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ArcheoTUI - A Tangible User Interface for the Virtual Reassembly of Fractured Archeological Objects

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Abstract

Cultural objects of archeological findings are often broken and fractured into a large amount of fragments, and the archeologists are confronted by 3D puzzles when reassembling the fractured objects. Scanning the fragments and reassembling the corresponding 3D objects virtually is an elegant (and sometimes the only) solution. An efficient user interaction for the complex task to orientate or position two 3D objects relative to each other is essential, eventually in addition to automatic matching techniques.

In this paper, we present ArcheoTUI, a new tangible user interface for the efficient assembly of the 3D scanned fragments of fractured archeological objects. The key idea is to use tangible props for the manipulation of the virtual fragments. In each hand, the user manipulates an electromagnetically tracked prop, and the translations and rotations are directly mapped to the corresponding virtual fragments on the display. For each hand, a corresponding foot pedal is used to clutch the movements of the hands. Hence, the hands of the user can be repositioned, or the user can be switched. The software of ArcheoTUI is designed to easily change assembly hypotheses, beyond classical undo/redo, by using a scene graph.

We designed ArcheoTUI on the demand of archeaologists and in a direct collaboration with them, and we conducted a user study on site at their workplace. This user study revealed that the interface, and especially the foot pedal, was accepted, and that all the users managed to solve simple assembly tasks. In a case study, we show the assembly of one of their fractured archeological findings.

Categories and Subject Descriptors (according to ACM CCS): I.3.1 [Computer Graphics]: Input devices I.3.6 [Computer Graphics]: Interaction Techniques H.5.2 [User Interfaces]: Input devices and strategies

1. Introduction

Cultural objects of archeological findings are often broken and fractured into an innumerable amount of fragments. A common tedious and time-consuming task for archeologists is to reassemble the fractured objects. So to speak, large 3D puzzles have to be solved. This task is sometimes made even more difficult because some of the fragments are either deteriorated by erosion, weathering, or impact damages, and are sometimes even missing. Moreover, in the case of stoned statues, the fragments can be heavy and must be manipulated carefully, because each move risks damage. Sometimes restorers even build external frames to hold fragments in position while other pieces are fitted, and there is always concern when the time comes to glue parts together that each is in the right place. Even worse, some very big and heavy fragments cannot be moved and assembled at all! Think of, for example, fragments that are underwater.

In recent years, 3D scanners have become ubiquitous for the acquisition of 3D models, and various researchers proposed to scan the fragments in order to use the ever-increasing computing power for a virtual computer-aided assembly. Once figured out how the virtual fragments fit together, the information can be used as a blueprint to reconstruct the real-world object.

On the one hand, the reassembly can be done manually by interacting with some standard 3D modelling software. On the other hand, a variety of techniques have been proposed to automatically reassemble the fractured objects recently. Most of these automatic techniques are based on pairwise geometric matching, see e.g. the stunning results of [HFG*06].

Since all the automatic methods rely on pairwise matching that is propagated bottom-up to reconstruct the fractured object, they fail when entire fragments are missing, or when the fragments are strongly deteriorated by, for example, erosion, weathering, or impact damages.

We are convinced that in archeology, the long-year work experience of the archeologists is crucial to solving the 3D assembly puzzle. The archeologists reason not only bottom-up by pairwise matching, but also top-down, by considering the assembly problem as a whole, and by taking into account the archeological context. Even though automatic methods assist the user to partly solve the assembly task by classifying and matching the fragments, they cannot fully replace a manual user interaction. Nevertheless, automatic techniques should always be integrated, either before the manual assembly for classification and matching, or after the assembly for precise alignment.

We observed that the user interaction techniques involved in classical existing 3D modelling software hinder the efficient virtual assembly of 3D objects, because the two 3D objects have to be positioned and oriented relative to each other. Since the archeologists are often unexperienced in the user interaction with 3D models by using the 2D metaphor of the mouse, in some laboratories the virtual assembly is somehow slowed down or even completely abandoned. Note that it is already difficult to position and orientate *one* 3D object by a 2D metaphor such as the trackball metaphor. Consequently, positioning and orientating *two* relative to each other is even harder, especially for non 3D experts.

