ArcheOS and UAVP, a Free and Open Source Platform for Remote Sensing: the Case Study of Monte S. Martino ai Campi of Riva del Garda (Italy)

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Abstract:
The article proposes a model of Free and Open Source platform for aerial archaeology. This solution is based on two main components: ArcheOS (software, for data processing) and an UAVP prototype (hardware, for data acquisition). ArcheOS (Archeological Operating System) is a GNU/Linux distribution developed for archaeological aims and released under GPL (General Public License), while the "Universal Aerial Video Platform" (UAVP) is an open source project, which shares knowledge, data, and resources with the aim to build a modern autonomously flying multicopter. The combination of these two elements grants the possibility to collect pictures for aerial archaeology (e.g. photomapping, survey, photointerpretation, etc...), but also to acquire 3D data, using the modern Computer Vision techniques. The main benefits of this "opens source remote sensing platform" can be summarized in: portability, versatility and low cost. Moreover, being an open project, it can be continuously improved by the feedback of the community.

Keywords:
ArcheOS, FLOSS, UAV, Aerial Archaeology

1. Introduction

The benefits of aerial photography in archaeology are manifold, but in most cases it is difficult for single researchers or small-scale enterprises to run a project with remote sensing techniques, due to logistical problems, high cost and the complexity of the necessary equipment. Hiring microlight aircraft can be quite cost-intensive besides the difficulty of taking zenithal pictures during low-altitude flights, while balloons are consuming noble gases which are subjected to severe safety regulations for storage and transport. Kites depend too much on wind to be considered a reliable instrument in any circumstances and radio-controlled helicopters or aircraft, with internal combustion engine, can be dangerous (explosion hazard in case of crash), noisy and require routine maintenance.

Combined use of open source hardware and software can be one possible solution to the problems described above. The case study of Monte S. Martino ai Campi di Riva del Garda (Italy) allowed us to complete an aerial archaeology project in difficult logistical throughout conditions, achieving satisfactory results and maintaining a low cost approach.

For a better understanding, before reporting our experiences in S. Martino, we have to describe briefly the two main components of our remote sensing platform (ArcheOS and UAVP) and the historical and archaeological characteristics of the site.

2. ArcheOS

ArcheOS (Archeological Operating System – www.archeos.eu) is a GNU/Linux distribution developed for archaeological aims

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and released by Arc-Team under GPL (General Public License). The system contains a selection of different applications which try to cover a wide range of archaeological needs.

Created in 2004, the ArcheOS-project was first presented to the scientific community during the annual meeting "Archäologie und Computer" of the city of Vienna (Bezzi et al. 2005). From the beginning, the main purpose was to introduce and to spread the use of Free/Libre and Open Source Software and to apply the ideology of the "Free Software" movement to archaeology itself. A central objective of the Free Software Foundation is the unimpeded circulation of data, knowledge and ideas. This is, in our opinion, also an essential condition for the better development of archaeology as a discipline. That is the reason why Arc-Team is suggesting a model of data-sharing inspired by the Open Source and Free Software movement.

The first release of ArcheOS (codenamed Akhenaton) was based on the GNU/Linux distribution PcLinuxOS 0.91 (beta). The selection of software and applications (all protected by GPL or OSI compliant licenses) was the result of many years of working experience and tests conducted by the Arc-Team company. The restrictions imposed by the General Public Licence give the system all the benefits of free software: ArcheOS is modifiable, redistributable, supported by the net community and moreover it is free (gratis). Technically, ArcheOS is a Linux-Live DVD which can be used "on the fly" by inserting the disk before booting the PC. In the live-mode the whole operating system will run using the RAM memory and no permanent changes will be applied to the computer. At the end of the session, the native operating system can be restarted without any modification. The live-mode is mainly suitable for testing the distribution, which can always be installed permanently after partitioning the hard-disk.

