid any blurry images as a result of the low lighting in the interior of the church. Structure for Motion (SfM) photogrammetry software was used to generate a point cloud of the church from the RGB and multispectral images using the GCPs to geo-reference the models. Finally, the point cloud model was generated, thereby providing an accurate documentation of the church. The methodology is presented in Figure 2.

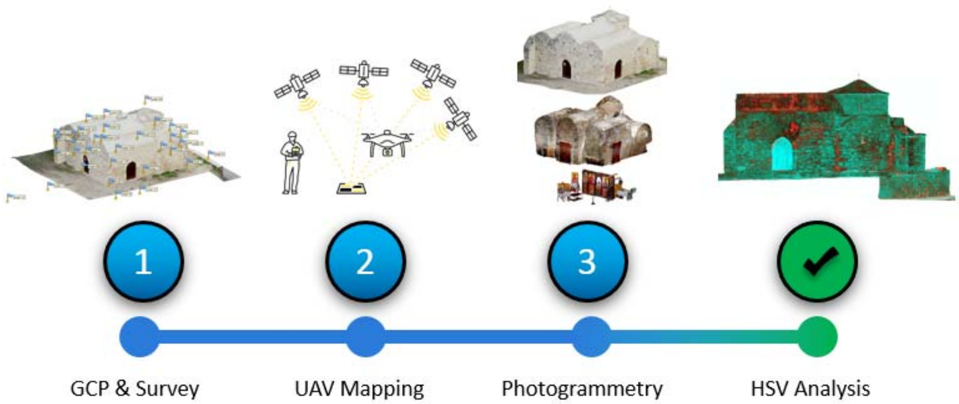

Figure 2: Methodology

2.3 Ground Control Points and Survey

To geo-reference the image, 36 Ground Control Points (GCPs) were placed inside and outside the church, that were both on the ground and on the walls in order to provide a better geometry around the structure. The GCPs were documented using a total station by providing X, Y, Z coordinates using the CGRS93 / Cyprus Local Transverse Mercator projection (LTM).

Figure 3: Ground control points with total station registration

2.4 UAV mapping

During the last years the use of UAVs for aerial surveys is becoming a consolidated application, commonly used for obtaining 3D models of the outer side of buildings [4]. UAVs can be used as a precise, automated and computer- controlled data acquisition and measurement platform, as a result of low-cost sensors such as off-the-shelf digital cameras, GPS/INS (Global Positioning System / Inertial Navigation System) based stabilization and navigation units [5]. In cultural heritage area UAV applications are mainly focused on documentation, observation, monitoring, mapping, 3D modelling and 3D reconstruction [6] as well as digital maps, digital orthophoto, digital elevation model (DEM) and digital surface models (DSM) [7]. UAV aerial imagery in combination with photogrammetry are emerging technologies providing an innovative approach to 3D documentation of cultural heritage [5].
In this study, a DJI Mavic 2 Pro with a 1-inch CMOS 20 MP Hasselblad L1D-20c camera was used in order to take images with 90% overlap around the church. The UAV was flown at a height of 16, 8 and 6 meters to take perpendicular, 45° and horizontal images around the church in order to get full cover of the monument.

2.5 Photogrammetry

Recent developments in photogrammetry technology provide a simple and cost-effective method of generating relatively accurate 3D models from 2D images [8-10]. Photogrammetry is a precise 3D measurement technique based on the triangulation of several high-quality images that allow for the collection of semantic and spatial data of a building or object. The main outputs of photogrammetric surveys, which are created from stitching and processing hundreds or thousands of images are 3D points clouds, 3D surfaces, ortho-photos and Digital Elevation Models. Several widely used commercial software are available in order to obtain 3D reconstructions of such buildings from images acquired by UAVs [11-14]. These tools, usually based on the Structure from Motion (SfM) approach, enables 3D reconstruction with camera manual or automatic calibration. The introduction of GNSS measurements in the photogrammetric reconstruction procedure, corresponding to the camera locations during image acquisitions, reduces the error level. The software implements image orientation and mesh generation through SfM and dense multi-view stereo-matching algorithms [15]. The first step in the program's procedure is SFM, which is a valuable tool for generating good quality meshes from images in a semi-automatic way. At this stage the software analyses the dataset, detecting geometrical patterns in order to reconstruct the virtual positions of the cameras that were used in order to align the images, including building a sparse point cloud [16].

Figure 3: 3D model of the Church generated using photogrammetry (Agisoft)

Laser scanners are commonly used to document such cultural heritage monuments. However, they are time-consuming, and it is difficult to scan high elements such as roofs, domes, etc. Digital photogrammetry is a more flexible technique that

provides better results in terms of appearance (texture) of the 3D models in less time, due to the higher resolution of the images employed to compute the model texture, compared to the panoramic ones normally used to texturize the laser scanner clouds. In addition, the points composing the clouds obtained with image matching based algorithms are usually colored by reading and averaging the RGB values of the pixels that generate the specific point of the cloud [17]. When combined with UAV images, it is quite easy to generate and complete a 3D model of the structure.
In this study, 1,104 images acquired from the UAV around the exterior of the church and 2,579 images acquired from the hand-held camera around the interior of the church, with a 3 mm/pixel resolution. The images were processed using Agisoft photogrammetry software, generating point clouds and 3D models.

