Motion Capture for Augmented Reality Storytelling in Archeology & Cultural Heritage Dissemination: Simulating an Animal Sacrifice at Ancient Phalasarna

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Abstract Augmented Reality (AR) employment in archaeological and cultural heritage settings are changing due to rapidly increase in computing power in mobile devices (smartphones, tablets and smartglasses). This has caused a transition from static only to richer and more dynamic environments including animation of human characters. This again opens for reconstructions and simulations of the intangible, particularly the significant context of human actions. Our chapter reports on an experiment with motion capture for AR simulation of an animal sacrifice at Ancient Phalasarna, Crete. The AR simulation was tested and evaluated by visitors on location. One conclusion is the importance of creating a balance between the fidelity of the human character's motions and their graphical appearance.

Keywords Motion Capture · Augmented reality · Digital cultural heritage · Computer animation · Situated simulation · Ancient Phalasarna

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1 Introduction

Augmented Reality (AR) applications in archaeological simulations and cultural heritage settings are rapidly changing from static only to richer, more complex dynamic digital environments, made possible by the increased computing power in handheld devices (in this case primarily smartphones and tablets, but eventually also smartglasses). When creating reconstructions of archaeological sites, we are thus no longer limited to static terrain, buildings, artefacts and simple movements, but can also include more complex computer animations, hence adding the highly desired context of human actions and activities.

This chapter presents an experiment with motion capture for AR simulation of an animal sacrifice at the 5th c BC temple of goddess Demeter at Ancient Phalasarna, currently being excavated by Dr. Elpida Hadjidaki-Marder under supervision of the Greek Ministry of Culture. The reconstruction of the temple is based on drawings of architects A. and Th. Nakasis, while the form and content of the animated sacrifice are drawn from the archaeological evidence combined with Walter Burkert's structural analysis of Greek mythology and rituals.

In the following we describe the technical and the archaeological backgrounds, as well as the design and production process, from plotting the sacrifice scene, through motion capture and implementation, to testing and evaluation with visitors on location. Finally, we conclude with a discussion of findings and provide suggestions for future implementation and research questions, including a brief report from a more recent follow–up experiment.

2 State of the Art and Research Challenge

When AR first entered the domains of archaeology and cultural heritage dissemination, a quarter of a century ago (Höllerer et al. 1999; Vlahakis et al. 2002), the digital reconstructions were, for quite some time, limited to static structures and objects. A decade later elementary computer animations became more customary (Liestøl 2014). However, animation of human movement was still rudimentary, extremely time–consuming and difficult to create manually with a decent result. Libraries of generic human motions and animations also tend to be incomplete, especially when one needs specific character behavior, which is primarily the case in archaeological and cultural heritage contexts. In recent years motion capture in various forms has become more easily available to broader user groups, and consequently, animation of human characters have begun to surface in AR applications. However, so far, the uses of motion capture in AR for archaeological reconstruction and cultural heritage simulations have been limited (Doulamis et al. 2017; Barbara and Grech 2022).

Investments in intangible cultural heritage are often focused on documentation and conservation of current practices and activities, which do not leave physical traces. Intangible and immaterial heritage, however, also includes the intangible context of human behavior, that is the practices that provides meaning to the 'dead' artefacts and material remains we often encounter in museum exhibitions (Yang et al. 2006; Staubermann 2020). In the tangible artefact–dominated world of archaeological dissemination, whether in museum exhibitions or on site, there is a craving for the intangible context of human actions and practices. There is a need to show how ancient tools were produced and for which purpose they were used, to display social and cultural human behaviors, and to demonstrate how rituals and ceremonies were performed and practiced, including known historical events. Finding ways to bring this knowledge to life is thus a pertinent problem and challenge to solve.

In archaeological reconstruction and simulation, the combination of augmented reality and motion capture of human behavior could be the answer to this deficiency. Consequently, the primary challenge in the research, development and experimentation reported here has been to explore and answer the question: How may we best utilize motion capture for depicting human actions when employing AR to simulate intangible heritage practices in combination with archaeological and historical evidence?