In 2006, the ArcheOS project experienced a lightning development thanks to the contribution of the Aramus Excavations and Field School (Kuntner and Heinsch 2008) of the University of Innsbruck (Institut für Alte Geschichte und Altorientalistik), which shifted its hardware to the free operating system. The field-work experiences in Armenia were used by Arc-Team to further develop ArcheOS (Bezzi et al. 2006). The feedback of Aramus Field School has been very important for building the new version, giving us the opportunity to consider the specific needs of an archaeological mission abroad. Moreover the possibility to share knowledge and software with students increased exponentially the community. From this collaboration started the Digital Archaeological Documentation Project (http://vai.uibk.ac.at/dadp/), a wiki system to publish on-line tutorials connected to the use of FLOSS and ArcheOS.

Thanks to the Aramus experience, a new version of ArcheOS was ready in 2007. The main features of the second release (codenamed Sargon) were the migration to the Kubuntu GNU/Linux v. 7.10, which ensured a better hardware integration, and a more accurate selection of programs, which derived directly from the hard test conducted in 2006. ArcheOS' historical timeline led in 2009 to the third release (codenamed Xenophon). The base GNU/Linux system was Kubuntu v. 9.04 which integrated the user interface KDE 4. The first three versions of ArcheOS were not upgradable: the only way to update most of the applications was to install the new release deleting the old one. In 2010 the computer scientist Fabrizio Furnari joined the developers team. He started to reorganize the structure of the project, paying attention to the stability of the operating system and to an on-line service to keep up to date with the different programs (deb-repository). As a result, in 2011 Arc-Team was able to share the current release (codenamed Caesar) based on Debian Squeeze v. 6.0.

ArcheOS tries to satisfy all the needs of an archaeological project, covering every single step of the operating workflow, from

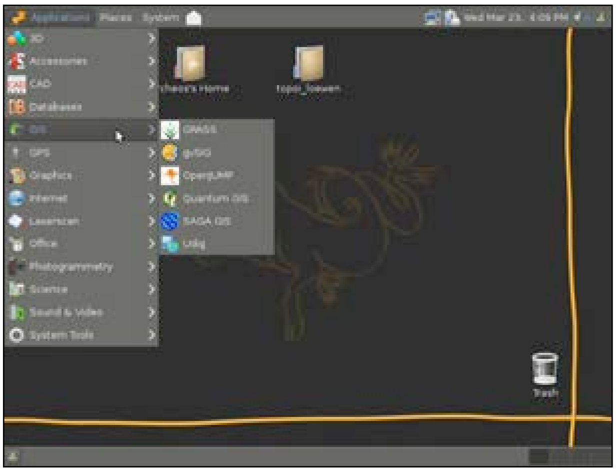

Figure 1. *ArcheOS' desktop and menu.*

data collection and storage to elaboration, publication and sharing. The software selection is organized by typology in different menus (Fig. 1). For instance the submenu GIS includes, among other applications, the powerful software GRASS, which integrates several high level analysis tools, QuantumGIS, an intuitive raster-oriented platform, and OpenJUMP, which is valued for its vector drawing potentialities (very close to CAD). The Graphics submenu offers different choices for raster or vector datasets: raster images can be edited using GIMP, while a vector drawing can be realized within Inkscape. Moreover Blender can be used for virtual reality projects (3D), while the application Stippler allows the user to turn a greyscale picture into "stippled" images (following the most common conventions of the archaeological drawings techniques). CAD software are represented by LibreCAD, for architectural 2D drawings, and FreeCAD, for parametric 3D modelling. The database submenu is filled with a wide range of applications, from the simple OpenOffice Base to the complete object-relational DBMS PostgreSQL (implemented with the geographical support PostGIS). In addition the new release of ArcheOS has been enriched with SQLite and SpatiaLite. Moreover, other peculiar professional fields are supported by specific software. For instance MeshLab represents the "killer application" for mesh editing, while Python Photogrammetry Toolbox (Bundler+CMVS/PMVS2) is an optimal solution for acquiring 3D point clouds with Structure form Motion and Image-Based Modelling techniques. Scientific 3D models can be imported inside Paraview, a multi-platform data analysis and visualization application, as well as in Virtual Terrain Project, a 3D viewer for geographical datasets. In most cases statistical analysis are delegated to the powerful software R. Obviously ArcheOS comes also with an office suite, many internet tools and multimedia applications.