In this paper, we present ArcheoTUI, a new tangible user interface for the efficient assembly of the 3D scanned fragments of fractured archeological objects. The key idea of the ArcheoTUI system is to use props as physical representation and control for the scanned virtual fragments. In each hand, the user manipulates an electromagnetically tracked prop, and the translations and rotations are directly mapped to the corresponding virtual fragments on the display. For each hand, a corresponding foot pedal is used to clutch the movements of the hands. Hence, the hands of the user can be repositioned, or the user can be switched.

The software of ArcheoTUI is designed to easily change assembly hypotheses, beyond classical undo/redo, by using a scene graph. This is important because the reassembly of archeological findings is a lengthy trial-and-error task.

ArcheoTUI was initiated by the demand of archeologists to improve the user interaction for the assembly task. We designed ArcheoTUI in a direct collaboration with a team of archeologists, and we show its efficiency in a case study of the assembly of one of their fractured archeological findings.

This paper is organized as follows. In Section 2, we review some related work on tangible user interfaces for the automatic assembly of virtual objects, and we recall some automatic assembly techniques. In Section 3, we present the set-up of our ArcheoTUI system. In Section 4 we describe the involved software, and in Section 5 we present a user study before we conclude with a case study and directions to future work in Section 6.

2. Related work

2.1. Overview

We structure the related work into two categories. On the one hand, we recall some related interaction techniques, and on the other hand, we discuss some automatic assembly methods that can be used in addition to the manual interaction that we propose.

2.2. Related interaction techniques

When assembling two fragments, the user has to manipulate two times 6DOF at a time, and classical user interfaces such as the 2D mouse or the keyboard are impractical for this assembly task. Our work is inspired by the seminal work of Hinckley et al. [HPGK94] where passive real-world interface props are used for neurosurgical visualization. In our ArcheoTUI interface, the user manipulates a prop in each hand, and the translations and rotations are directly mapped to the corresponding virtual objects on the display. Note that each of these props can be regarded as 6 degree of freedom flying mice (e.g. [WJ88, FP00]). We consider our user interface to be a tangible user interfaces (TUI): the tangible part, two wooden blocks, can be moved and rotated, and the visualization provides visual feedback. Even though the TUI concept was known before, as passive props [HPGK94], or as graspable user interface [HPGK94], the term TUI was first defined by Ishii and Ullmer [IU97] as user interfaces that "augment the real physical world by coupling digital information to everyday physical objects and environments". In order to unify the various different definitions and categorizations of TUI, Fishkin [Fis04] proposed two axis: the *metaphor axis* classifies the TUI in the way how the system effect of a user action is analogous to the real-world effect of similar actions. The *embodiment axis* qualifies the TUI about how closely the input focus is tied to the output focus.

Using TUIs for assembly is not a new idea. The assembly of numerous Lego-like blocks as props was already done with the ActiveCubes [KIK01]. Our work limits the number of props to two, one for each hand, resulting in a bimanual interaction technique ([BM86, KBS94]). Based on the conceptual framework of [Gui87], two-handed manipulation techniques were developed, see for example [HPGK94, PSP99, LKG*03], and a part of their success can be attributed to their cognitive benefits [LZB98].

In the ArcheoTUI user interface, two foot pedals are used that have to be hold down to clutch the movements of the hands to the movements of the virtual objects. This declutching mechanism was already used by Hinckley et al. [HPGK94] with only one unique foot pedal, and we extended this metaphor to two foot pedals: the left pedal for the user's left foot is associated to user's left hand actions, and the right pedal for the right hand's action, respectively. Foot pedals for two feet were also used by Balakrishnan [BFKS99], however, in contrast to our foot pedals, the role for each foot is not similar in their work.

