New Methods of Interaction in Virtual Reality for the Study of Archaeological Data

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Abstract
One of the biggest challenges that the analysis of archaeological data in virtual reality presents is the interaction.
Within the project of 3D reconstruction of Kaulonia archaeological site in Monasterace (Italy), developers had to deal with the need to implement an interface system inside the application without using external devices, in order to facilitate archaeologists in the data consultation.
A study about a system of movement and interaction with objects in the environment was conducted to create an interface for interaction based on look.
Subsequently, a method of interaction was developed by eliminating the problem of performing gestures and removing the entire "Learning Step" by users, so that it is possible to select and deselect elements, to move around in and rotate the view directly with the movement of the head.
As for the selection of the various elements within the application, a "cursor" specially implemented allows users to interact with the interactive elements: whenever the user sets a hotspot (point of interest) a pull switch is activated.
Within the application, it is possible to visualize a general overview of the excavation seen from above and to view the 3D models in the same spot where they were originally found: together with them, a brief historical description that contextualizes the object can be displayed.
A continuous progress of the study is allowing to explore new frontiers of digital data analysis in archaeology.

Keywords: Virtual heritage, Virtual Reality, Natural Interface, Virtual Archaeology, Cyber Archaeology, Interaction.

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Introduction

In the last years, Cultural Heritage and Virtual Reality worlds have been in contact many times creating positive collaboration both for academic and dissemination purposes.
With the spread of new technology to the public and not only to the researchers involved in high tech field and thanks to a more affordable cost of the new hardware, a new kind of synergy has developed between Cultural Heritage and Virtual Simulations. This synergy can improve the understanding of the data for researchers and students who will study the excavations, the findings and their context.

This paper describes the entire workflow and the approach used to experiment new kinds of interaction in virtual reality simulations for Cultural Heritage, an advanced system where experts and specialists can discuss, visualize and manage heterogeneous data in the same immersive virtual environment.

The Sanctuary of Punta Stilo at Kaulonia: a brief historical-archaeological framework

The area covered by 3D survey and modeling dedicated to development of the application described in the following paragraphs is the Sanctuary of Punta Stilo at Kaulonia (Monasterace), an ancient Greek colony founded by Achaeans people at the end of the 8th century BC in the extreme south of the Italian peninsula.
The site, on the edge of a cliff overlooking the Ionian Sea (fig. 1), was identified by Paolo Orsi (1915), who in 1911 brought to light the foundations of a large Doric style temple built around the years 470-460 BC and restored in the last quarter of the 5th century BC.

Figure 1: The Sanctuary of Punta Stilo.

After years of casual excavations, a systematic resumption of archeological investigation was undertaken between 1999 and 2014 by the University of Pisa and the Scuola Normale Superiore under the direction of Professor M.C. Parra, to whom (2011; 2013; 2014; 2015; 2016) the publication about new researches is due.
The investigation has allowed the sacred area to be explored in an in-depth and extensive way, in order to reach an integral view of the context, enabling firstly to define the topographical and chronological boundaries of the sacred area, which was frequented without continuity solutions from the end of the 8th to the late 4th century BC, when the temple probably collapsed due to an earthquake and the sacred area went out of use and was destined to accommodate facilities related to the storage of goods traded through the nearby harbor.

In particular, for the previous stages to the temple edification, sealed by a thick layer of waste related to its factory, the research has brought to light the remains of monumental buildings, altars, votive installations, portion of urban walls (from which an opening it was accessed to the southern Sanctuary area), areas destined for crafts related to metalworking, as well as has allowed to determine the gods worshiped within the Sanctuary, Zeus and Aphrodite.
Among the most notable discoveries, an area dedicated to the late-archaic votive offerings, characterized by the presence of several cippus fixed in the ground (the largest of them with a dedicatory inscription) and a deposition of bronze weapons, composed of two anatomical schisters and a chalcedon helmet dedicated to Zeus. An outstanding discovery is represented by a small bronze table found not far away, known as *Tabula Cauloniensis*, which has returned the longest Greek-Achaean inscription of Western colonies (Ampolo, Parra, & Rosamilia, 2013).
The area on which the Sanctuary is situated, as well as a large part of the adjacent coast occupied by the ancient city, suffered severe damage between 2013 and 2014 due to a series of violent storms which caused the collapse of the cliff and the permanent loss of large portions of wall structures, especially in the southern sector of the sacred area.

