The 6th International Symposium on Virtual Reality, Archaeology and Cultural Heritage VAST (2005)
M. Mudge, N. Ryan, R. Scopigno (Editors)

Virtual Reconstruction of a Dismembered Andean Mummy from CT Data

Fantini M.[1], Benazzi S.[2], De Crescenzio F.[1], Persiani F.[1], Gruppioni G.[2]

[1]Mechanical, Nuclear, Aviation, and Metallurgical Engineering- DIEM - University of Bologna - Italy
[2]Histories and Methods for the Conservation of Cultural Heritage - DISMEC - University of Bologna - Italy

Abstract

This paper describes the procedure adopted to provide the virtual reconstruction of a dismembered Andean mummy. Starting from Computed Tomography (CT) data of single fragments, advanced Computer Graphics tools and methods have been implemented to obtain the three dimensional (3D) model of the whole mummy in the proper anatomical position. The conservation of the mummy depends on caring for the external tissue and the internal skeletal structure. Therefore the main aim of this work is to decrease the number of damages due to the manipulation of the remains in traditional approach since restoration interventions can be performed by means of virtual tools in a CAVE (Cave Automatic Virtual Environment). At the same time it provides new challenges in cultural heritage dissemination and exhibition. Furthermore qualitative and quantitative information have been obtained for anthropological analysis and measurements.

Categories and Subject Descriptors (according to ACM CCS): I.3.8 [Computer Graphics]: Applications, J.2 [Physical Sciences and Engineering]: Archaeology

1. Introduction

Mummies are an important historical, cultural and scientific heritage. These remains are extremely brittle and are susceptible to breakage during manipulations and transportations. Furthermore they can be also damaged by improper storage environments. Therefore studies on mummies are performed by means of non-invasive sophisticated technologies, like Computed Tomography (CT).

Previous works in this field describe investigations on whole mummies [CMF*03] or only mummified heads [CMG*04] and [HH02]. Many authors show results on mummies, mostly coming from Egypt, [CMF*03], [HTE02], [PCR*03] and [MNDG*03]. Main achievements in such scientific context are related to improved comprehension of mummification techniques [JPTS02], [GAME99], new researches in paleopathology [RHB02], [CGN*02] and direct measurements of body parts [GGN*04]. Finally Ruhli et al. [RCB04] provide a detailed survey of the advantages given by the paleoradiology.

It is well known that the introduction of Computer Graphics and Virtual Reality provided significative benefits in the development of advanced tools supporting experts in retrieving additional information on mummies in the framework of Cultural Heritage analysis [ZZ99], [Bar00], [Add00] and [VFLJ02].

In this work the implementation of such techniques in a user-centred approach is described. It regards a novel and complex case study and aims at improving the quality in reconstruction of a dismembered Andean mummy and extending the procedure with a Virtual Assembly process for concrete restoration purposes. Since its particular fragility, direct manipulation interventions would further damage the remains of the mummy and cause the loss of small fragments of soft mummified tissue. It is evident that the importance of these achaeological finds, which bear witness to an ancient bio-cultural civilization, requires to take precautionary measures. Therefore visualization and interaction techniques were performed in a new collaborative approach within a Cave Automatic Virtual Environment (CAVE) and the actors in such Virtual Assembly process were engineers and anthropologists. [Weg95] and [HBG04].

This project was developed to lay out the mummy in a Virtual Assembly environment to validate the digital 3D model from an anthropological point of view. This procedure re-

© The Eurographics Association 2005.

quires the 3D surface reconstruction of the single parts from CT data and the virtual manipulation of these models in a CAVE in order to position them in the proper anatomical configuration.

Moreover the exploitation of digital models provided more morphological information and measurements for scientific purposes and the comparison with other mummies. Thus an additional amount of scientific considerations was achieved with regard to analysis procedures performed on the real remains.

Finally it is important to highlight the role of this work in the improvement of cultural heritage fruition. Usually these remains are presented in museums or exhibitions so that people are not aware of their real context and history. On the other hand, the stereoscopic visualization of the scale model is a powerful communication tool. Therefore knowledge and information on the mummy can be efficiently fused in a comprehensive vision of the whole digital 3D model by means of a well designed Virtual Reality environment.