3 The Archaeological Context

Phalasarna has been inhabited since prehistoric times and blossomed as an eighth century BC Dorian city-state, situated on top of a high promontory, at the far west end of the island of Crete facing the western Mediterranean Sea. The location of the town and its port gave the opportunity to the inhabitants to become skillful mariners, while Phalasarna's laws and social systems promoted excellence in military arts that led its citizens to offer themselves as mercenaries to Persian, Carthagenian, and Hellenistic kingdoms. Phalasarna was a naval power controlling the sea routes along the western Aegean Sea and maintaining watchtowers and naval bases along those sea lines. Ancient geographers took note of the artificial closed harbor, carved out of a lagoon, and ringed around with quays, walls, and towers (Müller 1855). The harbor and surrounding structures have been uncovered through research excavations ongoing since 1986 (Hadjidaki 1988, 2019a, b, 2020; Hadjidaki and Iniotakis 2000).

A temple dedicated to goddess Artemis is also reported (Dionysius Calliphontis 120) to have existed, but it has not yet been located. However, a temple dedicated to goddess Demeter, Greek goddess of agriculture, was located in 2022 and is currently being excavated (Hadjidaki 2022). It was built on top of the acropolis in the fifth century BC, at the same time as the Parthenon in Athens and the temple of Poseidon at Cape Sounion in Attica, with two Doric columns by the entrance covered with Corinthian rooftiles. Three lines of an elaborate staircase led to the paved interior (Cella) of the temple where dedicated offerings were found. Among them were elegant vessels of ceremonial importance such as jugs (hydria) with the name of the goddess inscribed on the shoulder of the vessels. The Cella had a door facing east that led to a sacrificial courtyard where layers of ashes and animal bones were uncovered (Fig. 1).

Fig. 1 The site of the fifth century BC temple dedicated to the goddess Demeter located on top of the ancient Phalasarna acropolis. The grand staircase facing south is clearly visible. The sacrificial area is to the left (east) of the temple, towards the boulders.

The sacrificial courtyard was the site where at least since Homeric times the process of Thesmophoria or animal sacrifice was carried out. A bull, pig, goat, or sheep was killed in ritual fashion, parts of it burned, and the entrails and meat then cooked and eaten on the spot within a holy circle by the women participants. The process is described in detail by (Burkert 1985, 55–57); see below.

4 Design and Direction

The terrain on the east side of the temple is not a flat regular plane. In particular, the circular ramp from where the procession moved towards the site of the sacrifice is uneven, first with a steep ascent then followed by a more modest descent entering the sacrificial area. The sacrificial area itself is less uneven but still not a level surface. Thus, it was necessary to identify a similar terrain for doing the motion capture since it was not possible to bring the recording equipment to the original site (Fig. 2).

Fig. 2 Left: Planning the procession sequence on the east side of the temple. Right: Intersecting photogrammetry models of the archaeological site and a substitute terrain at the University of Oslo campus.

To match the movement on the chosen substitute terrain with the original terrain, photogrammetry models of the two sites were compared and paths and positions were marked physically in the substitute terrain for the motion capture. One person acted as all the characters wearing the sensor suit, including members of the audience, while other individuals stepped in to mark the characters and positions that were not under recording.

The composition and order of the procession was drawn from Burkert's interpretation of 'the essence of the sacred act' in ancient Greek animal sacrifice (Burkert 1985). Burkert distinguish between various social groups and sizes of communities involved in the actual sacrificial rituals, where the family–based event may have the smallest number of participants. For practical purposes we had to choose a simplified version of Burkert's essential elements, however with key roles represented: the priestess, the sacrificer, the blameless maiden carrying the knife in a basket, one person guiding the sacrificial lamb, another carrying the incense burner, musicians, and finally an audience, a family or clan participating in and (hopefully) benefiting from the ritual.

