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Landscape Rippling: Context-based water-mediated interaction design

Weiyue Lin[1,2] | **Haoran Hong**[1,3] | **Yingying She**[4] | **Baorong Yang**[5]

[1]School of Informatics, Xiamen University, Xiamen, China

[2]School of Software and Microelectronics, Peking University, Beijing, China

[3]Graduate School of Frontier Sciences, The University of Tokyo, Chiba, Japan

[4]School of Film, Xiamen University, Xiamen, China

[5]College of Computer Engineering, Jimei University, Xiamen, China

Correspondence

Yingying She, School of Film, Xiamen University, Xiamen, China.
Email: yingyingshe@xmu.edu.cn

Baorong Yang, College of Computer Engineering, Jimei University, Xiamen, China.
Email: yangbaorong@jmu.edu.cn

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Abstract

With a core purpose of helping users to understand the context, a water interface provides possibility for enhancing user experience in interaction process. Starting from analyzing existing water-mediated interaction approaches, we proposed a water-mediated interaction design model and a corresponding user experience model, aiming to eliminate the boundary between users and the context with water as the medium. According to the proposed model, we implemented a water-mediated interaction system Landscape Rippling, with the painting "A Panorama of Rivers and Mountains" as its context. Ultimately, user experience tests of the interaction system demonstrate the effectiveness of this water-mediated interaction design model.

KEYWORDS

augmented reality, context-based interaction, interactive interface, water-mediated interaction

1 | INTRODUCTION

Tangible user interfaces (TUI) have been constantly emerging, which serve as user interfaces as well as part of interaction spaces, enriching the form of interaction and creating natural human-computer interaction (HCI). Water is one

Weiyue Lin and Haoran Hong have contributed equally to this study.

type of TUI, and its properties and characteristics make it possible to enhance user experience. Besides, water-mediated interaction has gradually come to the forefront of HCI researchers. However, there is still lack of design model that focuses on context. In this article, we propose a water-mediated interaction design model that aims to eliminate the boundary between user and context with a corresponding user experience model. Based on the model, we implemented a water-mediated interaction system, namely *Landscape Rippling*. In addition, user experience tests are conducted to verify the effectiveness of the proposed model.

2 | RELATED WORD

2.1 | Water-mediated interaction

The interaction system with water as the medium[1] was designed based on non-transparent liquid level and gesture control. It is used to solve the problem that is difficult to use handheld devices in the bathroom, swimming pool and other scenes. The display area of the subsequent water interaction system is no longer limited to water surface,[2] but there is lack of interaction design based on advanced display technology. In the design framework of liquid UI,[3] a series of existing technologies are mapped into the design space of liquid UI. Therefore, Ashley Colley et al. considered the influence of water interface on aesthetic design and user experience,[4] but the association between context and water has still not become a factor to be considered in interaction design. The work of William L. Raffe et al. provides guidelines for the design and development of water-related digital games[5] by classifying users according to six degrees of contact with water.

2.2 | Natural user interface

Natural user interface (NUI) is an interface that conforms to users' actual operation behavior requirements. It is easier to understand and reduces users' cognitive burden as much as possible.[6,7] In the interactive system,[8] users do not need to use special interactive devices, but rely on commonly used smart watches to sense gestures and interact with mobile robots. Sunjie Chen et al. developed a robot control system[9] based on gesture recognition.

2.3 | Multimedia learning and situational cognition

The use of multimedia to help users improve their cognitive level of context is widely used in the HCI. With the increase of media forms and technology, the value of situational awareness (SA) in the multimedia interaction have been paid attention to Reference 10. Jule M. Kruger and Daniel Bodeme studied the application of two multimedia learning principles to AR cases,[11] and they believed that AR technology brought new possibilities for multimedia learning design.