Being an open source project, ArcheOS is continuously under development, thanks to the support of a community of users/developers which shares knowledge, data and experiences to improve the quality and the usability of the operating system.

3. UAVP and Other Flying Drones

UAVP is an acronym for Universal Aerial Video Platform and refers to a project whose purpose was to build "a flying Open Source QuadCopter at a reasonable price". Like many other open source projects, the UAVP has grown rapidly. In fact the original device, born from the initiative of Wolfgang Mahringer, was followed in recent years with a community-driven design, which led to the new prototype: the NG-UAVP (Next Generation UAVP). From a technical point of view an UAVP model can be counted in the category of UAVs (Unmanned Aerial Vehicles), being a flying radio-controlled drone. Its main strengths, in the field of aerial archaeology, are connected with its stability and its capability to hover in place and are derived from its "quadcopter" structure. Also its electric power supply can be considered a benefit for safety during working operations, even if offset by disadvantages in terms of flight range.

In 2008 Arc-Team built its first UAVP prototype (Bezzi et al. 2008) based on the original Wolfgang Mahringer project (Fig. 2). Considering the complexity of this kind of flying machine, normal archaeological vocational training doesn't offer the specific

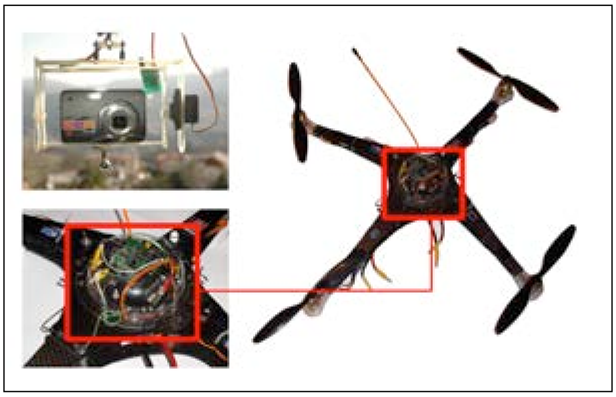

***Figure 2**. three images of the UAVP drone built by Arc-Team: the remote sensing device (up-left), the motherboard (down-left) and the quadcopter (right).*

***Figure 3**. The KKmultiCopter during the flight.*

skills needed to assemble and install the different parts of the hardware and software. For that reason collaborating with an expert in modelling (or an electronic engineer) is strongly recommended to successfully build and develop an UAVP. There are no particular difficulties in assembling the mechanical parts (frame), while the electronic components are effectively more sophisticated and require a minimum competence in soldering circuits and a basic knowledge about concepts like motherboards and processors. However the basic elements are few (many are optional) and it is possible to buy some preassembled SMDs (Surface Mounting Devices), like the motherboard (available already populated). The final prototype is composed of a carbon fibre frame and a support for a digital camera, equipped with an additional servomotor for its orientation. The electronic component is restricted to the essential elements: motherboard, gyroscopes, processor, linear acceleration sensor and electronic compass.

To experiment different solutions, in 2010 Arc-Team has built a KKmultiCopter drone (Fig. 3). This project is a simple set of hardware components already populated, developed by the public domain KapteinKuk model. The electronic elements are sell in a all-in-one solution integrated directly into the motherboard. The project is supported by a wide net community, particularly active in hardware/software development, and by several on-line resellers. After a long training (it is important not to underestimate the necessary time to learn how to pilot a quadrotor) the KKmultiCopter drone can impress for the stability of flight and the manoeuvrability.

4. The Site of Monte S. Martino ai Campi di Riva del Garda (Italy)

The archaeological site of Monte S. Martino is located in the area to the north of Lake Garda, about 800 metres above sea level. Its strategical position was connected to a network of several routes linking the Brescia territory (to the west) and the Alpine area (to the north). Only in 1880 did the site start to arouse the interest of the scientific community, but during the second half of the 20th century its territory, which was once used as pasture, was occupied by dense vegetation and did not preserve traces of remains on the surface. In 1969 a group of enthusiasts noticed the presence of numerous fragments of Roman throughout tiles and decided to start an excavation. Six years later the site came under the protection of the Provincia Autonoma di Trento: this was the beginning of systematic research in Monte S. Martino.