2. The Andean mummy

The mummy under investigation was sent from the Civic Museums of Reggio Emilia to the Department of Histories and Methods for the Conservation of Cultural Heritage (DISMEC) for research purpose and restoration interventions [LLO*03].

The mummy comes from the Necropolis of Ancòn, in the south-central coast of Perù and was shipped in Italy in 1893. Since the lack of equipment it is not possible to exactly date the mummy. Anyway remains from Ancòn area are usually dated from Late Intermediate (900-1440 AC) to Late Horizon Period (1476-1532 AC) of the ancient Peruvian history [Row60]. Moreover the kind of spinning of a small fragment of cloth found on the neck of the mummy confirms the place of origin and chronologically sets it to the X and XI century AD [RLC97].

Besides the original tightly flexed position Figure 1, that is typical of Andean mummies, had been reproduced by means of temporary strings, both internal and external structures had been seriously damaged. Once the strings have been removed the mummy showed six dismembered parts and looked in really bad conditions. Only the left upper limb could be considered in the proper anatomical position (Figure 2), while all the other limbs were separated from the body of the mummy. Currently six different main fragments are present: part of the bust with the head and the left upper limb, the right upper limb, part of the rachis, the pelvis (reduced to bony tissue), and the two lower limbs.

In Figure 3 is shown the right lower limb. It is also possible to see the loss of small fragments of soft mummified tissue due to the fragility of the remain.

First anthropological analysis revealed a female subject dead approximately at the age of 14-15 years. She was 144-150 cm height and her head was intentionally and tightly deformed as usually happened in the high society members [LLO*03]. Radiographic and tomographic investigations showed radiopaque areas which are related to a natural mummification process inside the skull due to the dry

Figure 1: *On the left a mummy of a colombian woman, found near Bogotà. On the right a peruvian mummy in seated position with the knees bended on the thorax.*

Figure 2: *The part of the bust with the head and the left upper limb in the proper anatomical position.*

Figure 3: *The right lower limb.*

© The Eurographics Association 2005.

climatic conditions of the peruvian coasts. A further radiopaque perimeter on the right parietal bone of the skull is related to a calcified tumefaction of soft tissue probably due to a stroke. Additionally spectrographic analysis have been performed in order to identify the specifc material of metal parts clearly highlited in the mouth of the mummy by tomographic investigations. These are principally copper fragments, but also silver, iron and partial chrome and lead have been revealed [LLO*03]. The above considerations lead to suppose that the mummy is a sacrifical victim. Ritual immolations on physically perfect children are considered a common custom in the noble society families of that times, like in the Inca Capacocha [Rei99].

3. CT data acquisition

Non-invasive investigative techniques have been applied to obtain as much information about the mummy as possible non-destructively.

In this project the single main fragments of the mummy were examined with Computed Tomography (CT) performed by Philips Mx8000 Dual Scanner as shown in Figure 4. The whole data-acquisition procedures were carried out by the radiology department of Faenza Hospital in april 2005.

Figure 4: *Philips Mx8000 Dual CT Scanner.*

The CT scanning was performed at 1,5 mm slice intervals with a slice thickness of 6,5 mm and the image matrix had a resolution of 512 by 512 pixels. The number of axial slices resulting from CT of each fragment of the mummy can be found in Table 1 and the data-sets were stored in six DICOM files.

4. Surfaces reconstruction

The digital 3D models of each fragment of the mummy were built from the CT data-set using Amira 3.1.1, an advanced software tool for 3D visualization, data analysis and geometry reconstruction.

The first investigation of the data was performed on the single slices and on the whole stack of images of each data-set. Three dimensional models of each data-set were then achieved semi-automatically by threshold-based segmentation, contour extraction and surface reconstruction. Manual interventions, such as filling holes or deleting bad faces, were performed in local regions to repair the models (Figure 5).