2.4 | Somatosensory control and environmental perception

Human pose recognition technology has become more accurate and efficient in recent years.[12,13] Using Kinect attitude camera equipped with color camera, infrared camera and infrared projector,[14] video images with depth information can be obtained by Light Coding method[15] and Time Of Light method.[16] Bone models are established after identifying the user's body parts.[17] Arduino is an open source electronic prototype platform including hardware (Arduino circuit board) and software (ArduinoIDE), which supports cross-platform development.[18] In Sipani et al.'s design[19] of intelligent environment monitoring system, Arduino Uno circuit board were used to monitor environmental parameters with utmost possible accuracy. Menon et al.[20] use Arduino sensors (with Wi-Fi module) accompanied by GPS coordinates to monitor and measure pollutants in the air in real time.

3 | OUR APPROACH

3.1 | Water-mediated interaction design model

Previous works on water interface show that water provides intrinsic appear to user's memories. The special characters of water raises to us that how to function water as both an interaction medium and a core context element, in order to eliminate the boundary between users and the context with natural interactions. In this article, we propose a water-mediated interaction design model which consists of three layers from abstract to concrete, as shown in Figure 1, by analyzing the context, the water as medium and user experience of the state-of-the-art water-mediated interaction approaches.[1-5]

3.1.1 | Concept layer

The concept layer is the foundation layer of the model. The water-mediated context should be defined at the concept stage, inspired by the need of immersion, induction, interaction, and imagination. At the beginning of interaction, creating immersion will help users to open their senses, be familiar with and immersive into the environment. Reasonable and natural induction will effectively guide the interactions with the interface, which is the core part of water-mediated interaction design, where the interactive context is highlighted with user interaction and the feedback of the system. The user will be prompted to make relevant imaginations and reflections during or after the interaction, which will eliminate the boundary between users and the context.

3.1.2 | Factor layer

The factor layer integrates the design concept of water-mediated interaction with key elements of the context, and concretizes the concepts of the system into targeted design ideas. It consists of context-based presentation, task-oriented induction, and water-mediated interaction. The context-based presentation will effectively achieve user immersion and presence, while preparing and paving the way for users' initial perception and understanding of the context. At this stage, the elements of the context should be decided. The context could be described into different tasks. Then task-oriented induction will help users to participate in the water-mediated interaction with less learning cost and more natural experience, and achieve a deeper understanding of the core context through specific tasks. The involvement of water in the input and output is an important feature of the water-mediated interaction, so the water is the non-negligible key point in the design of the interaction.

3.1.3 | Implementation layer

The implementation layer refines the design factors into details. It could be divided into four parts: mixed reality environment, progressive induction, water-based sensory interaction, and sensory feedback. The mixed reality environment,

