IRelics: Designing a Tangible Interaction Platform for the Popularization of Field Archaeology

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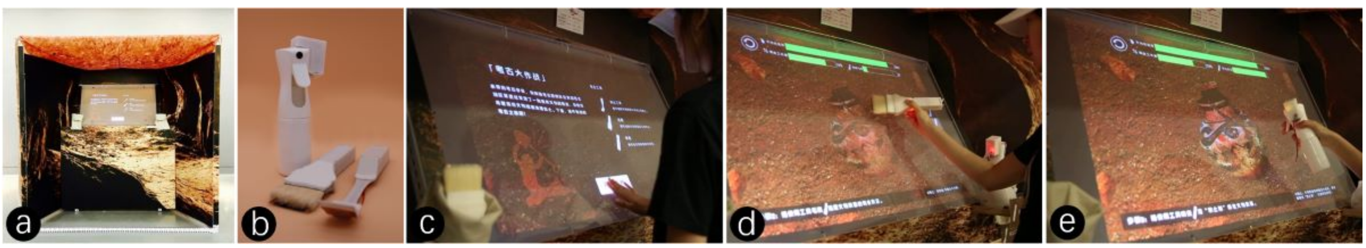

Figure 1. An overview of IRelics. (a) Front view of the platform, (b) The tangible tools, (c) Bare hand touching interaction is supported, (d) & (e) Playing the field archaeological game by brushing and spraying liquid.

ABSTRACT
We present IRelics, a tangible interaction platform for the popularization of field archeology. IRelics allows users to experience archaeological field work activities as a serious game by using a set of tangible tools. We developed an innovative LWIR (Long Wavelength Infrared Rays) sensing system, which implements the design of tangible tools that provide real manipulation experiences. By interacting with IRelics, a player may experience different archaeological activities such as excavation and cleaning. We conducted two observations to evaluate the usability and effectiveness at archeology popularizing. Findings suggest that the IRelics platform can enhance the engagement of the participants by providing a positive and interactive environment while teaching them unfamiliar knowledge.

CCS Concepts
•**Human-centered computing → User interface toolkits;**

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Tangible Interaction; Museum Education; Archaeological Popularization; Gamification; Thermal Imaging

INTRODUCTION
Recent public interest in cultural heritage and archaeology has been growing as reflected by the increasing popularity of television shows [19] and documentary films [24] about this subject. The interest of the audience is not exclusively on the artifacts and relics themselves, but also on the process of how the relics were excavated by the archaeologists. However, many people have misconceptions about the field, considering it similar to treasure hunting. The popularity of novels and television series about tomb-raiding, especially in China, has led to misunderstandings about the nature of field archaeology [36, 37] (Storylines often feature protagonists obtaining relics through tomb-raiding, which is in fact illegal). These misconceptions may lead to threats of theft from archaeological sites, or improper handling of archaeological sites by non-archaeologists during accidental discoveries.

In reality, the field archaeological process is complex and includes various steps such as analysis, excavation, data recording and so on, in which the discovery methods may also vary based on the geographical and historical factors. Additionally, greater familiarity with archaeological knowledge would allow people to have a deeper understanding of the relics. Hence, there is a need to correct the misconceptions about field archaeology and convey archaeological knowledge to the general public.

Archaeological field work involves the use of various specialized tools [16]. Previous works have proven that Tangible User Interfaces (TUIs) are suitable for simulating the actions involved in field archaeology [25] as they enable hands-on interaction with physical objects and usually provide high affordance to novices. Tangible objects and operations could help the audience obtain an intuitive sense of about the real process of field archaeology. Therefore, we designed IRelics, a TUI platform for popularizing field archaeology which allows users to experience archaeological field work activities as a serious game with the support of tangible tools. IRelics is designed to be used in archaeological museums, and as such the contents of the game can be modified to suit each museum.

Our contributions are summarized as follows:

1. Interviews with two professional archaeologists were conducted to attain details about field archaeology and design advice. Then we outlined a few criteria based on interview results to guide the platform design.

2. A TUI platform in accordance with the criteria that uses LWIR sensing to allow for users to interact with the device using their bare hands, archaeological tools, or liquids sprayed onto the display surface.

3. An archaeological serious game that teaches field archaeology practices that also serves as a design pattern for games based on the TUI platform.

4. Two user observations were conducted to obtain feedback on platform usability and educational benefits. A discussion on the effectiveness of outcomes is also provided.

RELATED WORK

Assistance systems for archaeological professionals

There have been numerous proposals for the use of VR or visualisation systems to assist the work of archaeologists. The VITA project [4] presented a collaborative mixed reality system for archaeological excavation to help professionals collaborate in visualizing and exploring excavation results off-site. The Archave project [34] integrated a CAVE-like structure and proposed tools for archaeologists to study historical sites. Barreau et al. [3] implemented several interaction metaphors to facilitate archaeological analysis. For the purpose of presentation and analysis, virtual reconstruction of archaeological sites has been proposed after archaeologists collected field data [7, 12, 32]. They concentrated on providing high-fidelity examples of reconstructions from a specific heritage or artifact. Hynst et al. [11] also synthetically proposed a work-flow for the reconstruction and visualization of archaeological sites. These projects provide a reference on the visualization and design of user interfaces for archaeological contents, however they are mostly aimed at serving professional archaeologists rather than the general public.

Museum Education and Archaeological Popularization

Recently, there has been a trend to adopt participatory and interactive methodologies in the design of museum exhibits [28, 27]. Various technologies were used in different applications, for example, multi-touch tabletop [5], VR/AR [10, 22], robotics [21] and tangible interfaces [26]. The purpose of using the new technologies in museums was to make the informal learning process more efficient and to enhance engagement. Thus, gamification is another common methodology in museum education [6, 30, 38].

In the area of archaeological popularization, as the challenges of teaching archaeology has been discussed in [8] (a gamification system for teaching archaeology students was proposed in this work), an archaeological education tool for the public should have low complexity and high engagement.

