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UAV SOLUTIONS FOR THE PROTECTION AND MANAGEMENT OF CULTURAL HERITAGE. CASE STUDY: HALMYRIS ARCHAEOLOGICAL SITE

Antonio Valentin TACHE[1], Irina Crina Anca SANDU[2,3], Oana-Cătălina POPESCU[1], Alexandru-Ionuţ PETRIŞOR[4*]

[1]National Institute for Research and Development in Constructions, Urban Planning and Sustainable Territorial Development “URBAN-INCERC”, URBANPROIECT Branch, Department of Territorial Cooperation, Environment and Territory Observation, 266 Sos. Pantelimon St., Sector 2, 021652 Bucharest, Romania
[2]Munch Museum/Munch Museet, Department of Conservation, Toyengata, 53 0578 Oslo, Norway
[3]Romanian Inventors Forum, 3 Sf. P. Movila St., L11, III/3, 700089 Iasi, Romania
[4]Ion Mincu University of Architecture and Urban Planning, 18-20 Academiei St., Sector 1, 010014 Bucharest, Romania

Abstract

Long-term cultural heritage protection is an essential condition for the sustainable development and preservation of territorial identity. Good documentation and registration of heritage objects allows for knowing, preserving and passing them to the future generations. Cultural heritage registration currently uses different techniques and methods of documentation, especially in archeology. In order to document archaeological sites and obtain their 3D digital models, several methods are possible, such as the combination of terrestrial recording and photogrammetric aerial methods, using unmanned aerial vehicles (UAVs) - drones. GIS and GPS were used to obtain the contours coordinates for several archaeological sites in Tulcea County from 2007 location data from a geospatial system for the location and protection of archaeological sites in conjunction with the UAV technology (a multi-rotor drone), along with a high-precision GPS (GPS Rover GNSS RTK ComNav T300), and specific software like Mission Planner and Agisoft Photoscan, for their accurate fit into the digital map of the county, aiming for a better protection of the historical site. The final result is a 3D model of Halmyris Citadel (Murighiol, Tulcea County), which can be used to help preserving the archeological site, and serve as a base for future on-site restoration works.

Keywords: *Cultural Heritage; Unmanned Aerial Vehicle; 3D Modelling; Global Positioning System (GPS); Archaeological site; orthophoto; Digital Elevation Model (DEM).*

Introduction

Cultural heritage is nowadays subject to threats due to factors such as the natural hazards, urban development or even vandalism. According to *F. Hassani* [1], a good documentation of heritage objects – including a possible reconstruction – is required. According to the general recommendations, the preservation of cultural heritage requires the harmonization and updating of both the general theory and the methodology for scientific research, preservation, restoration and dissemination [2-4]. An integrated approach is needed to allow the formulation of new directions for research priorities, requiring scientific, technical and artistic

* Corresponding author: alexandru_petrisor@yahoo.com

expertise in all related areas [5]. The information required for good archaeological documentation is obtained by using different innovative systems and technologies [3, 6-8], such as digital photogrammetry and TLS. 3D Laser Scanning allows for the creation of precise, complex and realistic x, y, z three-dimensional models, as well as scenes that can reflect the historical world. The registration of the respective object contains millions of x, y, z coordinate points – "cloud points" – of high resolution and precision.

Unmanned Aerial Vehicle (UAV) systems equipped with a digital camera have become one of the most promising techniques in recent years, and useful tools for data collection. These devices allow for the acquisition of high resolution images at different incidence angles. UAVs have advantages over traditional forms of archaeological aerial imagery acquisition, in particular through their ability to cover large areas at fixed altitude and speed, in different weather and wind conditions, essential capabilities especial in aerial thermography, for which there is only a short period of time in which images can be captured. Recently, UAVs have become popular especially for gathering information in archeology and architecture [9-14]. Moreover, these two domains use 3D applications to obtain digital terrain models (DTMs) and orthophotoplans with high topographic and spatial resolution. Both laser scanning and photogrammetry offer advantages and can be included in a methodology for documenting and protecting the cultural heritage that encompasses different approaches and solutions in multiple heritage contexts [15-17]. Temporal analyses and 3D multi-temporal reconstructions are essential for the preservation and maintenance of all forms of cultural heritage [18], and underpin decisions on heritage interventions and promotion [19]. GIS systems and BIM models can integrate digital data and real world representations coming from different systems [20-22], representing complementary methods used for decision-making purposes [23] and for solving various cultural heritage problems.