3D modelling: Computer graphics

Regarding the virtual simulation of the Doric temple, computer graphics techniques have been applied, using as a basis the data and the hypothetical reconstructions known in literature, and so far, available only in hard copy (Barello, 1995).
On the one hand, the method has provided for the acquisition and the vectorization of 2D data in 1:1 scale, while on the other hand, for the direct survey of architectural elements found in the most recent excavations. From these data, it was possible to realize the virtual simulation of the sacred building thanks to simple extrusion, revolution, lofting and Boolean operations and integrate it within the 3D model of the entire Sanctuary made by UAV photogrammetric survey (fig. 2).

Figure 2: 3D model of the Doric temple.

3D data acqusition: Photogrammetry as a measurement and analysis tool

Photogrammetry is the science that, using passive optical sensors, allows for three-dimensional metric information of objects by interpreting and measuring photographic images (Remondino, 2014). In the cases subject of study, the photogrammetric method know as Structure from Motion was used.

With regard to the acquisition procedure, in the terrestrial photogrammetry a series of converging photos are taken by moving around the object to be detected, in order to cover all its geometry, while in the aerial photogrammetry several vertical images are acquired according to a grid pattern, which can be reinforced by a series of oblique and convergent shots. In both methods, it is essential to ensure an overlap between photographs of 60-80% (fig. 3).

Figure 3: Terrestrial (left) and aerial acquisition procedure.

The software used, Agisoft PhotoScan Professional, foresees as a workflow the orientation of the images, the creation of the sparse and dense point cloud, the transformation into structured geometric model (mesh), and the generation of the photorealistic texture (fig. 4).

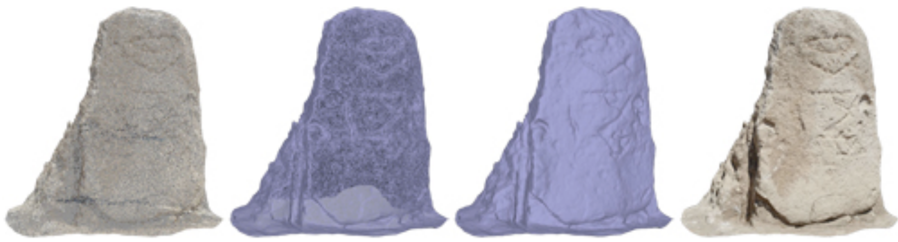

Figure 4: from the dense cloud to the textured polygon model.

Finally, the 3D object is scaled and oriented by setting a known distance or by entering known coordinates (absolute or relative to a local reference system).

For the aerial survey at the sanctuary of Punta Stilo, a hexacopter UAV equipped with an SLR camera was used. Among the steps imposed by the workflow, the first and most important is the design of the flight plan. The software manages georeferenced images imported from Google Maps, on which the operator has to position the flight plan.

The flight plan can be configured in two customizable patterns, grid and circular, for a maximum of 32 waypoints per mission. In addition, it is necessary to set the speed of the drone, the flying altitude (calculated from the take-off position), the distance between the waypoints, the holding time on the waypoint, the angle of sight of the camera and the shooting mode (eg. each waypoint, or every few waypoints, or - as in our case - every few seconds).

During the flight, telemetry, position and path of the drone are displayed on the laptop in real time (fig. 5).

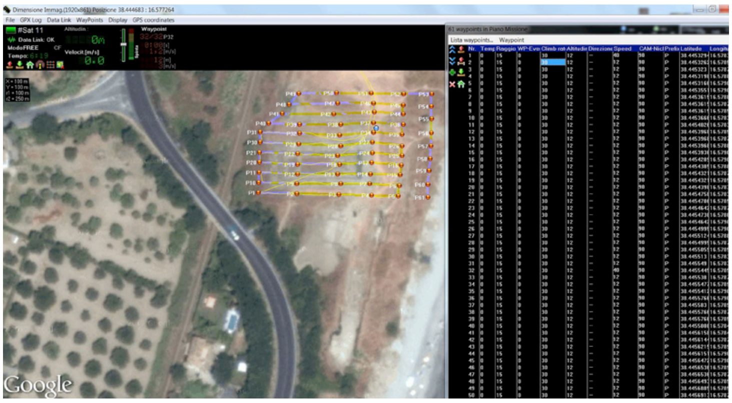

Figure 5: The position of the UAV along the waypoints, displayed in real time.

