Mediterranean Arhaeology and Archaeometry, Vol. 12, No 1, pp.11-20

TELEARCH - INTEGRATED VISUAL SIMULATION ENVIRONMENT FOR COLLABORATIVE VIRTUAL ARCHAEOLOGY

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Received: 10/02/2012
Accepted: 23/02/2012
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ABSTRACT

Archaeologists collect vast amounts of digital data around the world; however, they lack tools for integration and collaborative interaction to support reconstruction and interpretation process. TeleArch software is aimed to integrate different data sources and provide real-time interaction tools for remote collaboration of geographically distributed scholars inside a shared virtual environment. The framework also includes audio, 2D and 3D video streaming technology to facilitate remote presence of users. In this paper, we present several experimental case studies to demonstrate the integration and interaction with 3D models and geographical information system (GIS) data in this collaborative environment.

KEYWORDS: Collaborative systems, cyberarchaeology, GIS, remote interaction, data visualization.

1. Introduction

In modern archaeology large amounts of data are generated through the use of 3D laser scanners, photogrammetry, digital photography, computer vision and other forms of digital recording process. For interpretation and visualization of data archaeologists use variety of specialized software tools (some open source), which can usually handle specific type of data at a time. The tools allow for data documentation, decimation, analysis, visualization, archiving, and contextualization. At the end there is a lack of integration of tools in order to allow for comparison of different data sources. Majority of the tools also do not provide a straightforward way of sharing data within a large community of users and scholars. In short the digital process of interpretation in archaeology is still a standalone and not really collaborative activity.

Virtual reality offers flexible modality for visualization, exploration and interaction with spatial data. Shared virtual environments can provide remote user access to these data. The aim of proposed TeleArch framework is to integrate different data sources and provide real-time interaction tools for remote collaboration of geographically distributed scholars. The framework also includes audio and video streaming technologies (including light-weight 3D teleimmersion using stereo cameras (Vasudevan *et al*. 2011), which create a virtual presence of the remote user inside shared virtual space.

In this paper we focus on the integration and interaction with different data types relevant to the archaeological process. We present several experimental case studies to demonstrate the use of the TeleArch framework.

2. RELATED WORK

In the field of archaeology virtual reality has been adopted by several projects for reconstruction, simulation and dissemination of different kinds of datasets. In the beginning, virtual environments were primarily used for the visualization of the final reconstruction of a specific site. For example, in the ARCHAVE project (Acevedo *et al*.2001) several research teams have explored immersive 3D visualization of historical temple of Petra. The collaborative aspect of interaction was presented in VITA project (Visual Interaction Tool for Archaeology) by Benko *et al.* (2004), featuring a mixed reality system for exploration of a virtual dig. Another project with mixed reality was SHAPE (Hall *et al.*2001), which addressed education and social interaction in virtual museums. Earl *et al.* (2007) discussed the notion of playing and interacting within graphically reconstructed 3D worlds on a case study of Roman archaeological data, emphasizing the importance of spatial interaction. Helling *et al.*(2004) presented a case study of the Port Royal, a historical site in Jamaica, which focused on the dissemination of the reconstruction through a virtual reality exhibit. Several researchers have taken advantage of large virtual community and tools in Second Life, e.g.Nie *et al.* (2008) and Getchell *et al.* (2009). The Second Life however does not offer a scalable system which can handle immersive visualization or large datasets. The use of other 3D internet-based collaborative systems has been explored in the FIRB project (Forte & Pietroni 2008), using Virtools by linking three different archaeological sites through pre-determined 3D graphic libraries. More recent works include the Archeomatica Project (Sangregorio *et al.*2008) which focused on a case study of Cretan culture to archive and combine 3D models of high accuracy with traditional graphic and photographic documentations. The closest to our work is the project DECHO (Aliaga *et al.* 2011) which is addressing visualization of different data types, along with the data acquisition and data management. The framework provides ability to inspect and alter the appearance of archaeological objects and fragments in virtual environment. The project, however, does not provide immersive visualization or collaborative aspect of the interaction. On a smaller scale, the combined visualization of different data sources (with no remote interactive abilities) was also addressed by Petrovic *et al.* (2011) who developed an immersive framework for exploration of 3D LIDAR data overlaid with geographical information system (GIS) data.