In archeology, recent technologies allow for processing satellite and aerial images; increasingly specialized software is used to process the 3D images acquired and subsequently shape a 3D model for archaeological sites. This study aimed to create a methodology for deriving a high-precision three-dimensional model for documenting and simulating the virtual reconstruction of the Halmyris Fortress (Murighiol, Tulcea County, Romania) using a multi-rotor drone, a GPS of centimeter precision (GPS Rover GNSS RTK ComNav T300), and specialized software installed on a Laptop: Mission Planner and Agisoft Photoscan.

Materials and Methods

The data source was represented by the results obtained in the PATRIMON project in 2007 [24, 25], respectively the coordinates of the limits of several archaeological sites located in Tulcea County, determined at that time by using GIS and GPS techniques. This data source and the Ground Control Points were needed both for the UAV flight planning and for a better precision of the 3D model of Halmyris fortress. We have also considered several recommendations in the field of aerial images modeling: the use of a 50mm focal length lens and the capturing of an object in at least three images to prevent "dead" areas when extrapolating information by superimposing the images, as well as capturing images in RAW format to enhance the clarity of the model.

Murighiol commune in Tulcea County has an area of 80449ha, 87% being covered by the Danube Delta Biosphere Reserve. The access is also possible by numerous canals surrounding Razim and Murighiol lakes. The commune has a varied relief, bordered in the East by the Danube and in the South by lakes Murighiol I, Murighiol II and Sarat. Due to Halmyris and Zaporojeni Fortresses, the commune is listed in the Romanian National Spatial Plan (PATN) Section III - Protected Areas, as having "cultural heritage values of national interest".

The archaeological site "Halmyris Fortress", located in this commune, belongs to Group A of the Historic Monuments List (LMI) 2004 (TL-I-m-A-05844 from 01 to 03) containing the citadel itself, a settlement and a necropolis. The site is also listed with the National Archaeological Repertory (160920.02). According to the CORINE land cover and use classification [26-32], the Halmyris Fortress is located in an agricultural region, represented by large areas of non-irrigable arable land (Fig. 1). The site has an average elevation of 38.4m above sea level, according to the GPS coordinates. The Roman-Byzantine fortress has a trapezoidal shape, with an area of about 2 hectares, with 15 towers, three gates and three defensive waves. Several unveiled monuments were partially restored (Fig. 2). Examples include the North, Northwest, and West Gates, and the paleo-Christian Basilica containing a martyr's crypt, unveiled in 2001, containing the relics of Christian martyrs Epictet and Astion, killed in Diocletian's time.

Fig. 1. The archaeological site Halmyris Fortress is located in a non-irrigable arable land area.

Fig. 2. Consolidation-restoration of the fortress walls.

The GPS coordinates collected in the previous PATRIMON project were used to set the final shape of the contour of the city's outer walls. At that time, the site was integrated into the digital map of Tulcea County, and the protection area could then be drawn.

In 2017, the URBANPROIECT team went back to Murighiol locality to obtain the 3D model of Halmyris Fortress, using the UAV technology. In order to build the model, the following steps were taken: the flight planning by setting the outline of the polygon and generating flight on photogrammetric bands using the Mission Planner software; the actual flight at an elevation of 80m; processing the acquired photos using Agisoft software to generate a dense cloud of points based on the rare cloud of points; the generation of the thee-dimensional fabric of the Halmyris Citadel, in orthographic projection; and the generation of the Digital Elevation Model - DEM - and of the orthophotomap of the Halmyris Fortress.