5 Motion Capture

Motion capture recordings were collected using a Nansense Pro full-body suit, which contains 40 R2 sensors and is intended for use in animation. Each sensor contains a gyroscope, accelerometer, and magnetometer so that its orientation, rotation, and position relative to other sensors can be determined. The Nansense recording software uses a body solving algorithm to interpret motion of each body part. The suit includes detachable bands for the head and feet with one sensor each and detachable gloves with 12 sensors each. Data were streamed to a PC via cable connection and recorded in the Nansense software at a frame rate of 240 Hz. A height-tracking function was used so that changes in ground elevation were maintained in the recorded data. Although it was not possible to track the motion of objects in the environment, the subject wearing the suit grasped various props while acting out the different characters so that her hands would be in the correct position for objects to be added during animation.

The suit was determined to be the best option for motion capture because it can be used relatively easily in natural settings, unlike infrared-based optical systems. It also allows for detailed capture of the hands and fingers, even in cases where a person is grasping an object (as was the case in our data collection), which would lead to problems with occlusion for most camera-based systems that require a line-of-sight to maintain tracking. The main shortcoming of motion capture suits is that the sensors are susceptible to magnetometer interference, which leads to positional drift of individual sensors, disrupting their apparent spatial configuration. This was the main challenge that we encountered in our data capture. The fingers were especially affected since the sensors are close together and tend to interfere with each other. The outdoor setting also made it challenging to run a thorough calibration and monitor data quality while recording. Despite these challenges, the quality of data captured was generally satisfactory (Fig. 3).

6 3D–modelling and Animation

All the scene components were imported into the Unity engine, which is used to construct this type of interactive experiences. Then the terrain was assembled, which was generated using photogrammetry, the hand-modeled temple, the people models, as well as the aforementioned motion captured animations. The static 3D models and the motion capture were done independently, which means that discrepancies were expected. It is impossible to find an identical terrain off-site, and it's also very complicated to find even a similar terrain with only a 3D model at hand. This poses a challenge, to which one might consider multiple approaches: (1) after capturing and analyzing the animations in Unity, go back to motion capture and recapture them–this might also require one to look for a more precise terrain or even build one manually; (2) import the animations into 3D editing software and adapt them to the terrain; (3) import the animations straight into the Unity engine and use its Timeline feature to mix and match the animations to the 3D world. The first two approaches are time consuming and require excessive synchronization between different teams and need some very specific skills (either physical prop building or professional 3D rigging and animation). The third approach is much more rapid, but also much less flexible. One must understand that research in multi-disciplinary fields always involves a wide variety of tasks, which means that iterations at each stage are limited and often time restricted. With augmented reality projects, testing is also limited and must be carefully planned. This is why in the end the third approach made the

Fig. 3 The top two photos show motion capture of a person wearing the sensor suite to record movements for guiding the sacrificial lamb and the flute player, respectively. A small bicycle was used to keep the hand and bending of the body steady relative to the ground, and a wooden structure was applied to adequately position head and hands/fingers for the flute player. Suitable terrain at the University of Oslo campus was identified as sufficiently congruent with the actual terrain next to the temple of Demeter at Phalasarna. Middle screen shots show the exported motion capture files when displayed in FBX–Review and details of its implementation in the reconstructed AR–environment. Bottom photos depict the application in use on location with an iPhone 14 Pro Max, utilizing the Unity–based Sitsim AR platform. Note that both vertical and horizontal correspondence is not exact, due to the position and angle of the physical camera compared to the position and angle of the virtual camera. The lack of vertical alignment is deliberate since experience has proven that users prefer a 15% tilt offset to improve the visual relationship between the physical environment and the digital environment on the screen.

most sense in this project – having all the procession and motions in place was more important than making them perfect. The Timeline feature provided enough tools to quickly iterate and adapt the animations (cut, move, rotate, blend, loop, etc.) well enough for them to be informative and showcase the whole procession. It was very useful that the animated people had very limited interaction with each other or the environment, apart from the ground surface and one person holding a sheep by its neck, while another picked up a knife.

7 Methodologies: Media Design, Testing and Evaluation

The experiment–based research reported here was conducted as a media design project (Fagerjord 2012; Nyre 2014; Liestøl 2013, 2018) and informed by the key humanities disciplines: rhetoric and narratology, using theoretical–analytical concepts as topoi for synthesis and design for invention and experimental implementation of new rhetorical and storytelling techniques in AR mediation. In this project the adaptation of conventions from the documentary film genre has been a central source (topos) for many of the solutions in the narrative design. This overall approach was further supported by qualitative methodologies during the testing and evaluation with real user on location (user observation, written reply to questionnaires etc.).