Fragments	Number of axial slice
Bust, head, left upper limb	267
Right upper limb	203
Rachis	192
Pelvis	162
Left lower limbs	212
Right lower limbs	201
TOTAL	1237

Table 1: *Number of axial slices resulting from CT of each fragment of the mummy.*

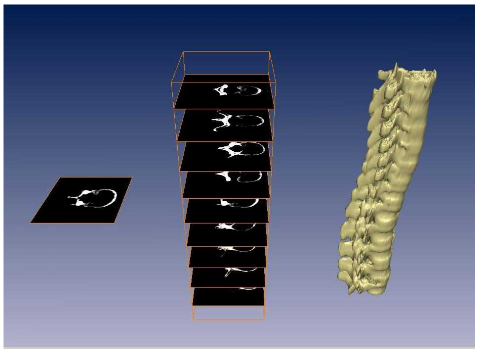

Figure 5: *Single CT slice, stack loading in bounding box and final model of the rachis resulting from the surface reconstruction process.*

The list of the digital 3D models of each fragment obtained with surface recostruction of soft tissues are shown in Table 2 with the number of points and faces of the triangular mesh in the best resolution.

Fragments	Nr. of points	Nr. of faces
Bust, head, left upper limb	301.447	609.512
Right upper limb	238.274	476.252
Rachis	913.229	1.828.696
Pelvis	277.089	554.860
Left lower limbs	442.570	884.445
Right lower limbs	404.265	809.540

Table 2: *Number of points and faces resulting from surface recostruction of soft tissues of each fragment of the mummy.*

By the exploration of the three-dimensional surface reconstructions it was more clearly confirmed the presence of

© The Eurographics Association 2005.

some typical aspects related to funerary customs that had been already noted in the previous radiographic assessment. In particular the model of the skull is shown in Figure 6. Different colors were used in the visualization of the surfaces to highlight the most important information available from the model. In this case it is very easy to identify the calcified tumefaction of soft tissue on the right parietal bone of the skull and the metal artifact put in the mouth of the mummy.

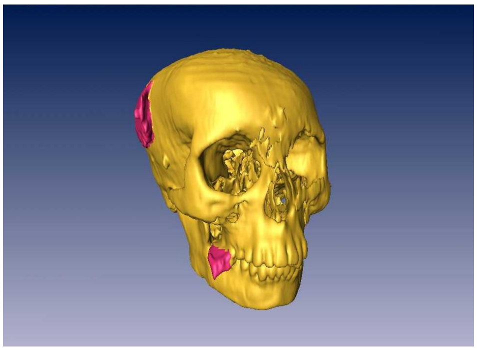

Figure 6: *The skull of the mummy. The calcified tumefaction of soft tissue on the right parietal bone and the metal artifact in the mouth are highlighted*

A CT data-set represents different tissue densities by greyscale intensity values; hard tissues, like bones, have high intensity while soft tissues, like skin, have lower intensity value. Therefore both internal and external structures of the mummy were reconstructed setting different thresholding values on the data-sets. For example in Figure 7 are shown two different models of the right lower limb.

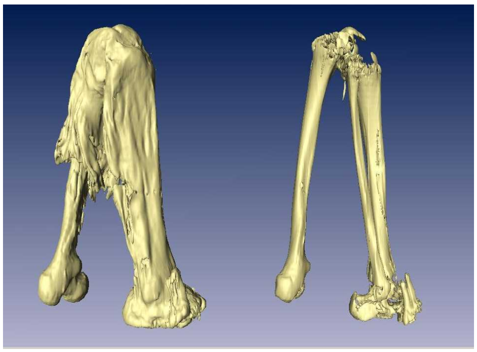

Figure 7: *Surface reconstruction of soft and hard tissues of the right lower limb by different thresholding values.*

Then specific anthropological analysis and measurements were conducted directly on the digital 3D models in particular representing the hard tissues of the mummy. For example, by the direct measurement of the length of the femur in the Virtual Environment it was possible to assess the stature of the female individual before death. Trotter and Gleser [TG52] created a chart of equations for estimating the living stature of unknown individuals based on the surviving long bones, like the physiological length of femur (LF). In this specific case, for female subject, the stature was calulated by the following equation:

Stature (cm) = 2.47 x LF (cm) + 54.10 +/- 3.72

LF = 36.08

Stature (cm) = 2.47 x 36.08 + 54.10 +/- 3.72

Stature (cm) = 143.22 +/- 3.72

It is important to remind that well defined landmarks on the surfaces of the bones are selectable only on the digital format, since the presence of soft tissue prevents the same operations on the real mummy. In the traditional approach anthropometric analysis are performed by special measuring instruments on these landmarks. Moreover these instruments are designed for skeletal structures and therefore the direct contact with the mummified tissues can seriously damage the remains.