Flight planning

Establishing the contour of the polygon: this was done quickly, based on the GPS coordinates previously determined in the PATRIMON project. In addition, in order to improve accuracy, new Ground Control Points (GCP) were collected outside the fortress's enclosure and marked with red paint for their recognition after the flight (Fig. 3). The point size of these milestones had to be greater than 10 pixels for an easier localization.

Flight generation on photogrammetric bands, using the Mission Planner software and flight parameters of 1cm/pixel resolution (Fig. 4). Mission Planner is a free, open-source application developed by Michael Oborne. Telemetry operates in the 433MHz band and establishes the wireless link between the multicopter controller and the ground station, respectively Mission Planner. The automatic flight control system combines the data obtained from the sensors with those obtained from the GPS to provide accurate information. For areas where the GPS signal is poor, the airborne platform can be controlled using the magnetometer.

Conducting the actual flight with the drone

The digital camera that captured photos and video was set to 1/1000 as exposure time and the flight altitude was set at 80m. The photogrammetric flight with the drone was achieved at 5.00 (P.M.) to get sharper contrasting photos that highlight the micro-relief elements of the terrain. Figure 5 presents the photogrammetric flight plan.

Fig. 3. Control points determined before the actual flight

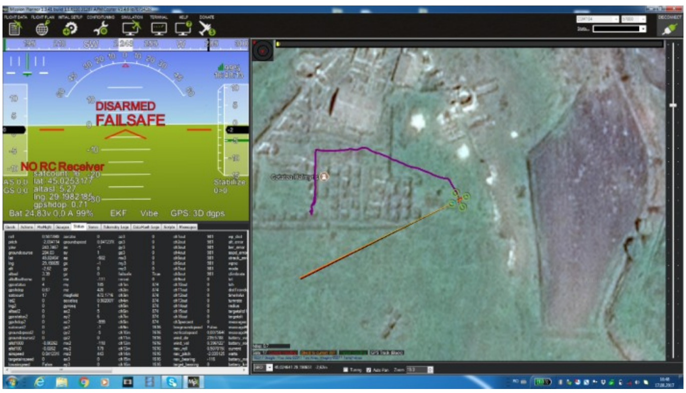

Fig. 4. Generating flight on photogrammetric bands

Fig. 5. Photometry flight plan accomplished with the drone, for Halmyris Citadel

148 aerial images were captured; several of them were selected for illustration purposes (images with .jpg extension with Geotag) (Fig. 6a - 6d).

Fig. 6. Aerial images of Halmyris citadel.

Data processing

After the completion of flights, all the photos taken were processed with the Agisoft program. This software has the ability to assemble all the photographs taken by the drone in the form of a rare cloud of points having a low precision of coordinates (Fig. 7).

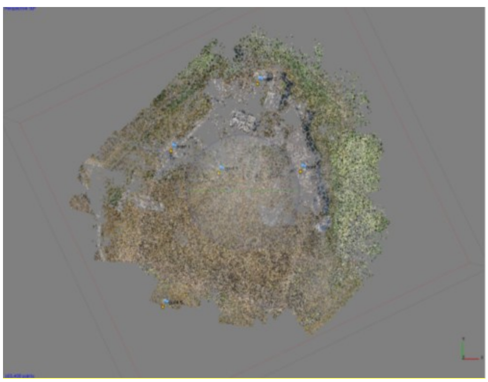

Fig. 7. Photos assembled as a rare point cloud using the Agisoft software.

Agisoft PhotoScan is an advanced 3D image modeling solution that relies on the technology of object reconstruction using multiple perspectives. Agisoft PhotoScan generates 3D models by reconstructing a dense cloud of points, generating a "mash" polygonal pattern. These techniques underlie the 3D reconstruction [33-34]. With the help of this software the Digital Elevation Model (DEM) could be obtained, as well as the orthophotomap of the Halmyris site.

The next step in image processing was to determine the ground control points on the assembled image, marked in red on the ground for their identification. In case of slight deviations from the GPS measurements of the drone, these points were manually repositioned. Finally, the optical parameters of the camera were recomputed according to the new positions of the control points. A dense point cloud was generated, based on the previous rare cloud of points and on the recalculation of optical parameters with a centimeter precision (Fig. 8).