With the rapid development of computer technology, content digitalization has become more widely utilized in archaeological museums [18]. Schiavottiello et al. [29] built a 3D realtime storytelling platform for cultural heritage interpretation. Paliokas et al. [20] provided an immersive education system based on 3D reconstructed archaeological landscapes. Multimedia systems provides chances for the users to explore the archaeological environments in an engaging way. There have been a few previous works that aimed to develop mixed reality applications for raising the awareness of archaeology [9, 17]. Archaeological artifacts can be presented in different ways (for instance, interacting with 3D-printed replicas, viewing virtual 3D models, etc.), and Pollalis et al. [23] evaluates the learning outcomes from interacting with artifacts in three different styles. However, field archaeology had not been emphasized in the aforementioned applications and related work. In terms of content, the game Excavate! [31] is the most similar to our work. The series of games also contain simulations of field archaeological processes, which in parallel with other tasks serve to educate the history behind the artifacts.

In contrast, our work focuses on the process of field archaeology itself, including detailed operations and subtasks. Moreover, IRelics gives accessibility to physical practices in field archaeology for novices allowing them to gain a better understanding of the area, while at the same time the tangible interactive style and gamification design could effectively enhance engagement and enjoyment.

TUIs related to archeology

TUIs usually provide good psycho-physical affordance for users who newly encounter them, and are easy to be accepted and performed [14]. Since archaeological interaction is unfamiliar to most people, a more acceptable way of representation is needed. We found it appropriate to embrace archaeological contents within the TUI design framework. Reuter et al. [25] designed a TUI for virtual reassemblies of 3D scanned fragments. They used tangible props for the manipulation of the virtual fragments. However, their reassembling tools were designed for professional archaeologists. Wakkary et al. [35] presented a museum guide prototype that integrates a tangible interface, audio displays, and adaptive modeling. They also leveraged the inherent playfulness and poetic simplicity of TUIs. While there have been several works on TUIs designed for archaeology-related scenarios, few were designed for the teaching or popularization of archaeology to the general public.

DESIGN

Expert Interview

To better understand field archaeology and what criteria our system should satisfy, we interviewed two archaeologists specialized in public archaeology and artifacts restoration respectively. They both have a wealth of field archaeological experience and we discussed with them our initial idea about letting users use tangible tools to experience the process of field archaeology.

They confirmed that the majority of work done in field archaeology was hands-on. Many different archaeological tools would also be used during the entire process, which could provide abundant resources for tangible interaction design. However, the public archaeologist (abbreviated as PA) concerned about whether the various tools would be attractive enough to the public. He expressed that:

> "The most important thing is to change their views on field archaeology. However, real archaeological processes take a long time and the work is tedious and boring. I don't think the audiences will be interested in exploring the whole process and learning all the details is not necessary for them."

The other archaeologist was more concerned with our approach to simulating archaeological processes:

> "How can you imitate the relics, the environment and the tools? I hope at least the audiences can know what we are using and how we are working in the archaeological sites."

We also discussed misconceptions about archaeology with them. They expressed concern that tomb-raiding novels and television programs about treasure evaluation may cause negative social impacts, such as encouraging robbery or the unintentional destruction of archaeological sites.

Also, there are misconceptions about the value of artifacts unearthed during archaeological digs. In archaeology, the completeness or monetary value of artifacts does not matter and all artifacts are treated equally as all artifacts have historical and academic value. Another misconception is that unearthed artifacts are the most important aspect of archaeological work. Often times, the environment that surrounds the artifacts are just as important in providing information to archaeologists. Thus, archaeologists must pay attention to the keeping of complete records of archaeological details in every aspect of their work, such as the layout of excavation sites, the number and types of unearthed artifacts, and so on.

In addition, the excavation of artifacts is not the only important process of field archaeology. The analysis of the sites and artifacts, as well as the cleaning and strengthening of artifacts, are also important tasks during the process and require professional expertise or the assistance of professional instruments.

Design Criteria

From the interviews, we concluded that in order to achieve our goals of effectively educating the general public about field archeology and correcting misconceptions, the following design criteria must be met:

Effectiveness of popularization In order to effectively popularize field archaeology, the system must evoke the interest of the general public and form correct and positive social understandings of field archeology.

Attractive to Museum management The system must be able to reach a wide audience. Thus museum management must be interested in implementing the system in their exhibits. As such, museums curators and developers should be able to modify or replace the game contents to fit their museum exhibits. Maintenance costs must also be low.

Realistic depiction of field archaeology The realism of field archaeology should be preserved as much as possible during the design process. While certain more complex procedures that are unnecessary for the public could be omitted, the remaining content should be as similar to real field archaeological processes as possible in order to accurately educate the public. The differences between popular misconceptions about archaeology such as treasure hunting or tomb-raiding should be emphasized in order to effectively correct false understandings.

Positive User experience The system should provide a positive experience in order to engage the user to learn the information presented no matter their familiarity or interest with archaeology. Thus, the interactions should be novice-friendly and engaging while still being educational.

IRelics Design Overview

The overview of IRelics platform is shown in Figure 1. IRelics is a LWIR camera-projector system. The game interface is projected onto a 2D-surface where the locations of tools or hands are detected by the LWIR camera (see Figure 2). IRelics supports several interaction styles, including the use of bare hands and arms, custom tangible tools, and liquids on top of the surface. When the user is interacting with the tangible tools, they receive both visual and tactile feedback simultaneously which creates a greater sense of realism in the interactions.

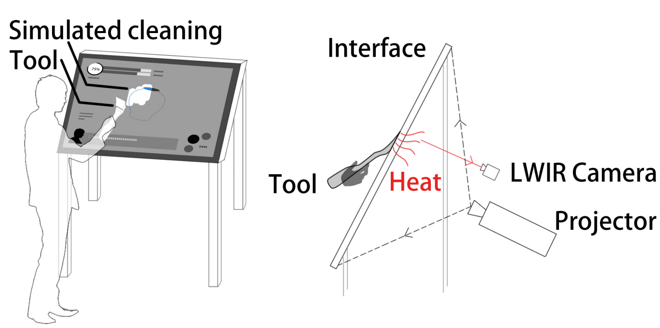

Figure 2. Schematic of input sensing.