2.3. Automatic assembly methods

The automatic assembly of fractured 3D objects is a groundbreaking idea, and there is a significant progress since recently, see for example [HFG*06] and the references therein. An exhaustive review of all existing automatic assembly methods is clearly out of the scope of this paper. Nevertheless, we state that the automatic techniques are generally based on pairwise matching of either geometric or photometric features. Geometric pairwise matching has been proposed by Papaioannou et al. [PKT01] by estimating the curvature, and by Huang et al. [HFG*06] by using a feature-based approach in combination with a non-penetrating iterative closest point algorithm (ICP [BM92]). Other pairwise matching approaches for shards of pottery surfaces estimate axis/profile curves [WOC03, KS04], but they are limited to surfaces of revolution. Photometric pairwise matching has been proposed by Sagiroglu [SE05] by estimating the photographic affinity between neighbouring fragments: the texture outside the border of the fragments is predicted using texture synthesis.

To our knowledge, all the automatic methods rely on pairwise matching that is propagated bottom-up to reconstruct the fractured object. Consequently, they fail when entire fragments are missing, or when the fragments are strongly deteriorated by, for example, erosion, weathering, or impact damages.

However, we are convinced that the automatic assembly methods are essential and should be used in combination with manual user interaction. The automatic assembly methods solve partial or entire assemblies, and they are able to classify the fragments into different categories and identify potential candidates for matching. The results of the automatic methods can be used as an input for the manual user interaction that we propose. And even more, after a user has manually proposed a new assembly hypothesis, automatic methods, such as the ICP algorithm, help to precisely align the fragments and can deliver a confidence value about the correspondence of the fragments.

3. The design of the ArcheoTUI user interface

3.1. Overview

The key idea of the ArcheoTUI system is to use props as physical representation and control for the scanned virtual fragments. For an illustration, consider the 6 items of the set-up of the ArcheoTUI system in Figure 1. In each hand, the user manipulates a prop (items 1 and 2). The props can be freely positioned and oriented in space. For each prop, there is a corresponding foot pedal (items 3 and 4). Only when the corresponding foot pedal is pressed down, the translations and rotations are directly mapped to the corresponding virtual fragment on the display (items 5 and 6). Consequently, the user gets a sort of passive haptic feedback when manipulating the props. Once the foot pedal is released, the movement of the corresponding prop is dissociated from the virtual fragment. Hence, the position and orientation of the virtual fragment is fixed, and the hands of the user can be repositioned. This is especially useful when the user feels uncomfortable about his arm positions, or when the physical props collide with each other. Thanks to this declutching mechanism, the user can also be switched while the virtual fragments stay in position, and thus another user can propose new assembly hypothesis.

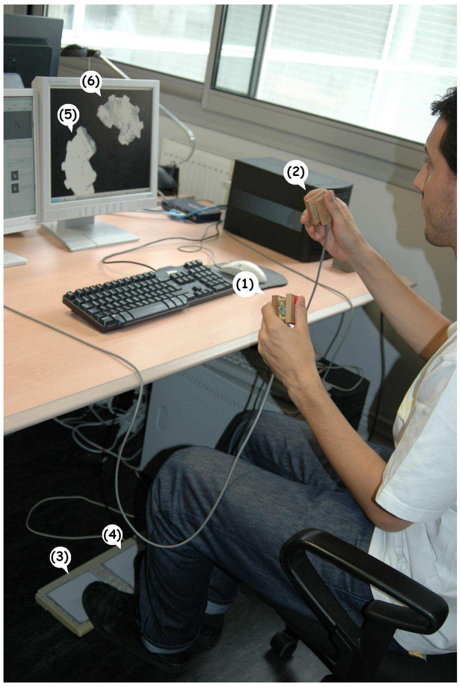
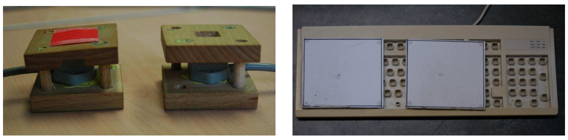


Figure 1: *The ArcheoTUI user interface.*

3.2. Technical concerns

Let us now have a closer look on some design decisions for our first prototype. The props are wooden blocks as illustrated in Figure 2(a). We chose the dimensions of $5cm \times 5cm \times 3cm$ for the simple ergonomic consideration that the prop can be easily grasped. In the center of each wooden block, there is a sensor that is tracked electromagnetically



(a) The props. (b) The foot pedals.