Until now the oldest archaeological finds brought to light so far at the site are represented by a blade of stone axe and a flint arrowhead, both related with prehistory and both discovered by chance. The axe blade probably

***Figure 4**. The roman buildings of the sanctuary in Monte S. Martino ai Campi di Riva del Garda.*

dates back to Copper Age (third millennium BC) and it is made of jade, a valuable raw material that comes from the Western Alps (Piemonte or Liguria). The flint arrowhead can be dated between the early stages of the Late Neolithic and the Early Bronze Age and it may have been lost during hunting activity (Mottes 2007, 163-164).

Almost all the pre-Roman artefacts from Monte S. Martino belong to the second Iron Age (VI - I centuries BC). The characteristics of these findings show an interaction between the two main cultural environments prevailing at the time, the Group of Fritzens-Sanzeno and the Group of Valcamonica (Marzatico 2007, 172-173). Probably the people who frequented the area during this period practised rituals similar or somehow connected to the so-called Brandopferplätze. In fact the excavations conducted in the highest area of the site revealed an archaeological record with layers containing a considerable percentage of carbon and significant traces of combustion together with fragments of pottery cups, probably crushed as cultural offerings.

Other traces of the pre-Roman period were found all over the site and recently emerged in the south-eastern sector, below a settlement dated between the IV and the VI Century BC. New structures were discovered in this area, exposing some parts of a square building, bordered by stone walls.

It seems that the identity of pre-Roman population was very strong and it partially survived after the arrival of the Romans. Since the end of the first century BC, a shrine was built in the same place of the pre-Roman rituals. The structure has been used until the third century AD and presents a rectangular plant (Fig. 4), which surrounds the highest part of the area. It is divided in several rooms, adapted to the terrain morphology and probably connected with the practical needs of the sanctuary. They were initially built only in the south-west area, but later other structures were added along the east side, giving the complex the current appearance. The building entrances were probably located on the West, South and East side, while the North side overlooks a precipice. The sacred function of the site is shown by the artefacts found in some collapsed rooms or in the proximity of the sanctuary. In this area were discovered fragments of three altars, two of which bear inscriptions which testify to the strong relationship between natives and Romans. In fact one of this epigraph is epichoric, being written in a local language, but employing the Latin alphabet. The second inscription is in Latin, but shows indigenous names (Valdo 2007, 343-346).

It is assumed that many different deities were worshipped in the shrine, and that the ancient indigenous beliefs were merged within the Roman Pantheon (Bassi 2003). The sanctuary, with its location in the territory of the Upper Garda Lake had to have a significant religious importance in the local area.

In the fourth and fifth centuries, numerous dwellings were built in the South-eastern area of the sanctuary, using artificial terraces. These structures are mainly built of stones and mortar and are partially excavated

***Figure 5**. The four different low-altitude flights in the areas free from vegetation cover.*

in the mountain rock. In the same area has been brought to light a building that stands out for its size. This characteristic, together with its position, is compatible with an hypothetical public function. Moreover, the village seems to be surrounded by fortified walls. From this point of view, the defensive configuration of the settlement, as well as its strategic position, allows to advance the hypothesis (to be verified) that it could have been a military garrison with logistical purposes. Anyway, all the investigated buildings were abandoned in the sixth or in the beginning of the seventh century, destroyed by fire. Some of the structures, however, were probably used also in later periods, like the one in which was found a coin of the Byzantine emperor Heraclius (610-641), located a few dozen of meters in North-west direction from the original nucleus. Perhaps already in the sixth century a small church abutted on the west wall of the public building, which became the front of the religious structure (Bellosi et al. 2010). During the twelfth or thirteenth century, the church was renovated: the apse was heavily reinforced, while the front wall was advanced westward; also the floors were redone and paved with stone slabs which raised the walking level. In this time the churchyard continued to be bounded by the South wall of the ancient public building (abandoned). In the proximity of the church entrance, a small structure and a tank probably served a building connected with craftwork productions. The area outside the church has been used as a burial place. The building was interdicted in 1612, as recalled in a document dated 1750. This paper decreed the destruction of the religious structure because of its poor condition. It is not known if the order has been executed, or if the church was abandoned until it was completely buried, but the final result was the abandonment of the site, which initially became a pasture and then turned back to wood, until was rediscover with the excavation of 1969.