For this type of qualitative and controlled testing on location where the focus is on a mix of UI elements and event/place related topics, valuable information and feedback can be drawn from even small numbers of testers if the questionnaire encourage qualitative and substantial answers. In usability studies, which is primarily focused on human–computer interactions, it is argued that five testers are sufficient (Nielsen 2012). With the site of the temple and the sacrificial area on top of a cliffy terrain access for and the availability of users were limited. For this research (related to a university course on 'media students as researchers' we had the chance to test with seven visitors during the limited time available. One would have preferred a somewhat larger number, but even single digit testers may provide valuable feedback and information. Testers were given a short introduction to the project and the general background, and supported throughout the testing if needed, but examined the application with as little interference as possible. Afterwards, they answered a written questionnaire (Fig. 4).

8 Results

Overall, the feedback from the visitors on location using and evaluating the app was very positive and encouraging. Here are some statements regarding the general experience of using the app:

> Excellent (female, 62).

> Really cool, brings it back to life, you can travel in time (female, 42).

> Easy to use, very informative (female, 52).

> It was like I really participated in this sacrifice (female, 33).

All participants except one answered that the AR simulation made them feel more connected to the ritual and when it took place in ancient times. The most important criticism was the lack of resolution regarding the character's body and clothing detail:

> Visualization of figures … quite blocky (male, 58).

Fig. 4 Photo of test application in use. The procession has arrived at the sacrificial area and the priestess is reciting her prayer in honouring the goddess Demeter.

> The models were of low quality (female, 34).

The characters movement, on the other hand, were more positively received:

> Very engaging (female, 52).

> Very smooth (female, 34).

Although the test/evaluation was limited it provided valuable feedback for an early iteration in a long–term design project like this. Based on the first round of testing with real users on location we can conclude that the prototype in general caused vivid and informative experiences for the users. They also seem to value the movement of the human characters in the animation sequence reconstructing the ritual of animal sacrifice. However, the graphical resolution of the characters involved was not impressive and even appeared 'dated'.

Consequently, it would be relevant in a follow–up production/case to improve the graphical quality of the characters in an animation, while using the same method for motion capture.

9 Follow–up Case: 'The Ides of March'

Since the same research and development team has conducted a new case study which can be seen as a follow–up to the Phalasarna case we would like to briefly mention some of its features and the feedback received from users. This time the topic was an historical event from ancient Rome, which has rather detailed classical descriptions: the assassination of Julius Caesar, which took place on the 'Ides of March' in 44 BC in Pompey's Curia. In some respect this is an easier site since it happened indoors so uneven terrain did not cause challenges for the motion capture and animation. However, the actions are more complex, involving more characters and much more interactions between characters. Following the conclusions from the Phalasarna case resolution, graphical quality and lighting of both characters and the environment were increased rather substantially (Liestøl et al. 2024) (Fig. 5).

The 'Ides of March' also includes significant improvements in reconstructing the senate chamber of Pompey's Curia as it may have looked with material surfaces as well as artificial and natural lighting and reflections (Fig. 6).

In the 'Ides of March' case the motion capture in principle followed the same procedure as in the Phalasarna case. However, to follow up on the much more complex actions of and interactions between characters, two Nansense Pro full-body suits were used simultaneously. Despite the increased investment in the motion capture process, the animation turned out to be immensely challenging and very time–consuming.

Three approaches to editing and iterating motion captured animation were described in an earlier section. For this project, it was decided to employ the process, where animation is imported into a 3D editing software and adjusted there. Due to the complexity of the actions and the number of animated characters in a small space, very delicate adjustments had to be applied, which would be impossible with either of the other approaches. The chosen process then required much more time dedication, but it was simply impossible to achieve a similar result otherwise. Finally, it was important to achieve a much higher level of realism not only in 3D models, but also in the movements and actions.