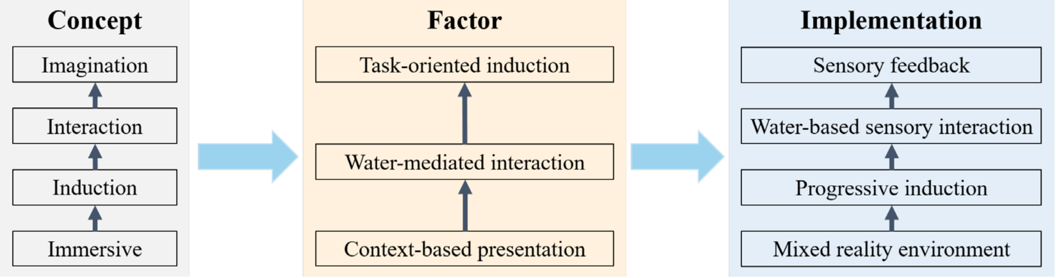

FIGURE 1 Water-mediated interaction design model

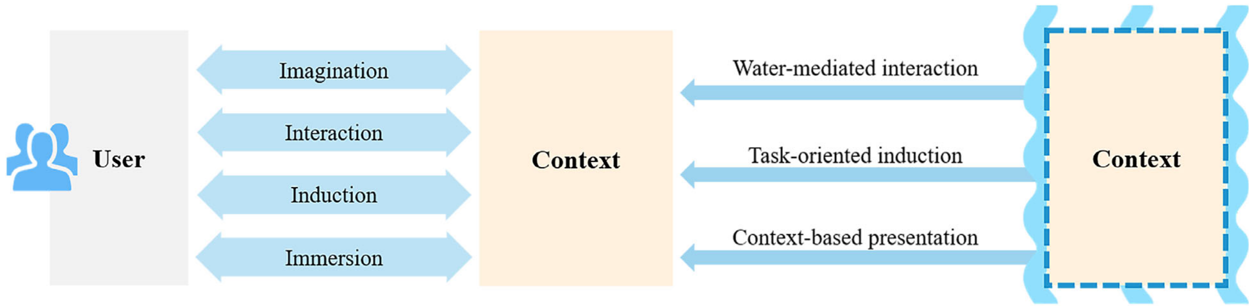

FIGURE 2 User experience model

together with the water-based sensory interaction and feedback narrate the context behind through the progressive induction. The mixed reality environment is the main part of this layer, in which the real water is taken as the interactive element that provides immersion in real environment, while the interspersed virtual scenes make the interactive environment more complete and real. In the water-mediated interaction, the progressive induction in interaction tasks can help users to participate in the interaction and effectively achieve natural interaction. Water is used as the interaction medium to realize the input and output through sensors. Different gestures in contact with the water, state changes of the real water and so forth. can be used as input, while the output can be the feedback of different sensory such as color, water waves, flowing water sound effects and so forth.

3.2 | User experience model

We also propose one user experience model of water-mediated systems, as shown in Figure 2. Users will have a sense of immersion under the presentation layer based on context. The mixed reality technology will help users to build a sense of familiarity and thus immerse themselves in the scenario. Task-oriented induction triggers user's engagement and interaction. Based on the immersion in the environment, users begin to actively engage in the interaction and devote more attention to it. Finally, the complete water-mediated interaction on the sensory channel triggers the highest level of user experience—imagination and empathy. At this point, users follows the induction to complete the interaction process in an environment based on context. The water medium participates in the input and output of the system to constitute natural interaction, stimulating users to think about the context in a personalized way and build a cognitive understanding.

4 | SYSTEM DESIGN AND IMPLEMENTATION

4.1 | Concept design

Based on the proposed water-mediated interaction design model, we take the "A Panorama of Rivers and Mountains" which is a famous Chinese painting as the core context and design a context-based water-mediated system Landscape Rippling.

The system contains three stages, including the arousing stage, the browsing stage, and the reinforcing stage. In the arousing stage, the user is first guided to restore the painting through pouring water, which will create a visual initial impression of the context. Then in the browsing stage, the screen will play a full browsing animation of the painting, at which point the user will have a further overall understanding of the painting. In the reinforcing stage, clouds block on the screen and users should push aside them with hands for detail of the painting. With the feedback of the interactions, users experience a sense of control and satisfaction, while deepening memory and awareness of context and triggering personalized emotions during contact with the water. Besides, the elements in the context are animated in combination with sound effects, which allow the user to enjoy the dynamic painting and further immersed into it.

4.2 | Factor design

4.2.1 | Design of the interaction environment

We project the painting on the water-mediated interface for large-scale presentation of the scene, and strengthen users' sense of immersion by emphasizing the composed context. That is, water used in the system is not only an interactive interface but also a component element of the environment. Therefore, a container of water is taken as the water-mediated interface. During the interaction, the speaker will play sound effects to create a mixed-reality environment where the user's sense of sight, touch, and hearing are blended. We choose a quiet and dimly lit interior to reach better effects.

4.2.2 | Design of induction

According to the proposed interaction design model, design of induction derives from the two tasks that users need to accomplish during interaction: pouring water to arouse the painting and pushing aside the cloud for detail exploration of the painting. We use an image-based guidance to present the front and rear interactions on the water interface in a translucent brush stroke or a brush animation. On the basis of not destroying the overall screen and user experience as much as possible, these clues are prompt and guidance for users to interact.

4.2.3 | Interaction gesture design

As mentioned, users should accomplish these two tasks for exploring the painting: pouring water to arouse the painting and pushing aside the cloud to explore the details of the painting, so interaction gestures are designed accordingly.