Figure 2: *The props and the associated foot pedals.*

by the Polhemus Liberty system with a precision of 0.08cm and a latency time of 3.5ms. Of course, it would be better to use a wireless tracking system such as the Polhemus Latus. Maybe we should remark at this point that at the beginning of the project, we tried wireless optical tracking with one camera and the ARToolkit, however, we quickly abondonned this idea due to occlusion problems.

Concerning the pedals, we used an additional keyboard and simply fixed two classical CD covers on the left and right CTRL keys (Figure 2(b)). Of course, this in an intermediate solution that works quite well, and future prototypes will integrate a more ergonomic solution with a better design. Note that we preferred the foot pedals compared to simple buttons on the props, because the props are rotated all the time and differently grasped by the users, thus the button is not always well accessible. We preferred to keep the possibility of buttons on the props for other actions.

Note that in our current prototype, when mapping the rotations of the props to the virtual fragments, the center of rotation is the midpoint of the virtual fragment's bounding box. However, in the future, we plan to let the user adjust the center of rotation for more accurate positioning.

3.3. Characteristics

One of the most important characteristics of ArcheoTUI is that there are two 6DOF inputs for a task that has twice 6DOFs. Furthermore, ArcheoTUI is a TUI according to the two axis taxonomy of Fishkin [Fis04]. Concerning the first axis, i.e. the relation between the input (the props) and the output (the display), the *embodiment* is distant. Concerning the second axis, ArcheoTUI has only the *metaphor of verb*: the motion of the physical objects corresponds to motion of the virtual fragments. In order to acquire also the *metaphor of noun* so that the shape of the physical object corresponds to the motion of the virtual fragments, we would have to print the fragments (and all the obtained partial assemblies) with a 3D printer, and then find a way to track the printed fragments.

Moreover, ArcheoTUI is a two handed interface using passive real-world interface props. The visualization on the display provides a feedback, and the props provide real-world tactile and kinaesthetic feedback [HPGK94]. Thanks to the two handed interaction, ArcheoTUI exploits proprioception, because a kinaesthetic feedback is given by the relative position of the hands. For example, when both hands are simultaneously moving to the left, the two virtual fragments are moving to the left as well.

In the following section, we present how the ArcheoTUI software exploits the ArcheoTUI user interface for more complex assemblies, when the fractured objects consist of for more than two broken fragments.

4. The ArcheoTUI software

We implemented the software for ArcheoTUI in C++ on a Linux Workstation. We used Qt for the graphical user interface and OpenSG for the rendering backend. The assembly of the pieces is represented in a scene graph, and the interior nodes contain the transformations that are specified during the user interaction. The broken fragments are organized in an SQL database that we integrated using SQLite.

A screenshot during the usage of the ArcheoTUI software on a dual screen can be seen in Figure 3. On the right screen, in the assembly window, one fragment (or a partial assembly) corresponds to the props of the left hand, and another fragment (or partial assembly) corresponds to the right hand. At any time, the user can assemble the two objects by hitting the space bar, and undo the assembly by pressing the DEL key. When two objects are assembled, the resulting partial assembly is associated to the left prop, and the right prop is liberated, so that another fragment (or partial assembly) can be associated. Note that assembling and disassembling by the space/DEL keys is an intermediate solution, and we are currently planning to use either a third foot pedal, or buttons on the props.