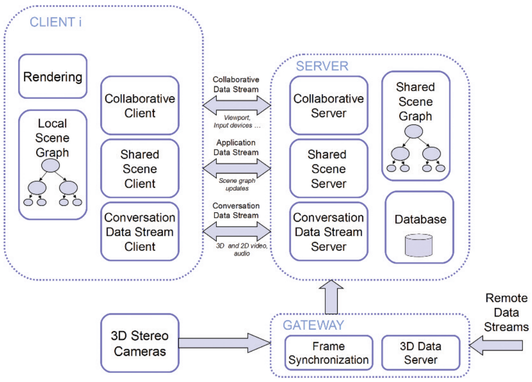

Figure 1. The main modules of the TeleArch software framework. Interaction between server and clients is established through three data streams: collaborative stream for navigation, application stream for scene updates and conversation stream for audio and video communication.

3. SOFTWARE FRAMEWORK

TeleArch software is aimed to provide the following concepts for exploration of archaeological data in a virtual environment: (1) immersive visualization, (2) data integration, (3) real-time interaction, and (4) remote presence.

3.1. Immersive Visualization

TeleArch software is built upon on OpenGL-based open source Vrui VR Toolkit (Kreylos 2008), developed at University of California, Davis. The Vrui Tookit provides abstraction of input devices and display systems, allowing developed applications to inherently run on various hardware platforms, from a laptop to large scale immersive 3D display systems, such as life-size display walls and CAVE systems. The framework also supports large number of input devices for interaction with ability to add new devices.

In traditional archaeology, the visual data mainly consists of photographs, 2D maps and drawings, typically integrated in a 2D GIS system. Adding the 3D dimension facilitates exploration of the spatial relationship of data which can in result provide a clue of the functionality of a specific artifact, stratigraphy or structure and their context. Moreover the 3D reconstruction of a site can consistently increase our capacities of interpretation by showing features and details otherwise not understandable. In fact the immersion in a 3D environment can increase the spatial awareness with respect to the data and provide a context for collaboration.

Immersive visualization on a 3D screen or a large display wall can provide the archaeologist to virtually re-visit stratigraphically the archaeological site layer by layer and in an articulated spatial domain of information. Through various set of tools the archaeologist can overlay all the digital data recorded on site with other data collected at the same location in order to analyze their context and spatial relationship.

3.2. Data Integration

We have implemented a centralized scene graph to manage distribution and synchronization of the scene across distributed clients (Fig. 1). The scene graph consists of hierarchically organized, interconnected nodes with parameterized spatial representation. The scene graph at this point supports the following low-level nodes: (a) general node implementing the relationships within the scene graph, (b) geometric nodes representing the drawable geometries (e.g. triangle mesh, points, polygons, lines), (c) transformation node defining the geometric relationship between connected nodes, and (d) grid node used for representation of environmental surfaces through grids or height maps. On the higher-level of representation the scene graph nodes are organized into data nodes which provide user with additional functionality through the graphic user interfaces and interactive tools. The data nodes include: (1) Wavefront 3D object (OBJ), (2) MeshLab layer files (ALN) and (3) shapefiles with database support (SHP and DBF file format).

3D Objects. 3D object node is a higher-level geometrical entity consisting of one or more mesh datasets and textures. Current implementation of TeleArch includes OBJ/Wavefront 3D file format reader with support for various texture formats. Triangles with different materials (and textures) are grouped and stored in vertex buffer objects (VBO). The VBOs allow for efficient rendering of relatively large models, e.g. 1 million triangles are rendered with the frame rate of 60 fps on NVidia GeForce GTX 8800. Typically the models use several tens to hundreds thousands of triangles while a scene could consists of 10 to 20 objects. In the future we will implement on demand streaming of data to more efficiently handle larger models.

In the virtual environment, users can load, delete, scale, move objects or attach them to different parent nodes. As an object in the scene is manipulated, a request message of the action and parameter updates are sent from the client to the server. If the node is not locked by another client, the parameters of the node get updated and the updates are broadcast from the server to all the clients.