5. The Remote Sensing Experience in Monte S. Martino

During the winter 2012 Arc-Team was hired to take aerial pictures of the buildings of Monte San Martino. Thanks to the difficult logistical conditions of the site (mountain area, arboreal vegetation, wind) it was a perfect situation to verify the effectiveness of the UAVP model. The strategy applied on the site included different low-altitude flights in four areas free from vegetation cover (Fig. 5), both in First Person View (FPV) and in Direct Visual Flight (DVF). All the project was supported by the advice and the practical help of two expert aeromodelers (Walter Gilli and Walter Morelli).

For the first flight, the drone was equipped with two different digital cameras: a Nikon CoolPix S210 and a GoPro HD Hero. The first device is a compact-camera with a 8.0 MP sensor, an angle of view of 64° and an aperture range of f3.1-5.9. The shoot signal is manually sent by a remote control. The second instrument is a sport-camera designed for extreme conditions. It has a 5.0 MP sensor, an angle of view of 127° and an aperture size fix to f2.8. The internal software can automatically take three pictures each second. Both the cameras have some benefits and some disadvantages, but finally the best results were obtained using the GoPro (Fig. 6). Despite a general low quality of the images, all the pictures taken with this camera were in focus (thanks to the fix aperture f2.8)

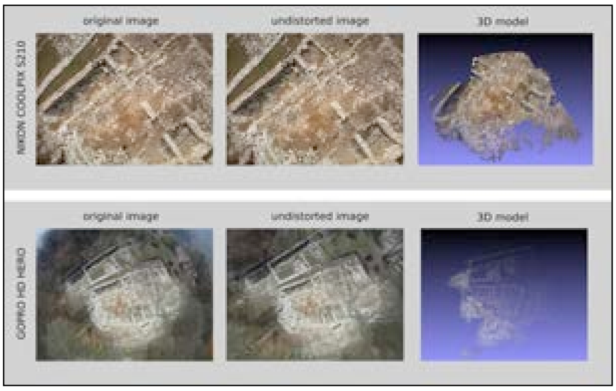

Figure 6. *Comparison between the two cameras: original picture, undistorted image, 3D point cloud.*

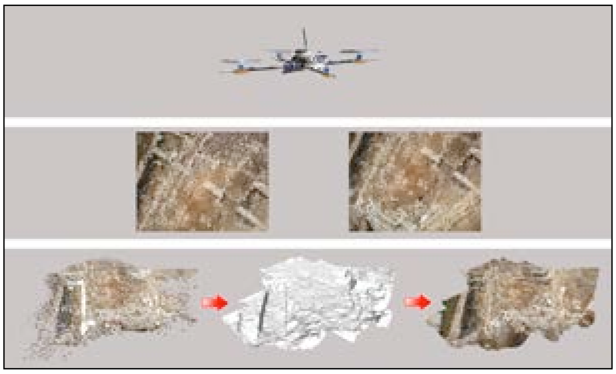

***Figure** 7. The data processing: from the original pictures to the final 3D model (point cloud, mesh, texture).*

and included the whole area of interest (thanks to the wide angle). The high lens distortion did not represent a problem, being removed during the post-processing phase. On the contrary, in windy condition, the Nikon camera was hard to manage: the manual shooting was a cause of problems in piloting the drone and the slow shutter speed, due to smaller diaphragm's aperture size, produced many images out of focus. For this reason, the other flights where supported only by the GoPro camera.