On the left screen, there are drop-down menus for the import of new 3D fragments, and for loading and saving assembly hypothesis. Furthermore, there are 7 windows that can be resized according to the user's preferences:

The fragment library (1) allows the user to browse through the database, and a list of the results shows thumbnails of the corresponding 3D fragments. These fragments can be associated to the left or right prop by a context menu, or they can be dragged to the desktop.

The desktop (2) provides a space to render certain fragments or partial assemblies easily accessible.

The scene graph of the current assembly (3) illustrates the assembly hierarchy. By clicking on the nodes on the scene graph, the corresponding fragment (or partial assembly) is highlighted by its bounding box, and it can be taken out of the entire assembly by dragging it to the desktop or to the fragment library.

The status bar (4) provides visual feedback which foot pedals are currently hold down. Furthermore, the speed of the translation of the fragments can be adjusted using a slider.

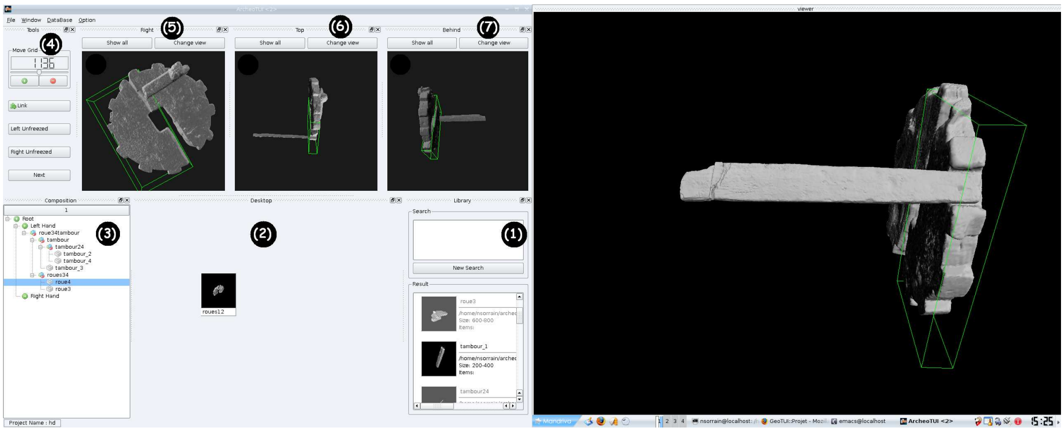


Figure 3: *A screenshot of the ArcheoTUI software.*

The side view (5), top or bottom view (6), and rear view (7) help the user to better perceive the 3D space.

We take advantage of the rendering power of OpenSG, but of course, for very detailed 3D objects, the framerate drops. We plan to integrate some in-core or out of core progressive level-of detail techniques in the near future.

We also integrated a collision detection using the Open Dynamics Engine (ODE). Our first approach was to stop the movement of the virtual fragments when a collision was detected. We found this solution rather disturbing due to the lack of an active haptic feedback. Consequently, by default, the collision detection is disabled. Nevertheless, we are currently implementing a second approach where we do not stop the movement of the virtual fragments, but highlight the intersecting geometry in a different color. Note that during all the experiments described in this paper, we used the ArcheoTUI software without the collision detection.

5. User study

5.1. Aim of the user study

We conducted a cognitive walkthrough based user study [PLRW92] to evaluate the ArcheoTUI user interface's ability to support the assembly task. The users were in an exploratory learning mode. We conducted the study on-site at the workplace of the archeologists, and in our research institute. The aims of the user study were the following:

- to see whether even non 3D accustomed archeologists accept the ArcheoTUI interface,
- to see whether the non 3D accustomed archeologists manage to solve simple 3D assembly tasks by using the ArcheoTUI interface,
- to know whether the archeologists can imagine using the ArcheoTUI interface for their daily assembly tasks,
- to evaluate whether the two foot pedal solution is efficient,
- to see whether the two foot pedals were used rather separately or simultaneously,
- to see whether the declutching mechanism (that breaks the correspondence between the relative position of the hands and the relative position of the props) does not perturb the user,
- to see whether there is a preference for the dominant hand,
- and to get user feedback for the development of following ArcheoTUI prototypes, from both non 3D accustomed and 3D accustomed users.