(1) Pouring water

In the first task, we abstract the participation of water in the restoration of painting. The initial painting image is dim and stale. The interactive approach here—pouring water to clean old painting, in line with the user's expectations of the function of water and a dust painting. Simplifying this process and abstracting into a simple water pouring operation will reduce the cost of user's learning the operation, triggering the user to participate in the interaction.

(2) Brushing water

The retained water in the container together with the painting image is an echo of the river, and users will interact with the water and getting sensory feedback. In the second task, the cloud mask displayed on the interface obscures part of the painting, and the user needs to disperse the cloud by brushing water, triggering a detailed display. People's subconscious experience for things blocking the sight are pushing them aside with hands. Such interaction gesture is in line with users' general experience, so that it can be more natural to accept and perform.

4.3 | Implementation

4.3.1 | Mixed-reality environment

Figure 3 shows the prototype of this system. The water in an acrylic container served as the medium for interaction. The props (water cup with water and wipes) on the desktop are used for tangible interaction, and sensor devices (Arduino Uno and raindrop sensor) on the side of the container are used to sense users' operation. The gesture camera (Kinect v2.0) collects users' gesture in operating area. Meanwhile, a projector is installed on the top to project digital graphics on the water surface. A PC (Windows 10) serves as main controller and provides computing resources. To ensure projection and audio effects, the entire system is set up in a dark, quiet indoor room. We select several areas with rich dynamic context (such as people, birds, boats, etc.) of the painting and remaster the core elements into a series of more detailed and vivid animations basing on the style of the painting, as shown in Figure 4.

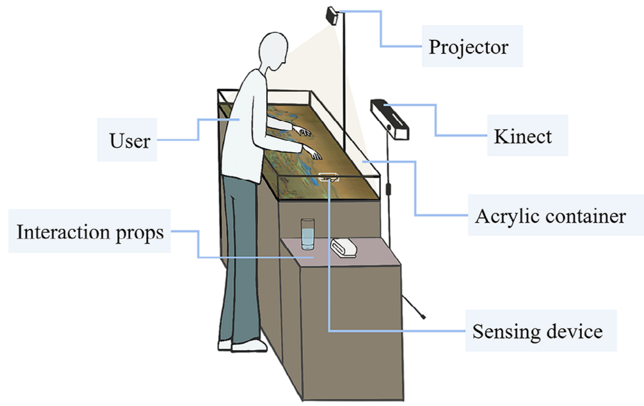

FIGURE 3 Prototype of Landscape Rippling

FIGURE 4 Remastered animation elements

4.3.2 | Progressive induction

The interaction process includes two sections. Brief simple animation of operations are used as graphical induction on the water-mediated interface, prompting users to perform operations, as shown in Figure 5 . In Section 1, masked animation of water cup pouring is performed on the starting scene at regular intervals to induct users' water pouring operation. In Section 2, the induction animation demonstrates pushing gesture on the cloud to guide users.

4.3.3 | Water-based sensory interaction

With a series of sensing and input devices as shown in Figure 6, a combination of tangible interaction and somatosensory interaction is performed in Landscape Rippling. To perceive the water pouring operation, a sensing device composed of a