The results were partially processed directly in the field using a rugged PC and a total station. The image elaboration was done with the software Python Photogrammetry Toolbox. At the end of the process all the pictures were undistorted (lens correction) and 3D point clouds of each area were created (Fig. 7). The undistorted images were rectified and georeferenced using the "Metodo Aramus", a combination of different software (GRASS, GIMP and E-FOTO) which allows the collection of good quality photomosaics, while 3D point clouds were transformed in mesh within the application MeshLab.

After the Monte S. Martino experience, new tests are planned to further develop the whole system. A possible implementation can be the integration of the new GoPro HD Hero2, which should solve some problems experimented with the old model. The 11.0 MP sensor, the variable angle of view (170° and 127°), the faster shutter speed and the automatic shooting are features that makes this camera a perfect device for aerial photography data acquisition through RC drones. Moreover a new frontier for UAV models is the integration of GPS navigation tools which allows to program autopilot flight and to maintain a desired position. The first tests conducted with the new configuration of the remote sensing platform are giving promising results.

References

Avetisyan, H., and W. Allinger-Csollich. 2006. "The Fortress of Aramus: Peliminary Report of Excavaions in 2004 and 2005." *Aramazd – Armenian Journal of Near Eastern Studies* I: 105-134.

Bassi, C. 2003. "Il santuario romano di Monte San Martino (Riva del Garda) nel contesto dei culti di origine indigena del territorio benacense." *Atlante tematico di topografia antica - Atta* 12: 7- 20.

Bellosi, G., A. Granata, and N. Pisu. 2010. "La chiesa dell'abitato in altura ai Campi di Riva del Garda." Paper presented at the annual meeting *Convegno Archeologico del Garda, Gardone Riviera, Italy, Novembre 6.*

Bezzi, A., L. Bezzi, D. Francisci, and R. Gietl. 2005. "ArcheOS 1.0 Akhenaton, the first GNU/Linux live distribution for archaeologists." Paper presented at the annual meeting *Archäologie und Computer - Kulturelles Erbe und neue Technologien, Vienna, Austria, November 7-10.*

Bezzi, A., L. Bezzi, and R. Gietl. 2006. "Aramus 2006: an international archaeological expedition completely supported by Free and Open Source Software." Paper presented at the annual meeting *Archäologie und Computer - Kulturelles Erbe und neue Technologien, Vienna, Austria, October 18-20.*

Bezzi, A., L. Bezzi, and R. Gietl. 2008. "Open Source and Archaeology: the next level. Building and developing hardware projects." Paper presented at the annual meeting *Archäologie und Computer - Kulturelles Erbe und neue Technologien, Vienna, Austria, November 3-5.*

Ciurletti, G. (ed.) 2007. *Fra il Garda e le Alpi di Ledro. Monte S. Martino. Il luogo di culto (ricerche e scavi 1969 – 1979).* Trento: Provincia autonoma di Trento.

Kuntner, W., and S. Heinsch 2008. "The Ostburg of Aramus, an urartian and achaemenid fortress. The stratigraphical evidence." Paper presented at the annual meeting *International Congress on the Archaeology of the Ancient Near East, Rome, Italy, May, 5-10.*

Marzatico, F. 2007. "Testimonianze preromane." In *Fra il Garda e le Alpi di Ledro. Monte S. Martino. Il luogo di culto (ricerche e scavi 1969 – 1979),* edited by G. Ciurletti, 169-194. Trento: Provincia Autonoma di Trento.

Mottes, E. 2007. "Materiali preistorici sporadici." In *Fra il Garda e le Alpi di Ledro. Monte S. Martino. Il luogo di culto (ricerche e scavi 1969 – 1979)*, edited by G. Ciurletti, 163-167. Trento: Provincia Autonoma di Trento.

Valdo, A. 2007. "Testimonianze epigrafiche." In *Fra il Garda e le Alpi di Ledro. Monte S. Martino. Il luogo di culto (ricerche e scavi 1969 – 1979),* edited by G. Ciurletti, 343-349. Trento: Provincia Autonoma di Trento.