To satisfy the *Design Criteria*, the tangible tools, as input devices, should retain their original physical affordances, which not only include appearance, but also in the way they are used. We investigated common tools used in field archaeological activities [1, 2] and selected the appropriate ones to be used as tangible tools (shown in Table 1). Our method is suitable for most of the elements listed in Table 1. Moreover, other tools which are not listed, such as large machines or electronic instruments, can be presented virtually in the software.

Furthermore, we designed our system to have the ability to handle the various interaction styles in the archaeological process: we summarized them to three main areas, inflexible tools, flexible tools, and liquids. Then we took trowels, brushes, and spray bottle as examples for implementation, which are common and representative archaeological tools in practical use. Other tools can be further expanded based on similar methods.

The interaction styles are similar to how commonly encountered trowels, brushes, and spray bottles are used (interaction style see Figure 3), but there also exists some differences: **1) Trowel:** The user holds the handle and slides the heated underside on top of the screen. The tool can simulate trowels of various sizes depending on game stage, for example a few stages require large quantities of dirt to be removed from the artifact while another stage may require the removal of small dirt flakes. **2) Brush:** The user holds the handle and moves the brush hairs on the surface of the screen. The tool is used to remove dust from the surface of artifacts. **3) Spray Bottle:** The user holds the bottle and pulls the trigger to spray water on the desired location. The liquid can represent dirt softeners which is used to allow the trowel to more easily remove dirt, or it could represent anti-oxidizers that are sprayed on artifacts to prevent damage from being exposed to air.

For the inflexible and flexible tools, the electro-thermal units such as heating wires or sheets should be assembled on the end of the tools. And for the liquid tool, such as spray bottles and droppers, the liquid, such as water or ethanol, can be directly detected by the sensing system in room-temperature environments because the liquid will absorb heat on top of the surface and naturally cause temperature change (see Figure 3 bottom right).

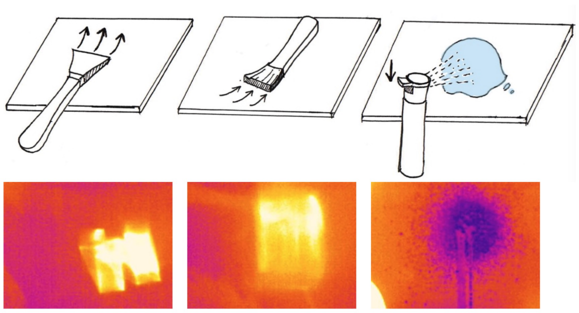

Figure 3. the interaction styles of the tangible tools (trowel, brush, and spray bottle) and their corresponding thermal profiles.

Inflexible Tools	pickax, pointing trowel, tweezer, cutting tools, recording tools ...
Flexible Tools	fine brush, cotton swab, ...
Liquid Tools	dropper, spray bottle, chemical solutions, ...

Table 1. Fieldwork tools

Application

In order to encourage user engagement, we chose a gamified approach in presenting field archaeology. Thus we developed a game engine which allows museum developers to quickly replace and modify game contents. It supports game logic, graphical rendering, input data processing and wireless communication with the tangible tools, etc. A game effects toolkit is also built in the engine, which includes sound effects, particles system, etc.

We developed an example game called "Archaeological Adventure" (see Figure 4 (a)). The player takes on the role of an archaeological student who arrives at a archaeological dig to join an archaeological exploration. The player has to complete several archaeological tasks such as excavation, cleaning, etc, represented by several game stages, in order to unearth an ancient artifact. Assisting them in those tasks are tangible tools which they should use to complete each stage. We expect the game to be a design paradigm for more game content based on real archaeological processes.

Figure 4. Game interfaces. (a) Game Start: Introduce the background. (b) Tutorial: Introduce the game interface, including the control areas and the areas only used for display. (c) The instruction dialog pops up to guide the player. Camera-like icon is the recording button. (d) Final Report: The upper area shows the historical introduction of the artifact, and the lower area shows the reviews of the player's performance.

Besides the tangible interaction, other game features are highlighted here, **1)** A tutorial is displayed at the start of the game (see Figure 4 (b)), teaching the user how to use the interface, such as the central excavation area, the recording button which can take screenshots, and the game stage objectives displayed at the bottom of the screen. **2)** The game stage consists of: removing large amounts of surface dirt, analyzing dirt composition, cleaning deep layered dirt, brushing dirt off the surface of the artifact, removing solid dirt clumps, spraying protective liquids. In every stage, a dialog box will pop up to provide the user with archaeological knowledge and how to use the tools (see Figure 4 (c)). **3)** In the final report screen (see Figure 4 (d)), there will be detailed information of the artifact, and a report display which shows the user's ability to operate the tangible tools (Operating Section), how often they recorded (Recording Section), and their understanding of the tasks (Understanding Section). The user is ranked low, medium, or high on every metric, and with additional messages displayed.

IMPLEMENTATION

Tangible Tools

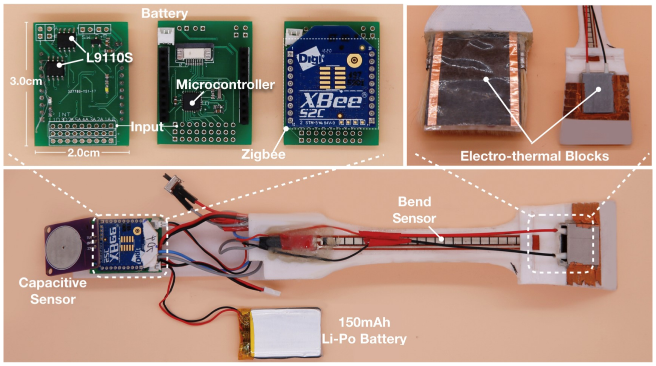

Figure 5. Hardware implementation of the tangible tools. Bottom: An overview of the trowel. Top Left: Details of the control board. Top Right: Electro-thermal blocks used in the trowel and brush.