Based on the dense cloud of points, the three-dimensional fabric of the Halmyris Fortress was generated, in orthographic projection, in the Build MASH computer language (Fig. 9).

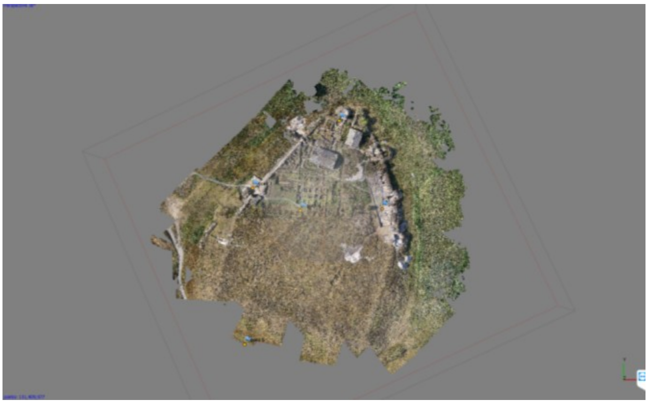

Fig. 8. Recalculating parameters and generating the dense cloud of points

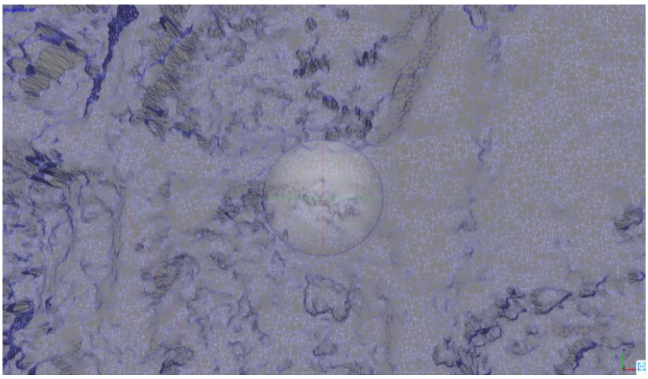

Fig. 9. Generating the 3D fabric of the Halmyris Fortress using Agisoft

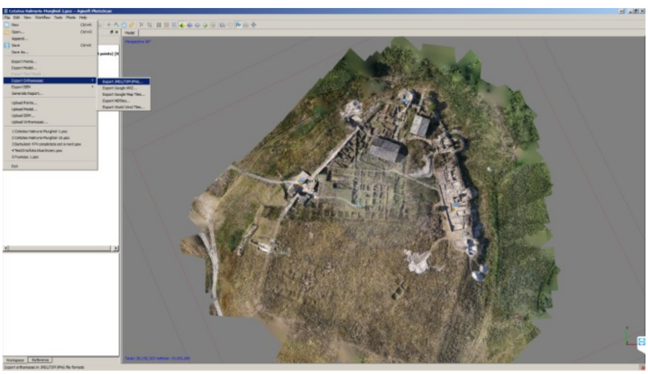

Fig. 10. The orthophoto of the Halmyris Fortress: overlay on the Google Earth format

Based on this model, the Digital Elevation Model (DEM) and the orthophotoplan of the Halmyris Fortress were generated. Agisoft Photoscan software allows the export of the point cloud, the 3D model and the orthophotoplan in different formats that can be viewed as .JPG or .TIF, as well as in GIS and Google Earth formats: .KMZ, .3DS, .WRL or .PLY autodesk (Fig. 10).

Finally, the Agisoft report in .PDF format was automatically generated and the errors occurred when generating the orthophoto and the 3D model, were verified. Figure 11 shows the 3D model of the Halmyris Fortress, based on the photogrammetric image processing.