A second operation involves the positioning of GCPs (Ground Control Points), which allow the correct orientation of the model and, in case of GNSS data use, its georeferencing.
Regarding the area surveyed, approximately 5500 m2, the flight plan provided for a grid pattern, with waypoints spaced 4 m on the x axis and 16 m on the y axis and the speed of the UAV fixed at 1.2 m/s at an altitude of 12 m, while the camera was set for a shoot every 2 seconds.
So, a picture every 2.4 m, ideal for a 70% overlap between the photos according to the flight altitude (Taccola, Parra, & Ampolo 2014).
Other monuments in situ, including the archaic cippus inscribed, were acquired with SfM terrestrial surveying procedures.
It is appropriate to mention the acquisition procedure of bronze artifacts found in the Sanctuary. The photogrammetric survey of the bronze weapons deposit and the Tabula Cauloniensis was carried out in two phases, before and after restoration (fig. 6).

Figure 6: 3D model of the bronze weapons deposit, before (left) and after restoration.

Virtual Reality Visualization

The large amount of data resulting from the excavation study must be handled wisely, interpreted and understood. In this regard, a virtual view helps to understand the data and their context of finding, providing a valuable support for study and teaching. It's not just making 3D models, but also integrating into the whole working process the possibility to use new interactive technologies. In fact, one of the great benefits of virtual reality, is the ability to enable more natural forms of interaction, that will support archaeologists in the understanding their digital artefacts.
A very important issue will be to understand what is the best interaction. This paper indeed describes the whole design process leading to the prototype application, used by the archaeologist to access the excavation data and findings, visualized in a Head Mounted Display.
An essential element for the use of data that is provided, is how to handle them: a natural interaction means interacting without any learning step, providing a functional and invisible interface to the user that provides the various commands useful for interaction. It is important therefore that the application enables the user to fully manage real-time features such as metadata viewing, the ability to parse the objects in detail, and highlight the most important parts of the study so to improve and facilitate the learning process
The application is born with a polyvalent purpose, primarily as an aid to scholars and students to study, analyze and learn the excavation and its findings, in order to make the learning process active, a real collaborative space where the user can freely visit the area and understand the morphology and the conformation of buildings.
Another purpose of the reconstruction is the dissemination, that allow the finds to be available to the public and to provide information on the objects and the historical context of the findings, providing the relative metadata.
A further important aspect not to underestimate is the conservation, since various storms destroyed a huge portion of the excavation, which can only be visualized through the 3d photogrammetric model. This digital resource is very precious and will allow for the study of the lost elements even by the new scholars who will approach them in the future.

Development of a new approach to the consultation and analysis: Oculus Rift

One of the main focus of this application is to develop a new approach for the consultation of the archaeological data, with a complex set of tools integrated in the applicaton. In the design phase, it was decided to use a head mounted display to make the excavation visualization more immersive and engaging as possible.
The first experiment was in fact based on an Oculus Rift (Head Mounted Display), without any input device. In this case, the interaction was limited because it was based only on the movement of the head.

In the new phase, thanks to a new Head Mounted Display (HTC ViVe), with dedicated virtual reality controller, it has been possible to develop a new interaction.
The concept of the application has been to satisfy two specific requests by the archaeologists:

- the ability to navigate in the 3D model of the excavation and to see the acquired findings
- the ability to interact with the findings, analyzing them closely.

When the project started in 2015, we have evaluated many interaction solutions: we tried to use a OptiTrack system that does the tracking of movements, but used in combination with

the helmet limited its practicality and portability; so, at first, we decided to just use a helmet for virtual reality, without any type of input device. As said before, when we started developing on Oculus, it was impossible to interact with the application without using external tools; an integrated controller for the movements came out later, so there was a need to develop a system of movement and interaction that use only the HDM sensors, without the need for additional hardware like joypad or any other similar device.
At that point, the question was: how to interact without external system?
We made an interaction study to understand, as well as how to interact, how to give feedback to the user on his actions within the virtual environment.
We thought that the interaction with eyes were the most natural thing: the user can directly observe what interests him; if his look is still for more than a specified time, the resulting action is triggered.
At that stage and with this type of interaction the user had a general overview of the excavation site, and once he got in the area of interest the view was locked at that point so he had the possibility to watch around his position at 360°, to select an object, to see the 3D model and the metadata. The 3d models rotated on themselves, without the possibility of interacting with them, same thing for the text, which was static.