Figure 4: 3D models of the exterior and interior of the Church

The models were generated separately for the exterior, interior and icons as chunks and then merged together using the GCPs to produce a solid 3D model. The reason for this is to get a better texture by eliminating the volume of information from the image textures of the exterior and interior materials.

2.6 Imaging Analysis using HSV color model

Although RGB is the commonly preferred color imaging space, there exists a variety of color spaces for use. This is because different color spaces present color information in different ways that make certain calculations more convenient and provide a way to identify colors that is more intuitive. E.g., RGB color space defines a color as the percentage of red, green and blue hues mixed together [18]. The use of HSV images for the 3D model may provide enhanced detail of the pathology of the materials, which were not evident in the 3D model created using RGB images. Beyond the RGB model, different color models have been developed [19], of which the two most common are the Hue-Saturation-Value (HSV) and Hue-Saturation-Lightness (HSL) [20]. HSV and HSL models are particularly useful because they describe the colors in a way closer to the human perception [21]. They are represented by using the cylindrical coordinate system, where the Hue is the angle around the cylinder axis, the Saturation is the distance from the axis while the Value/Lightness is the distance along the axis (Figure 5).

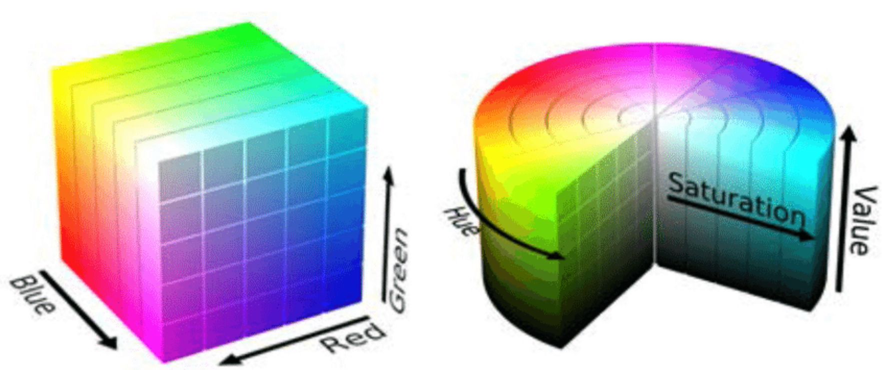

Figure 5: Left: Representation of RGB values; Right: Representation of HSV values

These two-color transformations are widely common cylindrical-coordinate representations points in an RGB color model. In this way, the intimal red, green, and blue values of this color model are transformed into new color components. In the HSV model, hue (H) defines pure color in terms of "green", "red", or "magenta", while saturation (S) defines a range from pure color (100%) to gray (0%) at a constant lightness level. Finally, value (V) refers to the brightness of the color [22]. The Value and Lightness are the quality by which we distinguish a light color from a dark one [23] and its value varies from 0% to 100%. This range (from 0 to 100) can be thought as the amount of light illuminating a color [24]. For example, when the hue is red and the value is high, the color looks bright. On the other hand, when the value is low, it looks dark.

The adopted algorithm that allows this transformation from RGB to HSL and vice versa was implemented by Smith [25] and subsequently by Fishkin [26]. Equation 1 shows the mathematical relationships that changes the RGB color model to a HSV color model [27]:

$$H = \frac{1}{2\pi} arctg\left(\frac{2R - G - B}{\sqrt{3(G - B)}}\right) \tag{1}$$

and

$$S = \sqrt{R^2 + G^2 + B^2 - RG - RB - BG} \tag{2}$$

and

$$V = \frac{1}{3}\ (R + G + B) \tag{3}$$

In this study, only the Hue and Saturation values were used in order to identify potential anomalies in the model.

3. RESULTS

The study took place on 23 December 2019 at the Agios Efstathios Church using the methodology described above. A Mavic Pro 2 UAV was used to document the exterior of the church, while the hand-held Canon EOS M3 camera was used to document the interior of the church. Photogrammetry was used to create a 3D model of the church. Once the 3D model was produced in RGB color, the HSV color model was applied. Figure 6 shows the 3D model of the church in RGB on the left, with the 3D model of the church in HSV values on the right. As is evident, the roof and walls of the church exhibit a red color, which is especially strong above the door of the church, which requires further investigation. The two striations on the right side of the model, which frame the window, indicate erosion resulting from water that is falling from the gutters. These anomalies were not evident in the model of the church that was done with RGB values. As such, the HSV model provide valuable information regarding potential external damage to the monument.

Figure 6: Left: Representation of RGB values; Right: Representation of HSV values

The 3D model that was generated in RGB (Figure 7, left) shows the interior pf the church. The vaults show white striations (highlighted in red), which can be assumed to be repairs that were done in the church. When the 3D model was converted from RGB to the HSV color model by dividing the values of Saturation (S) by Hue (H), the model reveilved extensive detail (Figure 8, right). The HSV color model image requires further in-situ investigation in order to identify the significance of each color variable in order to identify any potential deterioration or damage of the interior walls.

Figure 7. Section through the interior of the church. Left: RGB color model; Right: HSV color model

4. CONCLUSIONS

This paper examines how integrating various technologies, such as photogrammetry and converting the RGB and HSV color model can be used to identify any potential damages or deteriorations on the walls of the monument and examine the pathology of the structure. Further research is required to identify the findings and the potential use of the HSV color model for cultural heritage structures. Additional research can focus on correlating the hue and saturation values with the state of the structure. As well, multispectral cameras can also be used for comparison.

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