Many archaeological tools, such as brushes or spray bottles, can be easily converted into tangible tools that can be used with the IRelics platform. For tools that are more difficult to convert, such as trowels, we used 3D modeling software to build 3D models and modified non-functional parts. For example, the trowel handle was made hollow to allow for installation of the control board (see Figure 5). Then we 3D printed the models to build the Tangible tools.

In order to not modify the appearance of the tools significantly when converting them to tangible tools, we made an embedded system that includes a custom control PCB board with a very small size. The main processor is an ATmega8A (Atmel) and there are two PWM connectors on the board to support elements that require high current ($\sim$800mA) but with low voltage (2.5V–12V). These could be useful for extending the tangible output potential, such as driving motors to provide vibrations or driving flashbulbs to mimic a camera. In our prototype, we used one of them to drive electro-thermal blocks in the trowel and brush tools. Furthermore, there are 6 pins for analog inputs and 3 for digital inputs, which can support a wide range of additional sensors. We added bend sensors to detect operational force (trowel and brush) and capacitive touch sensors (trowel, brush, and spray bottle) to detect whether a tool is held by the user. If it is not held, the tool will stay in "sleep mode" where no power is supplied to the electro-thermal block and no wireless communication with the main system in order to save battery power (battery capacity in use: 150mAh). The temperature of the heating surface does not exceed 40 °C, thus ensuring safety for the users.

For wireless communication with the PC in IRelics, we used the wireless protocol of the Zigbee V2 [13]. The XBee Zigbee module can connect with the control board and there is another XBee receiver module connected to the PC over USB. The Zigbee protocol allows multiple tangible tools to send data to the base-station simultaneously. For now, they send data packages, which include sensor data and tool ID, at 20Hz intervals.

Display and Input

The main system is run on a laptop with an Intel core I5 8250U CPU and an Intel UHD Graphics 620 GPU. It is connected to a projector (XGIMI Z4 Aurora, 580 lumen) to back-project the graphical interface onto an ultra-thin screen film (–0.26mm thickness, PET). Thermal changes on the outside of the film would conduct through the film instantly and be captured by the LWIR camera. The backstage environment is shown in Figure 6. The screen size is 1.60×1.00m and the projection resolution we use is 1280×800 pixels. The LWIR camera we use is OPTRIS PI 160, resolution 160*120, temperature precision 0.1°C, 120 FPS.

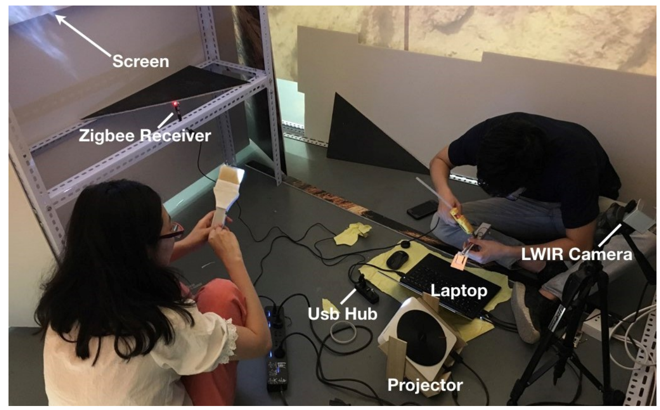

Figure 6. Backstage of the IRelics platform.

The projector and LWIR camera are calibrated to each other using similar methods as [15]. Since the resolution aspect ratio of the projector is consistent with the aspect ratio of the screen (16:10), the four corners of the projected image are manually calibrated to the four corner points of the screen. As the resolution aspect ratio of the camera is 4:3, we made it corresponded with the middle-top 960×720 pixels area of the screen which is the interaction area. With the homography matrix between the projection and real screen coordinates, four corner points of the interaction area could be calculated. Then, by touching these four points with a finger, four temperature stamps would be seen in the monitoring window. Manually adjusting the location and angle of the camera enables all the stamps to appear on the corners of the captured thermal image. In this way, the homography matrix between the projection and thermal camera could be easily calculated.

The core components are covered by a shelter and decorated with cave-like images to enable the best projection performance. The screen is slanted from the vertical orientation at 30 degrees to make user's gaze and operation more comfortable. As the screen is waterproof, most of the water flows off the surface. A horizontal groove is installed below the screen to collect the flowing water allowing it to be reused. Some amounts of water may remain on the surface, but this does not impact the sensitivity of other tangible tools.

Software

The game engine was developed using the OpenFrameworks C++ library, and the basic architecture is shown in Figure 7. There is a GUI renderer which is responsible for rendering the game screen at a 60Hz frame rate. All the game stages are stored in a sequential order. Each stage essentially consists of two images, one is rendered as the foreground layer and the other as the background layer at each game loop. Whenever the correct tool or action is performed on the correct region, then that part of the foreground layer will be set to transparent. After the foreground is cleared entirely, the current stage will be passed and the game engine pushes the next stage into the renderer.

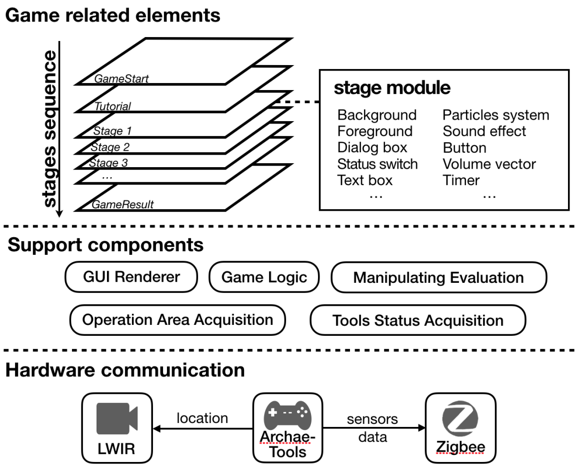

Figure 7. The basic architecture of IRelics game engine.

To acquire data on the area the user is working on, single channel source images mapped to the temperature values of the sensing area are transfered through inter-process communication (IPC) from the Optris imager program. The operational areas are found through contour finding based on the OpenCV library [33] and in which blobs containing less than 5 pixels or more than 3000 pixels are omitted in order to filter out interference and noise such as slight vibrations or screen shaking caused by user actions.