Development of a new approach to the consultation and analysis: HTC Vive

The next step was to evaluate the best solution to overcome the limitations of the previous system. The choice fell on "VIVE" head mounted display, which integrated the controls already tracked within the virtual environment, and a motion system that makes possible the use of the whole body (fig. 7). With these new opportunities, interaction was applied to archaeological data, with interesting developments.

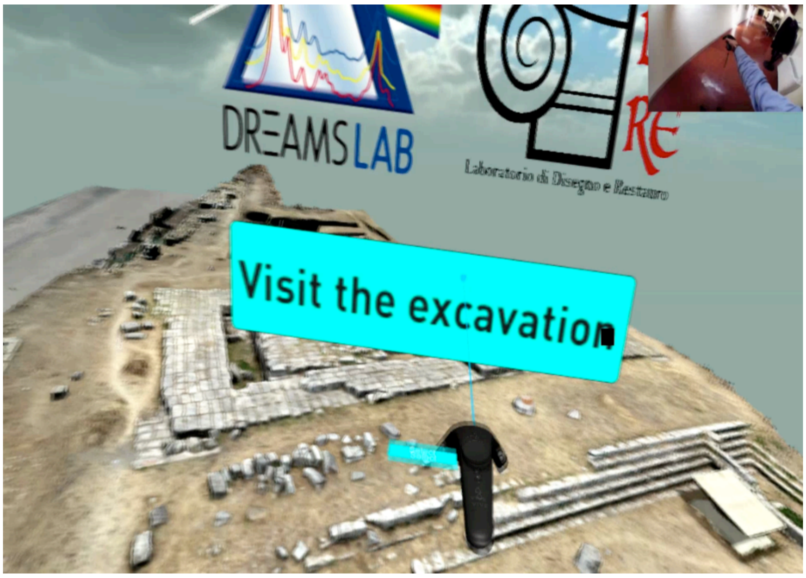

Figure 7: HTC Vive head Mounted Display with tracking system and controllers.

Firstly, it was integrated a free exploration of the excavation: now, there is much more freedom in the movement both in sight and in the management of the 3D objects and text associated with them.

It has also been integrated to the 3D simulation of the temple, to have a direct comparison between the evidence of what is there now and what was there originally. Then an additional feature has been inserted: the ability to change the direction of light, this feature allows users to better observe the finds, and in the case of the inscriptions this is very useful.
At the start of the application, the user can view the area of the excavation from the top, then he will be teleported into the most interesting area of the site where the artifacts were found. When in place, he can look around and select the various objects by pointing on each tag and clicking on the pad. Once the tag is activated, the user can observe in the left hand the finding, with the possibility of observing and manipulating it, watching the object details and shape. In the right hand, instead the text that explain the finding history will appear. In the case of objects with specific features, like the helmet, the object is automatically moved over the controller.
After seeing the discovery area and analyzing the individual finds, the user can find a menu where is possible to select the free movement mode.
In this mode, with the left hand, the user can select any point of the excavation where to be teleported, so to have a movement in the virtual space that is not too large in the real space.
The user can also reach the Doric Temple excavation site, where he can see the 3D simulation of the temple simply by activating the tags as for the previous objects (fig. 8).
With the light feature it is possible to perceive the real dimensions and understand the importance of this structure. By changing the angle and brightness it is also possible to understand how lighting in the temple was thought.

Figure 8: Findings Metadata and model

Conclusions

The project has reached a good point, but we are already thinking possible developing for the near future. Some interesting ideas are born by those who worked within the excavation: for example, it could be useful to expand the reconstruction, adding some other secondary findings and their metadata or to contextualize the site in its original environment.
Even more interesting would be the ability to integrate a mean to connect different helmets for collaborative visualization, making a real collaborative space for studying and teaching.
The application design process forced a reflection on the interaction modalities that archaeologists could use in virtual environments. This has made possible not only to visualize the 3D models, but also to interact with them, in order to better understand and use the data.
For archaeologists, it is very important to have the possibility to explore excavation scenarios in addition to displaying reconstructions of buildings or important findings.

Sections "The Sanctuary of Punta Stilo at Kaulonia: a brief historical-archaeological framework", "3D modelling: Computer graphics" and "3D data acqusition: Photogrammetry as a measurement and analysis tool" are by Emanuele Taccola. Sections "Introduction", "Virtual Reality Visualization", "Development of a new approach to the consultation and analysis: Oculus Rift", "Development of a new approach to the consultation and analysis: HTC Vive" and "Conclusions" are by Jacopo Baldini and Niccolò Albertini.

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