3D Layers. 3D layers combine several 3D objects that share geometrical and contextual properties but are used as a single entity in the environment. In this paper we present the use of 3D layers to visualize the stratigraphic layers of excavation. The framework supports Meshlab project format (ALN), which defines object filenames and their relative geometric relationship. The 3D layer node allows for objects in each layer to be grouped, assigned with different material and color properties, set transparency and visibility levels. Using a slider in the properties dialog, one can easily uncover different stratigraphic layers associated with the corresponding units.

GIS Data. Geographical information systems (GIS) play an important role in archaeology as they allow archaeologists to define spatial relationship of the data in micro (site) and macro (landscape) scale. Traditionally these are 2D maps of points, lines and polygons representing artifacts, structures, or stratigraphic layers. The TeleArch software incorporates shapefiles which are popular geospatial vector data format for commercial and open source GIS software. The shapefiles stores the geometric information in a shape format (.shp) while the associated attributes are stored in a dBase database file (.dbf). Each element consists of geospatial coordinates and is associated with several attributes, which may include the stratigraphic unit number, size information, location, depth, material etc. For our framework the user can access the database information through the GIS data property dialog of the specific shapefile. GIS data property dialog allows user to organize the GIS elements by different attributes. For example, a user can mark all the findings of animal bones with a single color to identify their spatial relationship with respect to other findings or even other models in the scene. Numerical attributes can be further clustered using k-means algorithm to group elements with similar properties by their values. For example, a user can group findings based on the shape area size and quickly identify large and small clusters of the artifacts. Each group of objects can be assigned with different colors, transparency level and visibility parameters. User can work on the GIS data locally (although the same dataset will be loaded for all clients) and once the layout is defined, it can be stored for later use or shared remotely with other collaborators to discuss the findings.

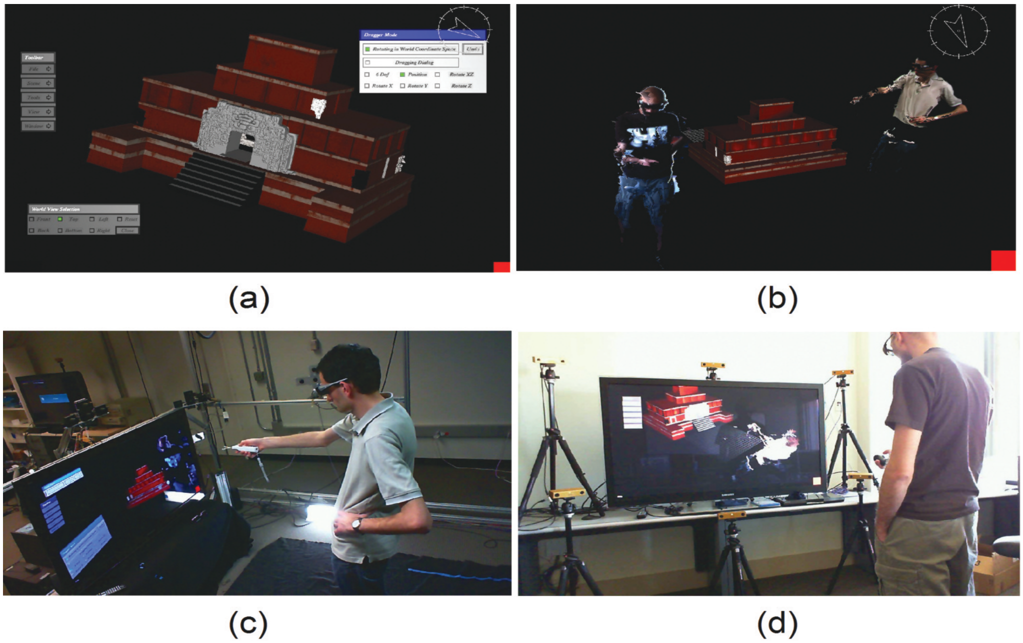

Figure 2. Collaborative 3D puzzle featuring a reconstructed model of a temple from Mayan city of Copan. (a) Model of the temple with laser scanned ornament fragments, (b) two remote users in the collaborative virtual space, (c) user at UC Berkeley, (d) user at UC Merced

3.3. *Real-Time Interaction*

Underlying Vrui VR Toolkit provides an abstraction layer for the input devices through the device manager which allows the Vrui application to use various generic tools driven by the physical devices. The application can thus work with generic tools instead of having to communicate directly to the i/o device. The tools can be dynamically linked to different buttons of the interface device in use. The Vrui VR toolkit inherently provides the following tools:

- navigation tools: for navigation through 3D space (e.g. free navigation, surface navigation);
- graphic user interface tools: for interaction with menus and other on-screen objects;
- measurement tools: for acquiring object geometry (e.g. dimensional and angular measurements);
- flashlight tool: for relighting parts of the 3D scene or pointing at salient features;
- annotation and pointing tools: for marking and communicating interesting features to other remote users.