Anthropologists claimed that the active investigation of the single digital fragments was very useful both to highlight singularities in the soft tissue and to conduct measurements on the skeletal structure.

5. The Virtual Assembly procedure

The last step of this project was to obtain the three dimensional model of the whole mummy in the proper anatomical position performing the Virtual Assembly of the available digital fragments. This complex task was the result of a collaborative process, where multidisciplinary experience and knowledge were required. In such a collaborative environment the information flow was designed in order to enhance the intellectual properties of anthropological analysis and the cognitive aspects of high end digital representations, together with the awarness of Virtual Reality (VR) experts in Human Computer Interface [SG00] and [RCYK03]. The data-set, which is the core element in this information flow (Figure 8), contains a huge amount of data with different levels of detail and thresholding values.

These experiments were performed in a Cave Automatic Virtual Environment (CAVE), a semi-immersive equipment based on three 2.5 x 1.9 m rear projected screens (Figure 9) [LPDC01]. Anthropologists were provided with stereoscopic visualization of scale 3D models and directly communicated with engineers in order to lead the iterative procedure of manipulation of the digital fragments step by step. Since the nature of the remains did not allow to locate the exact contact surfaces, the general lay out was determined by visual comparison. Therefore the stereoscopic visualization allowing the depth perception of models in the Virtual Assembly was an useful tool to validate the consecutive steps in this process. Moreover other archeological finds that are classified with the same place of origin, dated in the

© The Eurographics Association 2005.

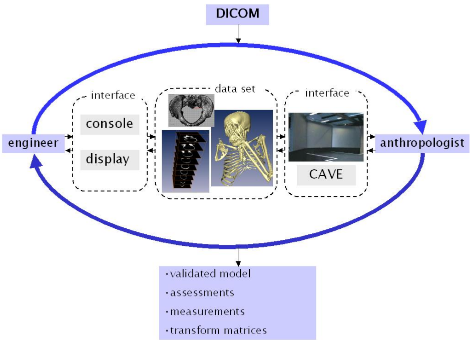

Figure 8: *The information flow in the collaborative environment.*

same historical period and comparable in terms of funerary customs were used as reference elements.

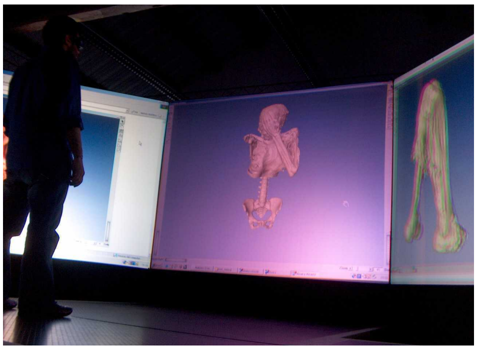

Figure 9: *The collaborative virtual environment in the CAVE (Cave Automatic Virtual Environment).*

The virtual model of the whole mummy with all the main fragments located in the proper anatomical position of funerary posture is shown in Figure 10. This is the result of the iterative process performed by means of virtual tools. The values of the transformation matrices to set each digital 3D model in the final configuration were stored to allow quickly virtual re-assembling of different reconstructed models from the intial data-sets. As expected the final lay out, validated by anthropologists, represent the typical tightly flexed position of mummies coming from Andean places and with the same date.

6. Conclusions

The conclusions of this work are related to the observation and measurement of benefits provided by the use of this Virtual Reality environment as a powerful tool in the framework of Cultural Heritage restoration. In this project the collaborative and multidisciplinary interaction between engineers and anthropologists has been very useful. Anthropologists claimed that several advantages have been observed in this work:

- The Virtual Environment of manipulation avoided to cause irreversible damages to the remains and the digital model of the whole mummy was validated before traditional restoration interventions;
- Quantitative measurements that can not be performed on the remains were conducted directly on the digital 3D models;
- The virtual model can be used as a guideline for future restoration interventions so that restorers will be able to repair the mummy with confidence of the position of single fragments.