Review Scoring Mechanism

At the end of the game, the player receives a review of their actions as evaluated by the system. **1)** The Recording section depends on the number of uses of the recording button. **2)** The Understanding section depends on the time counting when the user is holding the wrong tool. Using the tool ID, IRelics can know whether the user is holding the correct tool at each stage and count the times they are wrong. **3)** The Operating section depends on the number of times that the force of operation taken from the bend sensors exceeds the threshold (representing damage to the artifact).

USER OBSERVATIONS

To verify the usability and educational effectiveness of the IRelics, we performed two rounds of observations on how the users interact within two different design exhibitions (see Figure 8). The first exhibition was held in the art museum at our university campus and the second one was a cultural heritage exhibition held in an ancient town. We provided no compensation for participation in both rounds.

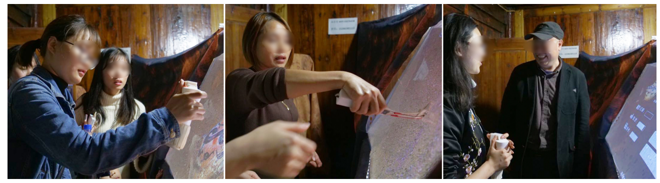

Figure 8. The R2 Observation. Left and Middle: Users trying our prototype. Right: The observer was having an interview with the user after his trial.

In the first round (R1), we focused on verifying the usability of the hardware. Only three game stages were in the game, which correspond to each of the three tangible tools. More than 50 visitors (more than 10 each day in a span of 5 days) tried IRelics and played the example game. An observer would stand beside the platform to give a simple introduction and instruct them on the interaction methods (touching with bare hands, using the trowel, brush or spray water using the spray bottle). We observed their actions and recorded the details. If the visitor encountered any problems or stopped to ask questions, the observer would help them or give appropriate explanations. The observer would also record any problems or questions, as well as any comments from the users.

In the second round (R2), participants played with a complete version of the "Archaeological Adventure". Pre-game interviews were first conducted to identify how familiar the participant was with archaeology. After playing the game, the participant was asked to complete a questionnaire with a few Likert-type questions each rated on a 5-point scale from "Strongly Agree" to "Strongly Disagree" to assess the educational effects: ***Q1.*** *You can retell the steps of this game process,* ***Q2.*** *The final report help you gain understanding of archaeology,* ***Q3.*** *You learned that environmental analysis is important to archaeology and* ***Q4.*** *You learned that detailed recording of data is important in the archaeological process.* Besides,they were also asked to select 4 adjectives from a list of words describing the game platform, such as "interesting" or "annoying".

During the in-depth interview, we asked the participants to recite the game-process and asked them to talk about the changes in their understanding of archaeology and what they considered to be the "central aspect" of archaeology. Advice and feedback were also welcomed in the interview. We compiled the answers to assess the effectiveness of IRelics in educating the user on the field of archaeology. 25 users tried the system and 20 effective questionnaires were collected in R2. There were 12 males, of whom 4 received more in-depth interviews, and 13 females, of whom 6 received more in-depth interviews. The others accepted informal interviews that allowed them to freely talk about the topic. There were a wide range of ages, education levels, and occupations in the tested users.

Findings

Usability Evaluation

The tool's haptic affordance made it easy for the users to interact with them correctly, and most of the participants got used to the interaction styles in less than 30 secs. The most common problem was how the users held the tools, as holding the tools in a way that wouldn't trigger the capacitive touch sensor would not wake up the micro-system of the tool. The problem was solved by enlarging the area of the sensing pad by pasting copper foil on the tool's surface and connecting the foil to the sensor.

In R1, the majority of participants could finish the game in 5 – 6 minutes. The time spent on each stage of the game was different: Stage 1 with trowel: 3 – 4 minutes, Stage 2 with brush: 1 minute, Stage 3 with spray bottle: 30 seconds. The time taken was highly correlated with the contact area of the tool with the surface. Nearly half of the participants showed fatigue or impatience after using the shovel for more than 2 minutes. Thus, we inferred that 2 minutes should be the maximum appropriate time for a stage. In R2, the time taken for each stage would be extended due to time spent reading the added instructions.

Most participants affirmed that both the input sensing precision and the speed were satisfactory, and they greatly enjoyed the tangible interaction styles. Several participants told us that they felt comfortable and delighted when they sprayed liquid directly onto the screen. The haptic feedback and real-time game response were deduced as the main reasons.

We also did not place enough consideration into how children would use our platform. There were more than 10 children (6-12 years old) that tried our platform. Since most of them were not able to play completely independently (common difficulties included not being able to understand the texts, not being able to use tools correctly, not being tall enough, etc.), they required the assistance of their parents or the observer. Despite this, the parents of the children were fond of our design. They thought that our design is a good method of education since in addition to teaching, it also exercises the children's hands-on ability. Moreover, IRelics could also be a medium to promote relationships within the family as we observed that parents could understand and give spontaneous guidance whenever their children could not understand.

Educational Effectiveness

Before completing the game, users generally had low understanding of archeology. All of the users that were tested (25) reported that they "were not familiar with archeology", 5 expressed that most of their knowledge regarding archeology came from television shows, and described it as "digging for treasure" or "appraising antiques".