During the testing on location with invited guests and visiting tourists the relatively high resolution and quality of both movement and graphical solutions were

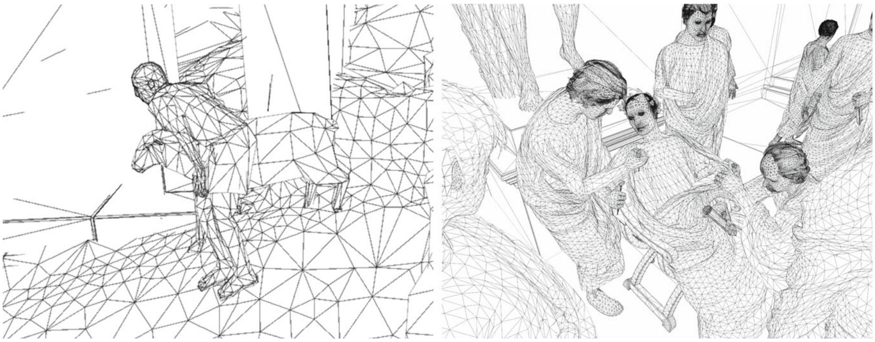

Fig. 5 Left: the character guiding the sacrificial lamb in the Phalasarna simulation displaying a 'blocky' mesh with a low triangle count. Right: The opening moment during the assassination of the dictator Julius Caesar. Casca is providing the first attack on Caesar from behind, while Cimber holds him down by the toga initially pretending to beg for his brother's pardon. The triangle count per character are multiple times higher.

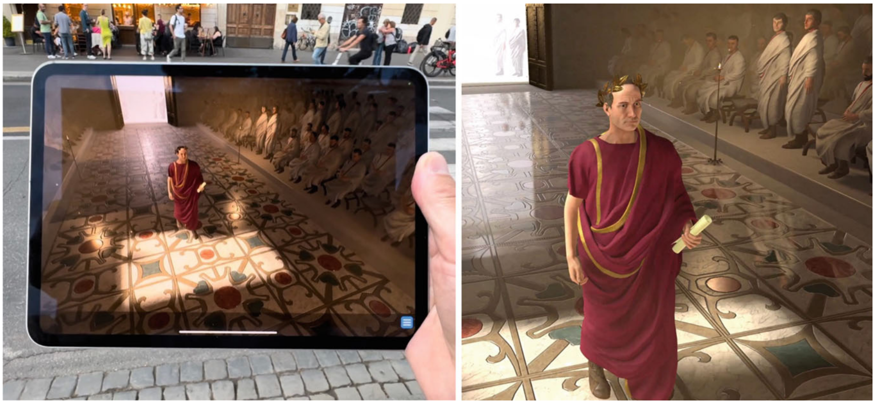

Fig. 6 Left: The 'Ides of March' test application in use on location in Via di Torre Argentina in Rome, looking west across today's street level and towards the main entrance in the reconstruction of Pompey's Curia on the screen. Right: Detail from a screen shot of the application showing the high graphical quality of the environment and its inventory.

highly appreciated. Consequently, the criticism we saw directed towards the limited graphical quality of the models in the Phalasarna case is absent in the 'Ides of March' simulation. As the quality and detail obviously increased, the risk of the phenomenon known as the 'uncanny valley' effect (Bolter et al. 2021) grew. However, there was no direct feedback from users to indicate that they experienced the 'uncanny valley'. Almost all of the ten testers regarded the realism of the scene and the characters as convincing.

10 Conclusion

We started this chapter by pointing out the change in AR development from static environments to scenes with increasing use of animation and human characters that have been ongoing over the past decade. In the Phalasarna case feedback from users testing the system indicated that the animations for human characters provided by motion capture were adequate, while the graphical quality and detail of the same characters were too simple, 'blocky' and 'old'. With the 'Ides of March' case the graphical quality was improved as much as possible exploiting the best available hardware (iPad Pro M4). Overall, the testers of the latter case were satisfied and impressed by both the characters' movement and the quality of their graphical resolution and realism.

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