We have added several tools with custom functionality to provide interaction with the virtual objects and data:

- draggers: for picking up, moving and rotating objects;
- locators: for rendering mode manipulation (e.g. mesh, texture, point cloud);
- selectors: for performing different actions on objects related to local functionality, such as object rendering style (e.g. texture, no texture, mesh only), retrieving object metadata, focusing current view to object principal planes etc.

3.4. *Virtual Presence*

As identified in the early beginning of

collaborative virtual environments, the virtual presence, also referred to as user embodiment, represents a key issue in successful collaboration of geographically distributed users (Benford 1995). In the TeleArch framework we adopt the real-time 3D teleimmersion framework (Vasudevan *et al.* 2011) where multiple stereo cameras are applied to capture the user from different perspectives to create an integrated 3D mesh model.

The data from each stereo camera is streamed to the remote location(s) via a gateway server. On the receiving side, the 3D mesh is extracted from each view and integrated with the remaining views. The 3D model of the user thus captures metric geometry allowing for projection of the user in life-size form into the model environment. As the user changes the virtual viewpoint through either tracked head movement or navigation tool, the 3D avatar is rendered at the corresponding position. With proper calibration of the display, the cameras and the tracking system, the 3D body is aligned with the data thus allowing user to point at features he/she identifies on the stereo screen, while the remote users can see his/her avatar pointing at the same feature at their location. Through this embodiment the remote user can point and gesture while interacting with the data using various tools.

At any time, individual users can switch to the remote user's point of view or select face-to-face mode for direct conversation. The latter functionality will bring the local user in front of the remote user to facilitate a view similar to a video conferencing.

Alternatively, the users without a 3D video system can use a webcam to project their image into the virtual space at their remote location. The webcam image is presented as a billboard object streamed via the collaborative library extension of Vrui VR Toolkit.

4. CASE STUDIES

We have evaluated the TeleArch software in series of local and remote experiments. For the remote experiments we have connected between Berkeley and Merced, which are connected through Internet 2 at the distance of approximately 200 km. For interaction and navigation we used Wii Remote (Nintendo) by tracking its position and orientation with a passive tracking system (TrackIR, NaturalPoint). The virtual environment was presented on a 55-inch 3D Television display with active shutter glasses. The users were captured by a set of stereo cameras Bumblebee2 (PointGrey, Inc.). In the following sections we describe two case study experiments focused on data integration and interaction.

4.1. Collaborative 3D Puzzle

The digital reconstruction process in archaeology involves a bottom-up phase, the fieldwork documentation (data capturing) and a top-down phase, that is the interpretation and communication process. The top-down phase is based on comparisons and analogies with the archaeological remains in situ and its original context (how it was in the past). For example we can imagine the original shape of a Greek temple studying its ruins and remaining structures, but also comparing its architectural elements with other temple of the same period and cultural context.

The virtual re-composition of a monument or a site requires a step-by-step approach, which can entail several attempts to assemble architectural elements, decorations, colors with different textures, hopefully reconstructing different phases. We can imagine this activity as a 3D puzzle, where the collaborative efforts of different scholars can improve the interpretation and an effective reconstruction. In TeleArch we did a first experiment with the Mayan city of Copan (Maya Arch 3D Project) and more specifically on the virtual reconstruction of the temple 22. This is a critical case study because several fragments of the decoration and architectural elements are disseminated in different European archaeological museums and the reconstruction is problematic. After the implementation of the model of the Temple 22 for TeleArch the collaborative experiment was focused on the simulation of several possible 3D architectural reconstruction of the temple, assembling and disassembling the principal elements (obtained through laser scans) like a 3D puzzle. The two remote users were able to in real time load and position ornament fragments onto the model (Figure 2).