The questionnaire results (see Figure 9) imply that: ***1)*** *The platform helps users memorize the archaeological process effectively (from Q1),* ***2)*** *The review report is useful in educating users on archaeological topics (from Q2),* ***3)*** *Introductions and notifications based on GUI attracted less attention from users (from Q3 and Q4).*

In the in-depth interview, we obtained more detailed opinions, which helped us deduce the factors behind the results of the questionnaire. Firstly, most of the participants (9 of 10) were able to recite the steps of the game, including how to use the tools, thus showing that IRelics was effective in helping users retain knowledge. However, all of the participants expressed that they did not notice the recording function despite the

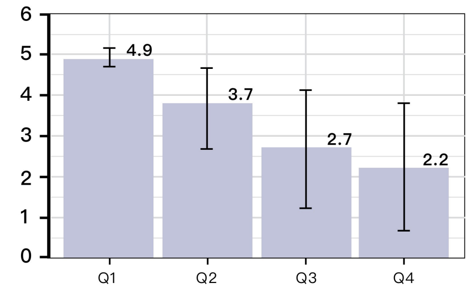

Figure 9. Results from the Likert-type questions: Q1. Ability of steps retelling. Q2. Effectiveness of final report. Q3. Awareness of the importance of environment analysis. Q4. Awareness of the importance of detailed recording.

tutorial at the start instructing them to use the record function frequently. Once the game had begun all the participants' focus was on the interaction with the tangible tools, and they only noticed their lack of recording once they had reached the final report and saw that their score in the recording section was "low". For environmental analysis, due to the frequent dialog boxes, the score of Q3 is greater than Q4, nonetheless, many were overly focused on the tangible integration aspect and would often skip over dialogues. Overall, the outcomes were still very positive since all of the participants interviewed could give more specific and detailed descriptions and explanations of field archaeology, indicating that they had gained a better understanding of the processes involved in field archaeology, as well as significant interest and desire to discuss the subject further.

Emotional Feedback

When choosing adjectives to describe the IRelics platform, most users chose "popular", "attractive", "interesting", and "meaningful". The vast majority gave the prototype a positive evaluation and affirmed the educational value and interestingness of the prototype and expressed their hope of seeing similar products in museums as early as possible.

DISCUSSION

Inertia of Interaction Styles

In R2, our example game utilized a mix of tangible interaction and 2d interface interaction. In practice, most of the user's attention is focused on the tangible interaction aspect. This is evident in the fact that the use of certain 2D functions is low (such as the recording button). When a task requires the user to switch from the use of tangible interaction to 2D interaction, there is a clear sense of inertia as the user wishes to remain in the tangible interaction mode. For example, when advancing into a subsequent stage's pre-instructions, many users will continue to interact with IRelics and use the tangible tools as if they were still on the previous stage. This causes the reader to be distracted from reading the instructions. Therefore, for tasks that are considered to have a high impact on satisfying the criteria, we recommend using the form of tangible interaction. For instance, as recording is important based on the feedback from the archaeologists, a tangible tool "camera" can be easily built with our custom MCU and the 3D printing model. Once the user presses the "shutter", the flash lights up, and a screenshot will be taken by the main system. The presence of the tangible camera will remind the user to use it more frequently compared with the virtual camera button on the screen.

For the situations that users have to change focus from tangible interaction to 2D surface interaction, a gradient animation effect or a voice reminder is considered to be added in between two tasks, to provide users with a psychological buffer.

Interact with Liquid

Interacting with liquid plays a significant role in gameplay. Not only does the spray tool enable several types of archaeological simulation, but the interaction style provides a delightful and smooth user experience as well. However there are some considerable tradeoffs while applying liquid in the interactions. Although most of the water would flow off the surface after the user sprayed water on it, the screen tended to stay wet for a while after. The wetness does not affect the normal use of tangible tools but does impact bare-hand interaction. We observed that a few participants, especially female participants, expressed displeasure while touching the wet screen with their hands. Therefore, in later experiments we usually recommended the participant to touch the screen using the tools instead. Also, the experimenter would dry the surface with a towel every few rounds, which increased experimental workload. A practical approach in a real museum setting will be to install an air dryer at the side of the screen to keep it dry.

Another issue is the dispersing effects rendered in the game. It is difficult to make this interaction realistic because a liquid will not disperse in the same way as on a real 3-dimensional object. Since IRelics adopts a 2D graphical display, there is a tradeoff between making the tangible tools more available and improving the realism of the game environment. The combination of tangible techniques and 3D-reconstruction techniques [7, 32] may open up future research opportunities.

Limitations and Future Work

After conducting the user study, we refined the shortcomings in the current system into several aspect and proposed corresponding solutions:

1) Over-cautiousness when using tools: since users are often unfamiliar with tangible interaction styles, they often need a period of time to get used to using them. For example in the use of the spray bottle, many hesitated when told to spray water on top of the display. To solve this, instructions on how to use the tools could be presented in the game interface.

2) Due to the smaller contact surface of the trowel in comparison with the brush and the spray bottle, it takes a longer period of time to complete tasks using it. This led to many users experiencing fatigue and declining patience while using the tool. Thus, if IRelics is to be used with a larger display, the contact area of the tools with the display surface must also increase in order to prevent disinterest.

3) Users are less sensitive to text information. Since the tangible tools are more novel and interesting than the text information presented, the user's attention is less focused on text information, leading to them not noticing important aspects of the game. Thus, important information is recommended to be augmented by dubbing or exclusive presentation.

4) Children require assistance to use IRelics. Since the use of tangible tools is attractive to children and the system is likely to be implemented in museums, the platform should be able to be used by people of all ages including children. From our observations, we obtained feedback and experience that will help us improve the design for children. The system must have reasonable height, easy to understand content, and encourage parental interaction with their children.

CONCLUSION

Archeology is a subject that not only requires professional knowledge but also practical, hands-on experience. Former experiencing platforms related to the topic usually took advantage of 2D/3D graphical interfaces, or VR/AR [9, 17]. These interfaces are good at conveying visual information but are limited in terms of realistic interactive input.

IRelics is a novel TUI platform for the presentation of field archaeological activities. One of its contributions is that its interaction style is a combination of visual and tactile factors which provides real-time realistic feedback more similar to real actions in comparison with traditional styles in which only visual information is involved. Within the design process, the details of IRelics system were also presented, and a set of tangible reforming methods were conducted to build tangible input devices referred to archaeological tools. The combination of tangible tools with LWIR sensing technique has been proven to be stable and repeatable, and the MCU we developed for the tangible tools is affordable and extensible for extensive usages of other tangible interaction styles.