The ArcheoTUI interface is designed for setting up initial positions as an input to automatic alignment methods. Consequently, we rather strived to estimate whether the users were capable to roughly position the objects, and did not evaluate the precise alignment.

In this first explorative user study, we did not include a comparison to classical 2D interfaces. Past experiments have shown that non 3D experienced archeologists had major difficulties to learn the manipulation of 6 degrees of freedom with the 2D mouse. Furthermore, we wanted the users to fully concentrate on our new ArcheoTUI interface, and did not want to scare them with the more complex 2D metaphors to manipulate 6DOF.

5.2. The set-up of the user study

15 subjects participated in our user study, 8 archeologists that are regularly confronted by assembly tasks, and 7 computer scientists. They were not paid. 3 of the volunteers were female (all archeologists), and 12 volunteers were male, aged from 25 to 56 years, 34 years in average. 13 volunteers were right handers, one was lefty, and one ambidextrous. 9 subjects were 3D experts, and 7 subjects had already manually assembled 3D objects.

In order to efficiently collect and exploit the results of the

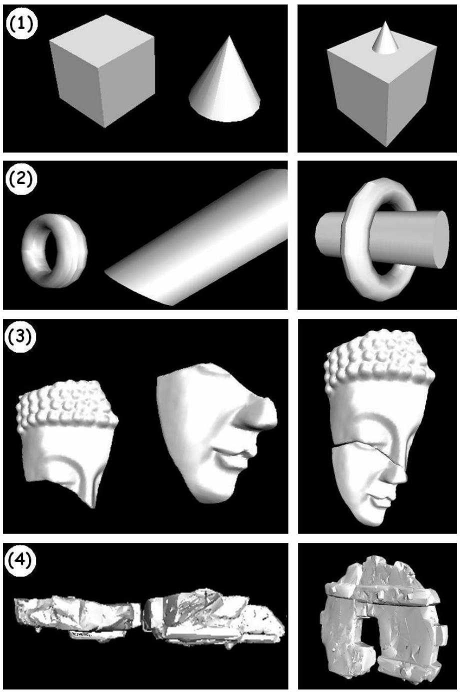


Figure 4: *The first family of four pairwise assembly tasks.*

user study, we were three persons to organize it. A first person explained the task and conducted the experiments, a second person observed how the users were handling the props, and a third person was accompanying the questionnaire in order to catch all relevant feedback. The questionnaire was designed to get a qualitative and subjective feedback of the ArcheoTUI user interface. In addition to our observations, we recorded the important user actions of the ArcheoTUI software into a logfile.

5.3. The assembly tasks of the user study

The participants were asked to accomplish 6 simple assembly tasks that we divided into two families. The first family consists of 4 pairwise assembly tasks. For each assembly task, the subjects were asked to assemble two fragments from an initial starting position (Figure 4(left)) to a given target assembly that we printed on a paper sheet (Figure 4(right)). We limited the time to accomplish each task to two minutes.

The second family consisted of 2 assembly tasks with more than two broken fragments (Figure 5) in order to see if there are missing features in the software used in the ArcheoTUI system. The time was limited to 3 minutes for the task 5, and 4 minutes for the task 6.