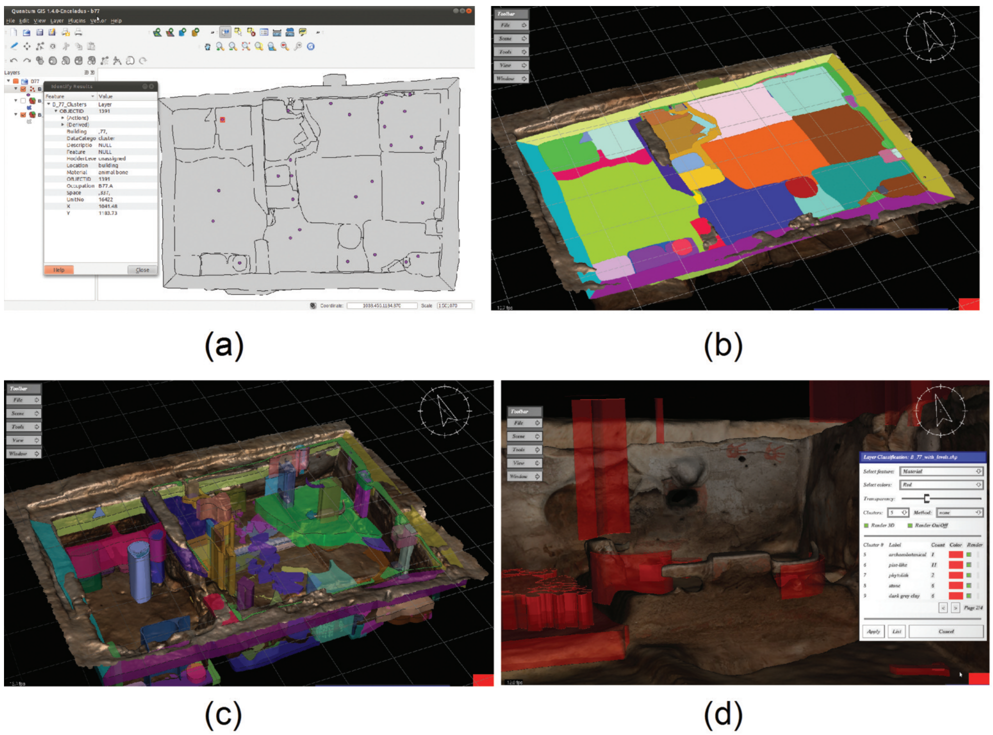

Figure 3: Integration of geographical information system (GIS) and laser scanned data (from Çatalhöyük, Turkey) into the collaborative environment: (a) a typical GIS program interface used by archaeologists, (b) GIS data is overlaid with the 3D laser scanned model, (c) using GIS database information on depth of the archaeological units (3D layers) solid polyhedra are extracted to visualize clusters at different depth, (c) detail of the inside of the dig with overlaid animal bone clusters.

4.2. GIS Integration and 3D Layers

The Çatalhöyük Research Project (http://www.catalhoyuk.com), related to the archaeological investigation of the Neolithic site of Çatalhöyük in Turkey, is one of the key case studies experimented in the TeleArch system.

Here the goal is the 3D reconstruction of all the phases of excavation including stratigraphic layers and archaeological finds. More specifically, a Neolithic house (building 77) was entirely recorded and documented by laser scanner (with an accuracy of 1 mm) and computer vision (accuracy 0.5 cm) and the 3D model was georeferenced with all the stratigraphic layers and clusters coming from a GIS platform (ArcGIS). As it is possible to see in Figures 3 and 4 the visualization and interaction of data creates an augmented knowledge of the site, showing connections and relations not visible or accessible in the reality. In this way the excavation becomes a reversible process, where different datasets can coexist in the virtual space and new research questions arise from the collaborative simulation. The model of the building was then updated after the 2011 fieldwork, so that it is possible now to compare archaeological layers and datasets recorded in different years: 2008, 2010, and 2011.