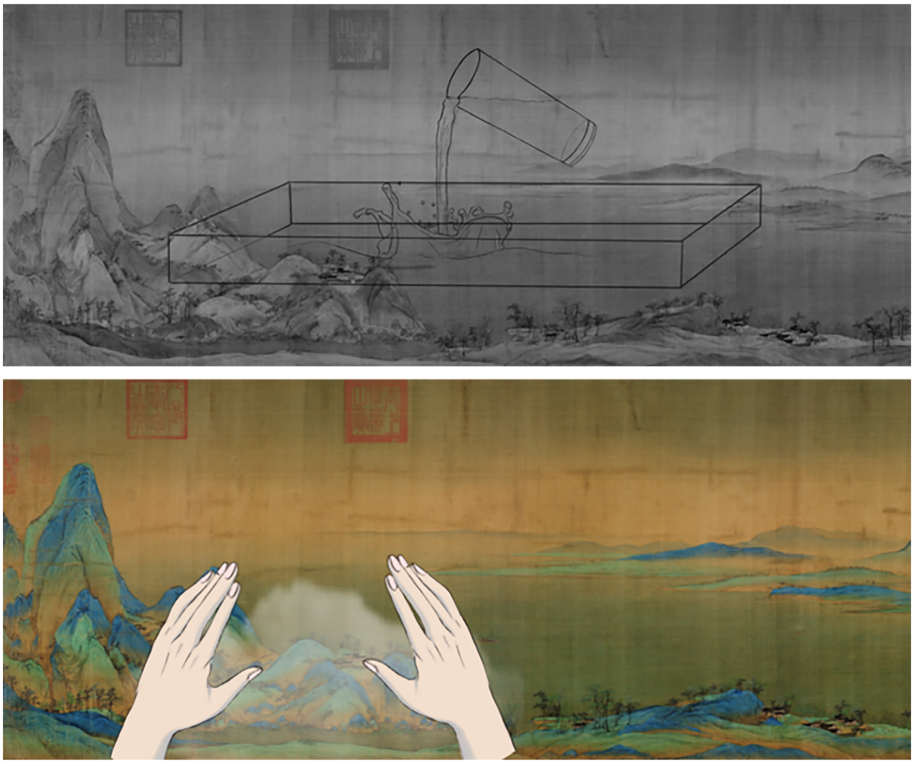

FIGURE 5 Induction animation

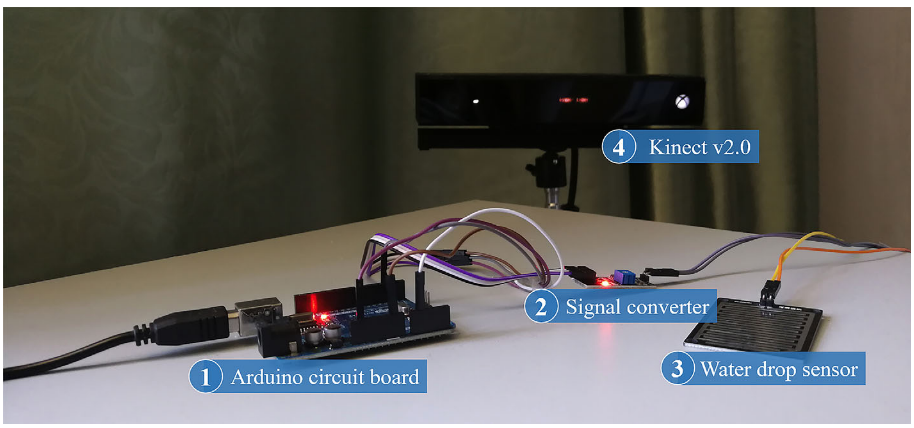

FIGURE 6 Sensing and input device

water drop sensor and an Arduino circuit board is installed on the side of container to sense the change of water volume. In the reinforcing stage, a Kinect v2.0 is installed to collect RGBD images of users, then videos are segmented and skeleton of users are constructed to extract motion of joint points.

4.3.4 | Sensory feedback

Controller program integrates and extracts data from sensor and camera into command information, then project digital graphics on the water surface, and play sound effects, cooperating with the physical effects of water surface fluctuations caused by users' operations, to achieve feedback in multi-sensory channels. The interrelated visual and tactile feedback combined the movements of virtual cameras and stereophony to respond to users' operations multimodally. The entire water-mediated interaction system is based on an immersive mixed reality environment, which inducts users to establish interactive communication with context and obtain multi-sensory feedback.

5 | EXPERIMENTS

5.1 | On effectiveness of water-mediated interaction design model

To verify the necessity of emphasizing context in water-mediated interaction system, an experiment is conducted to explore the impact of interaction elements and context on user experience. We set up a gesture interaction program where users need to control with gestures and dye a virtual cloth. The experimental environment is shown in Figure 7.