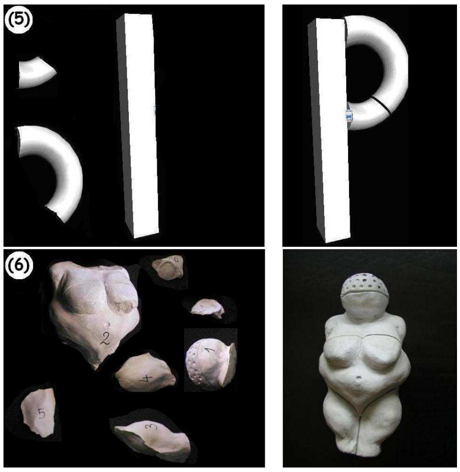


Figure 5: *The second family of assembly tasks with more than two fragments.*

5.4. The overall success of the assembly tasks

Of course, our major interest concerns the question whether the subjects managed to solve the 6 given simple 3D assembly tasks by using the ArcheoTUI system. For the tasks 1 to 5, we considered the assembly successful when the fragments were roughly well aligned. However, the success of task 6 was more difficult to evaluate due to the lack of time for the experiment. We decided to validate the success of this task when 3 pieces were roughly well assembled.

	Task 1	Task 2	Task 3	Task 4	Task 5	Task 6
Yes	15	15	15	12	11	12
No	0	0	0	3	4	3

Table 1: *Success of the assembly task.*

The success of the 6 tasks is depicted in Table 1. All the participants accomplished the first three assembly tasks without having used the ArcheoTUI user interface before. The last three assembly tasks were more difficult, however, we explain that some few participants had no success due to the very tight time restrictions.

In the questionnaire, some questions had to be answered on a scale from 1 to 6 (6 was best). The subjects rated 5.2 on average the easiness to learn the interaction, and they averaged 4.3 for the easiness of use. The subjects rather think that the ArcheoTUI user interface could help them to solve 3D objects assemblies (4.6 on average) and to solve archeological assemblies (4.5 on average).

The questionnaire also showed that estimating the depth dimension of the virtual fragments on monoscopic displays is difficult. We observed that the non 3D experts are often surprised to discover incorrect assemblies after rotation. On

	Left pedal		Right pedal		Left and right pedal simultaneously	
	Number	Accum. time	Number	Accum. time	Number	Accum. time
Mean	52.2	221sec.	57.9	277sec.	4.7	22sec.
Standard deviation	9.8	61sec.	24.2	100sec.	8.0	49sec.

Table 2: *Means and standard deviations for the foot pedal usage of the 15 subjects.*

the other hand, the 3D experts tended to repeatedly validate incorrect assemblies on purpose, in order to refine the assembly under a different viewing angle. We regret that we did not integrate shadows on a floor and some walls in the 3D scene for a better perception of the depth dimension. This would have given the opportunity, even for non 3D experts, to elaborate better navigation strategies.

5.5. The props

The users were taught that the props are designed to control two digital objects at a time with the left and right hand. We observed that one participant was manipulating one single prop with two hands. Moreover, we noticed that the attention of the users was sometimes focused to only one prop, and sometimes to the two props at a time.

The answers in the questionnaire revealed that the users like the easiness and rapidity to position and orient the virtual fragments in 3D space. They also enjoyed the bilateralism to manipulate two digital objects with two hands in space. Some users complained about twisting their wrists. This is due to an insufficient use of the declutching mechanism, and these users need more training. Moreover, the users found it easy to roughly position and orient the fragments, but they had difficulties to finalize a very precise assembly. This confirms our idea of a semi-automatic method: we allow the users to elaborate assembly hypothesis using ArcheoTUI that can then be used as an initial position for automatic alignment methods such as the ICP.

5.6. The foot pedal declutching mechanism

We were particularly interested in the usage of the foot pedals, and especially the number of times each pedal was pressed down and how long it was hold down during all the assembly tasks, and whether both pedals were used at the same time. The results that we collected from the logfile are shown in Table 2, and they gave us various important insights.

First of all, the declutching mechanism of the pedals was used. Moreover, there is no big difference between the usage of the left and right foot pedal, despite the fact that 87% of our subjects were right handers. We were a little bit suprised because we expected a more frequent usage of the foot pedal of the dominant hand for local precision tasks.

The logfile shows also that the foot pedals were used one after another rather than simultaneously. This implies a limitation in parallel bimanual performance, what is not supprising concerning the insights of symmetric bimanual interaction [BH00].