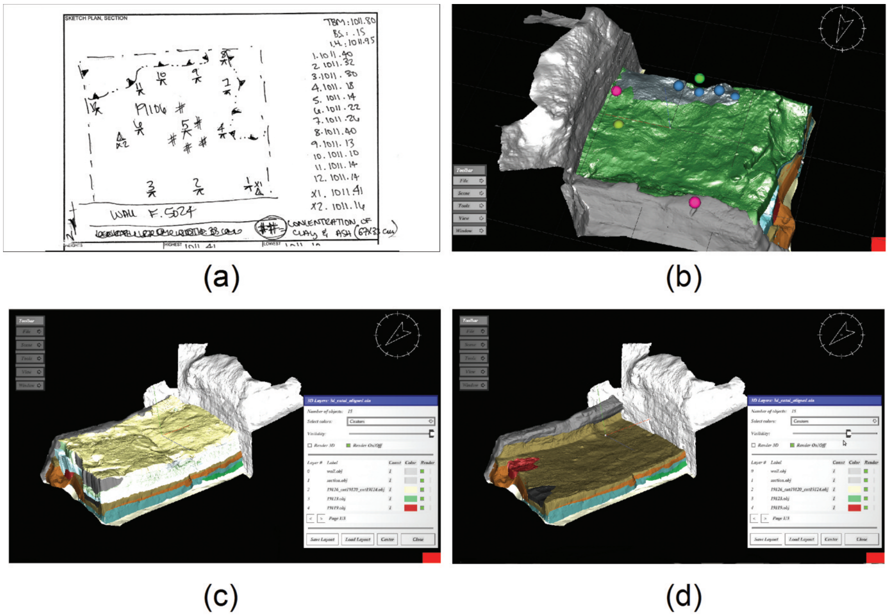

Figure 4. Spatial 3D layers with GIS data: (a) a typical sketch depicting an archaeological unit with findings, (b) laser scanned data aligned with the GIS data of the same unit, (c) and (d) 3D layers were scanned at different time instances to reveal the excavation process.

5. DISCUSSION AND CONCLUSION

The TeleArch system is still in a preliminary and experimental phase of development. Nevertheless, the first applications to different case studies, formats and models are satisfactory and promising from the analysis point of view. The system is flexible, inexpensive and powerful, with an adequate capacity of real time rendering and various analytical tools: measuring, lighting, dragging and moving objects, changing textures and colors, uploading 3D models and libraries, exchanging data in real time between different locations. The advantage of TeleArch is the collaborative virtual environment where different categories of data and formats can be integrated, visualized and analyzed in real time.

The visualization and integration with TeleArch represents the final step of the digital workflow, starting from the archaeological fieldwork (data capturing), post-processing of models (meshing of point clouds), and digitalization of drawings and outlines to a GIS format. Once all the datasets are in TeleArch it is possible to elaborate the 3D data in a collaborative way. At this stage the simulation stimulates new feedback and research questions of the operator who can interact with models and data identifying new features otherwise not identifiable. The regeneration and simulation of 3D models in a cross-data platform can stimulate new interpretations and assists the research in the validation of the previous ones. In archaeology this stage of the work is crucial since during the excavation a relevant amount of information is removed or destroyed during the digging procedures.

The long term plan is to offer the TeleArch software under an open source license to be freely available on the web to users or developers, either for standalone or collaborative use. We are currently adapting the existing software architecture to provide intuitive interface for the users and easier installation and updating procedure. In the next three months we are planning to provide a beta testing based on invitations to a small community of archaeologists. We are developing several improvements of the existing functionality to offer automatic registration of models and the GIS data, additional tools for querying and editing GIS data objects, and various mesh manipulation tools. We are also developing support for Microsoft Kinect camera that will simplify the installation and use of 3D video for remote collaboration. Other future development will involve the implementation of more sophisticated and analytic tools for models and metadata and the possibility to re-elaborate 3D information in real time (e.g. by segmentation, cuts, volumetric studies, 3D puzzling). We are planning to use the system also for educational purpose, allowing students to familiarize themselves with the complexity of archaeological datasets coming from different sites and contexts.

ACKNOWLEDGEMENT

Teleimmersive archeology project was supported by Center for Information Technology Research in the Interest of Society (CITRIS) at University of California, Berkeley. We also acknowledge financial support from NSF grants 0703787 and 0724681, HP Labs, The European Aeronautic Defence and Space Company (EADS) for the implementation of the teleimmersion software.

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