On the other hand, we believe that this work is also a real contribution to the evolution of innovative interfacecs in the framework of Cultural Heritage fruition. The implementation of Virtual Reality is a mean to access and to publicize the complex historical features encapsulated in the archaeological finds. In this particular case the remains of the mummy can be shown in museums or exhibitions together with the stereoscopic visualization of the whole virtual model. It is important to highlight the cognitive aspect of a representation that brings to the observer a complete but simplified vision of the mummy. To augment the perception with historical, social, geometrical and material information without overloading the occasional observer seems to be the most challenging aspect in this field.

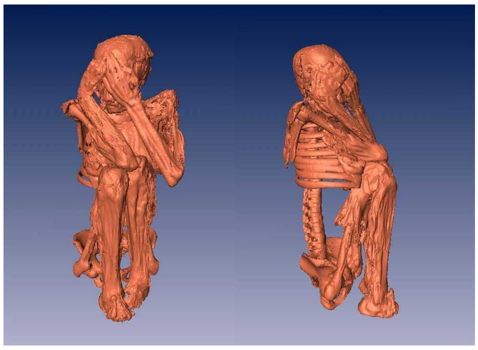

Figure 10: *The virtual reconstruction of the whole mummy in the typical tightly flexed position (front and side view).*

7. Acknowledgements

We give thanks for the support provided in this project on technical aspects about CT scanning the whole staff of the radiology department of Faenza Hospital and dott. Carlo Orzincolo.

References

[Add00] Addison A. C.: Emerging trends in virtual heritage. *IEEE MultiMedia 7*, 2 (2000), 22–25.

© The Eurographics Association 2005.

[Bar00] BARCELO J. A.: *Visualizing what might be. An introduction to virtual reality techniques in archaeology*. ArcheoPress, April 2000.

[CGN*02] CIRANNI R., GARBINI F., NERI E., MELAI L., GIUSTI L., FORNACIARI G.: The "Braids Lady" of Arezzo: a case of rheumatoid arthritis in a 16th century mummy. *Clin Exp Rheumatol 20*, 6 (Nov 2002), 745–752.

[CMF*03] CESARANI F., MARTINA M. C., FERRARIS A., GRILLETTO R., BOANO R., MAROCHETTI E. F., DONADONI A. M., GANDINI G.: Whole-Body Three-Dimensional Multidetector CT of 13 Egyptian Human Mummies. *Am. J. Roentgenol. 180*, 3 (2003), 597–606.

[CMG*04] CESARANI F., MARTINA M. C., GRILLETTO R., BOANO R., ROVERI A. M. D., CAPUSSOTTO V., GIULIANO A., CELIA M., GANDINI G.: Facial Reconstruction of a Wrapped Egyptian Mummy Using MDCT. *Am. J. Roentgenol. 183*, 3 (2004), 755–758.

[GAME99] GAAFAR H., ABDEL-MONEM M. H., ELSHEIKH S.: Nasal endoscopy and CT study of Pharaonic and Roman mummies. *Acta Otolaryngol 119*, 2 (Mar 1999), 257–260.

[GGN*04] GARDNER J. C., GARVIN G., NELSON A. J., VASCOTTO G., CONLOGUE G.: Paleoradiology in mummy studies: the Sulman mummy project. *Can Assoc Radiol J 55*, 4 (Oct 2004), 228–234.

[HBG04] HUA H., BROWN L. D., GAO C.: Scape: Supporting stereoscopic collaboration in augmented and projective environments. *IEEE Comput. Graph. Appl. 24*, 1 (2004), 66–75.

[HH02] HOFFMAN H., HUDGINS P. A.: Head and Skull Base Features of Nine Egyptian Mummies: Evaluation with High-Resolution CT and Reformation Techniques. *Am. J. Roentgenol. 178*, 6 (2002), 1367–1376.