Through the two observations, we gathered a large amount of feedback and advice. Additionally, responses proved that audiences were highly engaged in experiencing IRelics and the effects of improving the awareness of field archeology were clear. Limitations and future work were also discussed, and we will further enrich the set of tangible tools and improve the quality of the platform in the future. Furthermore, we will promote cooperation with archaeological museums since most of them are also responsible for archaeological research and hold abundant source materials, and we could help them develop specific applications based on IRelics for popularizing archeology to the general public.

Further, we think that IRelics, our TUI platform designed to popularize and educate people on the field of archeology, can be applied similarly to other fields that involve hands-on experience and tool use, such as medicine or agriculture, in the future.

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REFERENCES

[1] Wendy Ashmore and Robert Sharer. 2013. *Discovering our past: a brief introduction to archaeology*. McGraw-Hill Higher Education.

[2] Philip Barker. 1993. *Techniques of archaeological excavation*. Psychology Press.

[3] Jean-Baptiste Barreau, Ronan Gaugne, Yann Bernard, Gaétan Le Cloirec, and Valérie Gouranton. 2014. Virtual reality tools for the west digital conservatory of archaeological heritage. In *Proceedings of the 2014 Virtual Reality International Conference*. ACM, 4.

[4] H. Benko, E. W. Ishak, and S. Feiner. 2004. Collaborative mixed reality visualization of an archaeological excavation. In *Third IEEE and ACM International Symposium on Mixed and Augmented Reality*. 132–140. DOI: http://dx.doi.org/10.1109/ISMAR.2004.23

[5] Nuno Correia, Tarquínio Mota, Rui Nóbrega, Luís Silva, and Andreia Almeida. 2010. A Multi-touch Tabletop for Robust Multimedia Interaction in Museums. In *ACM International Conference on Interactive Tabletops and Surfaces (ITS '10)*. ACM, New York, NY, USA, 117–120. DOI: http://dx.doi.org/10.1145/1936652.1936674

[6] Herminia Wei-Hsin Din. 2006. Play to Learn: Exploring Online Educational Games in Museums. In *ACM SIGGRAPH 2006 Educators Program (SIGGRAPH '06)*. ACM, New York, NY, USA, Article 13. DOI: http://dx.doi.org/10.1145/1179295.1179309

[7] M. M. A. Gallo, F. Spadafora, F. Manfredi, F. Bruno, and A. Lamarca. 2013. 3D reconstruction of an outdoor archaeological site through a multi-view stereo technique. In *2013 Digital Heritage International Congress (DigitalHeritage)*, Vol. 1. 169–176. DOI: http://dx.doi.org/10.1109/DigitalHeritage.2013.6743727

[8] Kristoffer Getchell, Alan Miller, J Ross Nicoll, Rebecca Sweetman, and Colin Allison. 2010. Games methodologies and immersive environments for virtual fieldwork. *IEEE Transactions on Learning Technologies* 3, 4 (2010), 281–293.

[9] Tony Hall, Luigina Ciolfi, Liam Bannon, Mike Fraser, Steve Benford, John Bowers, Chris Greenhalgh, Sten-Olof Hellström, Shahram Izadi, Holger Schnädelbach, and others. 2001. The visitor as virtual archaeologist: explorations in mixed reality technology to enhance educational and social interaction in the museum. In *Proceedings of the 2001 conference on Virtual reality, archeology, and cultural heritage*. ACM, 91–96.

[10] Wolfgang Hürst, Xhi Jia Tan, and Ferdinand de Coninck. 2016. Using Digital Extensions to Create New VR Museum Experiences. In *Proceedings of the 13th International Conference on Advances in Computer Entertainment Technology (ACE '16)*. ACM, New York, NY, USA, Article 45, 6 pages. DOI: http://dx.doi.org/10.1145/3001773.3001822

[11] Stefan Hynst, Michael Gervautz, Markus Grabner, and Konrad Schindler. 2001. A Work-flow and Data Model for Reconstruction, Management, and Visualization of Archaeological Sites. In *Proceedings of the 2001 Conference on Virtual Reality, Archeology, and Cultural Heritage (VAST '01)*. ACM, New York, NY, USA, 43–52. DOI: http://dx.doi.org/10.1145/584993.585000

[12] N. Ibrahim and K. A. Azmi. 2013. Preserving Malay architectural heritage through virtual reconstruction. In *2013 Digital Heritage International Congress (DigitalHeritage)*, Vol. 1. 739–742. DOI: http://dx.doi.org/10.1109/DigitalHeritage.2013.6743830

[13] Digi International Inc. 2018. Digi XBee and XBee-PRO Zigbee RF Modules - Digi International. https://www.digi.com/products/xbee-rf-solutions/2-4-ghz-modules/xbee-zigbee. (2018). Accessed August 08, 2018.

[14] Hiroshi Ishii, Dávid Lakatos, Leonardo Bonanni, and Jean-Baptiste Labrune. 2012. Radical atoms: beyond tangible bits, toward transformable materials. *interactions* 19, 1 (2012), 38–51.

[15] Daisuke Iwai and Kosuke Sato. 2005. Heat sensation in image creation with thermal vision. In *Proceedings of the 2005 ACM SIGCHI International Conference on Advances in computer entertainment technology*. ACM, 213–216.

[16] Martha Joukowsky. 1980. *A complete manual of field archaeology. Tools and techniques of field work for archaeologists*. Prentice-Hall, Inc.

[17] Mathieu Loiseau, Elise Lavoué, Jean-Charles Marty, and Sébastien George. 2013. Raising awareness on archaeology: A multiplayer game-based approach with mixed reality. In *European Conference on Games Based Learning*. Academic Conferences International Limited, 336.

[18] Nick Merriman. 2004. *Involving the public in museum archaeology*. Routledge, 85–108.

[19] CCTV Network. 2017. National Treature-CCTV large-scale cultural exploration program. http://tv.cctv.com/cctv3/special/guojiabaozang/. (2017). Accessed November 30, 2017.

[20] Ioannis Paliokas, Vlad Buda, and Iancu Adrian Robert. 2010. Archaeo viz-a 3d explorative learning environment of reconstructed archaeological sites and cultural artefacts. In *Signal Processing and Multimedia Applications (SIGMAP), Proceedings of the 2010 International Conference on*. IEEE, 211–214.