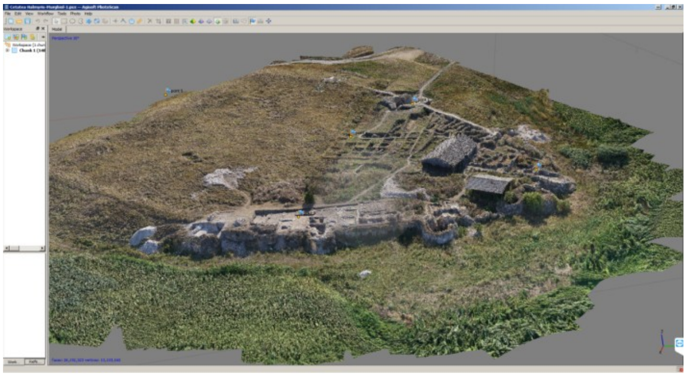

Fig. 11. Displaying the 3D model of the Halmyris Fortress on the basis of photogrammetric image processing

Results and discussion

The final Agisoft report contains drone flight information (number of images, flight altitude, ground resolution, flight area, projections, etc.), camera calibration and error estimation, including ground control points, digital DEM (resolution and density points), as well as all processing parameters (rare and dense cloud points including errors, reconstruction and texture parameters, ortho-mosaic, etc.)

In the case of the Halmyris Citadel, the Agisoft report shows that the drone flew at an average height of 78.1m, the 148 images taken covering an area of 0.0505km^2. The ground resolution was 1.01cm/pixel. The camera model was ILCE - 6000 (30mm), having a 6000×4000 resolution and a focal length of 30mm, resulting a size of 4×4μm for a pixel. For the camera, the average error was 8.721252m. The same Report shows that the errors of the five initially ground control points (GCP) were between 1.85794m (point no. 4) and 9.56645m for point no. 5 (Fig. 12).

Fig. 12. Locations of the 5 Ground Control Points (GCP)

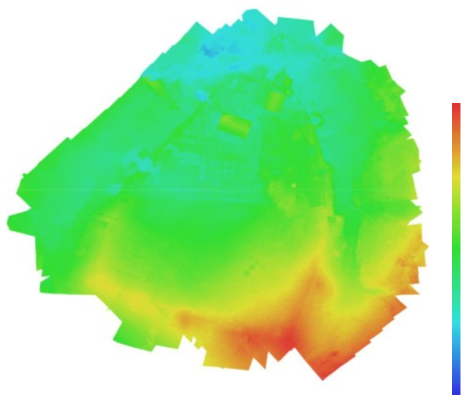

Fig. 13. The resulted DEM

The resulted Digital Elevation Model (DEM) had a resolution of 2.01cm/pixel and a point density of 2468.92 per square meter (Fig. 13).

Conclusions

This research demonstrates the ability of UAV techniques to obtain specific products (3D models and orthophotomaps) with a very high level of detail that serve as a basis for future very accurate studies and analyses. These techniques can provide a very large amount of information that can be gathered in a very short time, using inexpensive data processing solutions requiring a short processing time. The precision of the 3D digital model depends greatly on the number of ground control points collected with GPS, as well as on the GPS precision.

Moreover, with the 3D model of an historical site (such as the Halmyris Fortress), a virtual reconstruction of the entire historical landscape can be obtained [35]. Thus, land modeling can be done by geo-referencing historical maps of the region including the archaeological site, obtaining an "historic" elevation map, and finally adding large scale landmarks. 3D objects modeling involve decorating the virtual historical landscape with objects and structures. This is usually done from a 3D digital library, and the 3D geometry can be obtained with Google Sketchup. In terms of presenting the results, the digital historical model of the terrain together with the 3D historical elements can be used as input for the display in 3D viewing software (such as Vue Infinite) along with other elements representing the ecosystems belonging to the landscape.

Abbreviations

3DS - Autodesk 3DS Max file format.
BIM – Building Information Modeling
DEM – Digital Elevation Model
GCP – Ground Control Points
GIS – Geographical Information System
GPS – Global Positioning System
JPG – Image File Format
LMI - List of historical monuments from Romania
PDF – Portable Document Format
PLY – Polygon File Format
PNCDI - National Development and Innovation Research Plan
TIFF – Tag Image File Format
TLS – Terrestrial Laser Scanning
UAV - Unmanned Aerial Vehicle
WRL - Virtual Reality Modeling language

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