Inspired by the evaluation of user's presence experience in virtual environment,[21] we use immersion, induction, interaction, and imagination of the concept layer in our design model to evaluate user experience. The control groups in the experiment are: one group with anhydrous interface that lacking of water elements in both factor layer and implementation layer, and two groups with less relevance between interaction gestures and context in the implementation layer, as shown in Table 1. Fifteen users were informed about procedure of the experiment and experience the system in four different states as shown in Table 1, namely state 1 to state 4. Then they filled out the questionnaire for each state. The questionnaires used are in the supplementary document. The users' answers were divided into five levels, scoring from 1 to 5. We analyzed the scores of state 4 and the other three states.

Figure 8 shows the comparison between state 1 and state 4, while Figure 9 shows the comparison results between state 2, state 3, and state 4. Figure 8 indicates that the average scores in state 4 which is with water-mediated interface are generally higher than the anhydrous interface in state 1. That is, with the presence of water as the interactive medium, users gave higher scores for various experience spots, covering the four major indicators of users' experience model. In

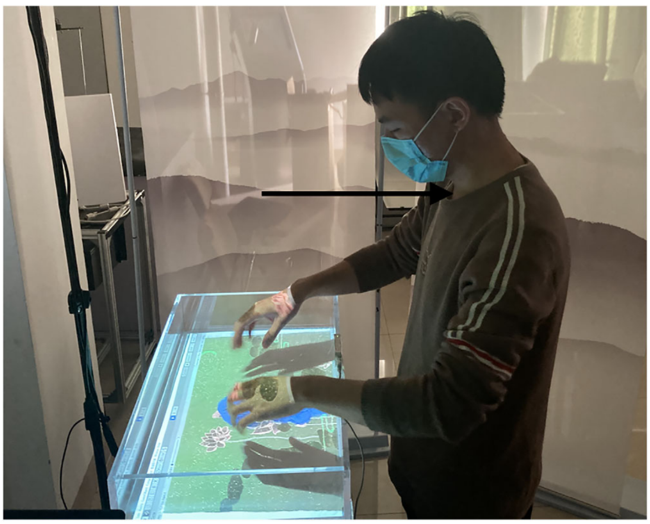

FIGURE 7 Experimental environment

TABLE 1 Design of control experiment

Interface	Gesture	Relevance
Anhydrous	Stir	Strong
Water-mediated	Hold still	Weak
Water-mediated	Hold moving	Medium
Water-mediated	Stir	Strong

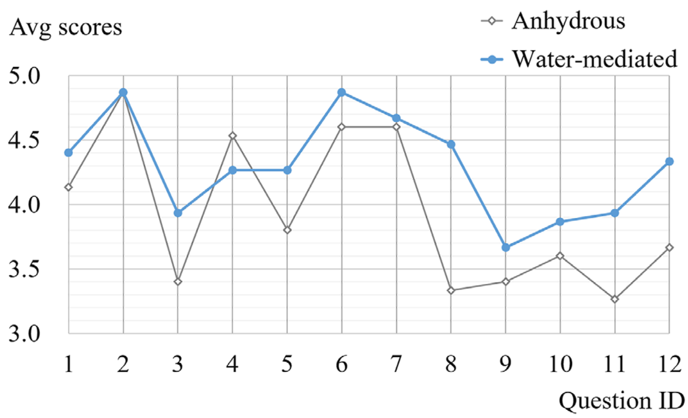

FIGURE 8 User scores in control experiment of interface conditions

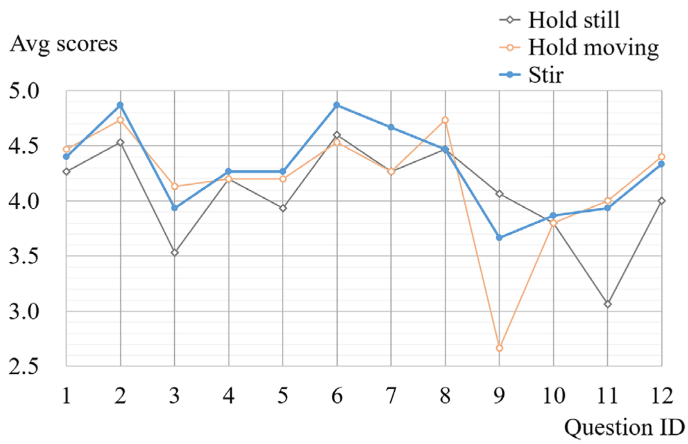

FIGURE 9 User scores in control experiment of relevance between interaction gestures and context