[21] Caroline Pantofaru, Austin Hendrix, Andreas Paepcke, Dirk Thomas, Sharon Marzouk, and Sarah Elliott. 2013. Programming Robots at the Museum. In *Proceedings of the 12th International Conference on Interaction Design and Children (IDC '13)*. ACM, New York, NY, USA, 305–308. DOI: http://dx.doi.org/10.1145/2485760.2485797

[22] Christina Pollalis, Whitney Fahnbulleh, Jordan Tynes, and Orit Shaer. 2017. HoloMuse: Enhancing Engagement with Archaeological Artifacts Through Gesture-Based Interaction with Holograms. In *Proceedings of the Eleventh International Conference on Tangible, Embedded, and Embodied Interaction (TEI '17)*. ACM, New York, NY, USA, 565–570. DOI: http://dx.doi.org/10.1145/3024969.3025094

[23] Christina Pollalis, Elizabeth Joanna Minor, Lauren Westendorf, Whitney Fahnbulleh, Isabella Virgilio, Andrew L. Kun, and Orit Shaer. 2018. Evaluating Learning with Tangible and Virtual Representations of Archaeological Artifacts. In *Proceedings of the Twelfth International Conference on Tangible, Embedded, and Embodied Interaction (TEI '18)*. ACM, New York, NY, USA, 626–637. DOI: http://dx.doi.org/10.1145/3173225.3173260

[24] Hangzhou Qianying Cultural Innovation Inc. Qingying Studio Tsinghua University. 2017. Masters in the Forbidden City. http://www.imdb.com/title/tt6448192/. (2017). Accessed November 30, 2017.

[25] Patrick Reuter, Guillaume Riviere, Nadine Couture, Stephanie Mahut, and Loic Espinasse. 2010. ArcheoTUI: Driving virtual reassemblies with tangible 3D interaction. *Journal on Computing and Cultural Heritage (JOCCH)* 3, 2 (2010), 4.

[26] Francesca Rizzo and Franca Garzotto. 2007. "The Fire and The Mountain": Tangible and Social Interaction in a Museum Exhibition for Children. In *Proceedings of the 6th International Conference on Interaction Design and Children (IDC '07)*. ACM, New York, NY, USA, 105–108. DOI: http://dx.doi.org/10.1145/1297277.1297298

[27] Jessica Roberts. 2015. Exploring Effects of Full-body Control in Perspective-based Learning in an Interactive Museum Data Display. In *Proceedings of the Ninth International Conference on Tangible, Embedded, and Embodied Interaction (TEI '15)*. ACM, New York, NY, USA, 445–448. DOI: http://dx.doi.org/10.1145/2677199.2691606

[28] Maria Roussou, Elina Kavalieratou, and Michael Doulgeridis. 2007. Children Designers in the Museum: Applying Participatory Design for the Development of an Art Education Program. In *Proceedings of the 6th International Conference on Interaction Design and Children (IDC '07)*. ACM, New York, NY, USA, 77–80. DOI:http://dx.doi.org/10.1145/1297277.1297292

[29] N. Schiavottiello. 2015. ArkTeller: A new 3D real-time storytelling platform for cultural heritage interpretation. In *2015 Digital Heritage*, Vol. 2. 753–754. DOI:http://dx.doi.org/10.1109/DigitalHeritage.2015.7419620

[30] Akihiko Shirai, Yuki Kose, Kumiko Minobe, and Tomoyuki Kimura. 2015. Gamification and Construction of Virtual Field Museum by Using Augmented Reality Game "Ingress". In *Proceedings of the 2015 Virtual Reality International Conference (VRIC '15)*. ACM, New York, NY, USA, Article 4, 4 pages. DOI: http://dx.doi.org/10.1145/2806173.2806182

[31] DIG-IT! GAMES PRODUCTION STUDIOS. 2018. Excavate - Dig-it! Games. https://dig-itgames.com/excavate/. (2018). Accessed November 18, 2018.

[32] Veronica Sundstedt, Alan Chalmers, and Philippe Martinez. 2004. High Fidelity Reconstruction of the Ancient Egyptian Temple of Kalabsha. In *Proceedings of the 3rd International Conference on Computer Graphics, Virtual Reality, Visualisation and Interaction in Africa (AFRIGRAPH '04)*. ACM, New York, NY, USA, 107–113. DOI: http://dx.doi.org/10.1145/1029949.1029970

[33] Satoshi Suzuki and others. 1985. Topological structural analysis of digitized binary images by border following. *Computer vision, graphics, and image processing* 30, 1 (1985), 32–46.

[34] Eileen Vote, Daniel Acevedo Feliz, David H Laidlaw, and Martha Sharp Joukowsky. 2002. Discovering petra: Archaeological analysis in vr. *IEEE Computer Graphics and Applications* 22, 5 (2002), 38–50.

[35] Ron Wakkary and Marek Hatala. 2007. Situated play in a tangible interface and adaptive audio museum guide. *Personal and Ubiquitous Computing* 11, 3 (2007), 171–191.

[36] Wikipedia contributors. 2017. Daomu Biji — Wikipedia, The Free Encyclopedia. (2017). https://en.wikipedia.org/w/index.php?title=Daomu_Biji&oldid=804476168 [Online; accessed 5-August-2018].

[37] Wikipedia contributors. 2018. The Lost Tomb — Wikipedia, The Free Encyclopedia. https://en.wikipedia.org/w/index.php?title=The_Lost_Tomb&oldid=838544704. (2018). [Online; accessed 9-August-2018].

[38] Nikoleta Yiannoutsou, Ioanna Papadimitriou, Vassilis Komis, and Nikolaos Avouris. 2009. "Playing with" Museum Exhibits: Designing Educational Games Mediated by Mobile Technology. In *Proceedings of the 8th International Conference on Interaction Design and Children (IDC '09)*. ACM, New York, NY, USA, 230–233. DOI: http://dx.doi.org/10.1145/1551788.1551837