We observed the users in order to see whether the users looked at their feet and the foot pedals during the manipulation. Starting from the 4th task, all the subjects did not look at their feet anymore, and nine subjects never looked at their feet at all.

The questionnaire revealed that the users were very enthusiastic about the idea to use foot pedals for a declutching mechanism. They especially liked to rapidly fix object positions by simply releasing the pedals. Moreover, they appreciated the possibility to reposition their hands for a better focus on the assembly task. However, some users requisitioned simple buttons on the props instead of the foot pedals, and one user complained about fatigue.

Thanks to the clutching mechanism, the user can start the movement of the props at any desired location. Note that in contrast to the ActiveCubes [KIK01], the physical assembly of the props is not performed, but only the assembly of the virtual fragments. The relative position of the props is not mapped to the virtual fragments. The resulting discontinuity between the relative position of the props, and the relative position of the virtual fragments, could perturb users. However, as the users focused on the view of the virtual fragments, we did not notice real perturbations. Indeed, the feedback for the user is only a visual one. However, this fact did not hinder the user in its assembly task.

We conclude that the declutching mechanism with the two foot pedals is an interesting approach when assembling two broken fragments. Since the users are already familiar with foot pedals (for example in their cars), and since the *left* (resp. *right*) foot is associated to the *left* (resp. *right*) hand, the users did not encounter strong difficulties.

6. Conclusions and future work

We used the ArcheoTUI interface to solve a real-world assembly task. We scanned 8 fragments of a fountain that was found on the site of the Barzan thermae, Charente Maritime, France. The origin of the fragments is estimated to the 1st century AD, and a photo of the fragments can be seen in Figure 6.

We reassembled the scanned fragments with our ArcheoTUI user interface. The fragments and the final assembly can

Figure 6: *Photos of the fractured fountain parts.*

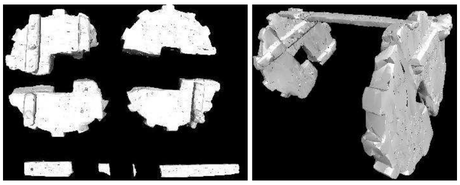


Figure 7: *The virtual fragments and the assembly.*

be seen in (Figure 7). We plan to continue the assembly of the over 150 remaining fragments of the fountain by using the ArcheoTUI user interface.

With the ArcheoTUI system, archeologists are now capable to interactively assemble 3D fractured archeological objects. Thanks to the virtual assembly, they are no more limited by the physical restrictions of broken fragments such as the heaviness that they encounter in traditional archeology. The results of this first user study underlined the acceptance and usability of the ArcheoTUI interface in our particular archeological context. We noticed a very short learning period. These results encouraged us to further improve our system and drive additional user studies in order to evaluate the efficiency of the interface in comparison to other more classical user interfaces.

One part of ongoing work addresses the perception of the depth dimension of the virtual fragments. Of course, increasing the realism with shadows on a floor and a wall will improve the perception. However, we are convinced that virtual assembly is even more efficient with stereo displays, either by using reality centers or autostereoscopic displays. We are currently porting the ArcheoTUI system for our virtual reality center on a 10mx3m stereoscopic wall and we are integrating an ARtracking head tracking system. Thanks to the implementation in OpenSG, this is rather straightforward. It would also be interesting to see the contribution of active haptic feedback, for example by replacing the two electromagnetically tracked props by two Phantoms.

We are also currently integrating the ICP algorithm for an automatic snapping as a precise alignment of the initial position indicated by the user interaction. In the later future, we strive to integrate any automatic reconstruction technique, as for example [HFG*06, SE05], that can reduce the amount of required user interaction.

We also think that an interesting though expensive direction would be to print the 3D fragments with a 3D printer and analyze the benefits when the shape of the physical objects corresponds to shape of the virtual fragments.

Acknowledgements

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