[HTE02] HOFFMAN H., TORRES W. E., ERNST R. D.: Paleoradiology: Advanced CT in the Evaluation of Nine Egyptian Mummies. *Radiographics 22*, 2 (2002), 377–385.

[JPTS02] JANSEN R. J., POULUS M., TACONIS W., STOKER J.: High-resolution spiral computed tomography with multiplanar reformatting, 3D surface- and volume rendering: a non-destructive method to visualize ancient Egyptian mummification techniques. *Comput Med Imaging Graph 26*, 4 (Jul 2002), 211–216.

[LLO*03] LENARES M., LONGHENA M., ORZINCOLO C., VANDINI M., BERNABÒ-BREA M., MACELLARI R., LORUSSO S., GRUPPIONI G.: Studio etno-antropologico su una mummia andina conservata presso i civici musei di reggio emilia. *Quaderni di Scienza della Conservazione 3* (2003), 69–84.

[LPDC01] LIVERANI A., PERSIANI F., DE CRESCENZIO F.: An immersive reconfigurable room (i.r.r.) for virtual reality simulations. In *Proceedings of the XII ADM International Conference* (2001), pp. E1–9/E1–15.

[MNDG*03] MURPHY W. A. J., NEDDEN DZ D. Z., GOSTNER P., KNAPP R., RECHEIS W., SEIDLER H.: The iceman: discovery and imaging. *Radiology 226*, 3 (Mar 2003), 614–629.

[PCR*03] PREVIGLIANO C. H., CERUTI C., REINHARD J., ARAOZ F. A., DIEZ J. G.: Radiologic Evaluation of the Llullaillaco Mummies. *Am. J. Roentgenol. 181*, 6 (2003), 1473–1479.

[RCB04] RUHLI F. J., CHHEM R. K., BONI T.: Diagnostic paleoradiology of mummified tissue: interpretation and pitfalls. *Can Assoc Radiol J 55*, 4 (Oct 2004), 218–227.

[RCYK03] RHEE S.-M., CHO E., YOU H.-S., KIM M.-H.: Architectural design and simulation in the heterogeneous collaborative virtual environment. In *CW '03: Proceedings of the 2003 International Conference on Cyberworlds* (Washington, DC, USA, 2003), IEEE Computer Society, p. 120.

[Rei99] REINHARD J.: Frozen in time. *National Geographic* (November 1999).

[RHB02] RUHLI F. J., HODLER J., BONI T.: Technical note: CT-guided biopsy: A new diagnostic method for paleopathological research. *Am J Phys Anthropol 117*, 3 (Mar 2002), 272–275.

[RLC97] RUARO LOSERI L., CAVATRUNCI C.: *Oro, riti e miti dell'antico Perù*. Marsilio Editore, 1997.

[Row60] ROWE J.: Cultural unity and diversification in peruvian archaeology. In *Men and Cultures: Selected Papers of the Fifth International Congress of Anthropological and Ethnographical Sciences* (1960), pp. 627–631.

[SG00] SHIRMOHAMMADI S., GEORGANAS N. D.: An architecture for collaboration in virtual environments. In *VR '00: Proceedings of the IEEE Virtual Reality 2000 Conference* (Washington, DC, USA, 2000), IEEE Computer Society, p. 283.

[TG52] TROTTER M., GLESER G. C.: Estimation of stature from long bones of American Whites and Negroes. *Am J Phys Anthropol 10*, 4 (Dec 1952), 463–514.

[VFLJ02] VOTE E., FELIZ D. A., LAIDLAW D. H., JOUKOWSKY M. S.: Discovering petra: Archaeological analysis in vr. *IEEE Comput. Graph. Appl. 22*, 5 (2002), 38–50.

[Weg95] WEGMAN E. J.: Affordable environments for 3d collaborative data visualization. *IEEE MultiMedia 2*, 6 (1995), 68–72, 74.

[ZZ99] ZHENG J. Y., ZHANG Z. L.: Virtual recovery of excavated relics. *IEEE Comput. Graph. Appl. 19*, 3 (1999), 6–11.

© The Eurographics Association 2005.