the control experiment of relevance between interaction gestures and context, the statistical results of user scores shown in Figure 9 shows that using the most relevant gesture has higher scores than the other two gestures, which are with weak or medium relevance to the context. There are a few spots where scores of the experimental group are lower than those in control groups, which is due to the deviation of users' understanding of the presented context.

In summary, when using interaction gestures with strong context relevance, the water-mediated interface is generally more capable of bringing users immersion than the traditional interface, and can effectively eliminate enhance concentration of users.

5.2 | User experience test

In this section, the functions and interaction effects of the Landscape Rippling system are verified. The experiment was conducted in a quiet and dark indoor environment. Fourteen participants filled out the questionnaire. According to the proposed user experience model, the evaluation spots in each aspect were designed in the questionnaire. The answer are divided into five levels, scoring from 1 to 5. In addition, to evaluate users' cognition changes about the core context after interaction, the participants were asked to fill two different questionnaires before and after the experience. By comparing the changes in users' cognition about the context before and after interaction, it could be inferred that whether the participants have established their understanding of the context after interaction. We collected and analyzed questionnaires to clarify the effectiveness of the proposed model.

5.2.1 | Immersion

As shown in Figure 10, none of the participants felt uncomfortable in the process of contacting water. Forty three percentage of users gave full marks, and all participants believed that the design of water-mediated operations are reasonable. Most participants were affirmative towards contacting water during interaction, which shows that water as an interaction medium can create a satisfying experience for users and enable users to get a sense of immersion in the interaction environment which conforms to their cognition.

Only 29% of users agreed with the feeling of being in the scene of the painting during interaction, 57% of the users hold neutral attitude, and 14% of the users disagreed. According to the interview, participants thought that it was because of the limitation of the display field. The limited observation range, the blurring of the image after being zoomed in, and the color style of original painting all lead to the lack of connection between the presentation context and participants, affecting users' sense of reality.

5.2.2 | Induction

As shown in Figure 11, all participants believed that the interaction process was attractive to them. It shows that the water-mediated interaction system could reasonably and effectively induct and attract users to participate in the interaction on the basis of providing a sense of reality and immersion. Sixty four percentage of participants believed that as the interaction progressed, they were constantly learning about the "A Panorama of Rivers and Mountains," which verifies the effectiveness of our system's progressive induction.

5.2.3 | Interaction

As shown in Figure 12, 64% of participants believed that their operations had received quick feedback, and only 7% of users believed that they did not receive feedback in time during the interaction. Eighty six percentage of participants believed that the interaction of the system is natural and intuitive, which shows that the water-mediated operations is consistent with user's expectations and experience. Meanwhile, 64% of participants believed that the water surface could be relevant to the river in the painting. The relevance between the interaction and the presented context is conducive to further promote users' imagination and resonance of the context.

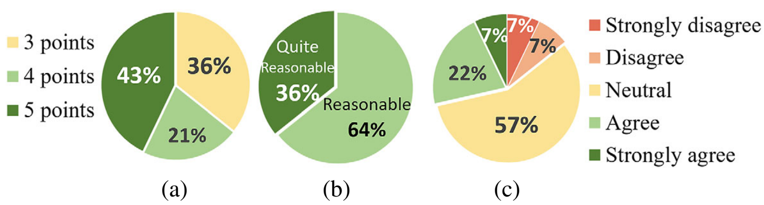

FIGURE 10 Statistics of UX in immersion part: (a) Please score your comfort level when contact the water. (b) Please score the reasonability of the water-mediated operations. (c) How do you feel that you are in the scene of the painting?

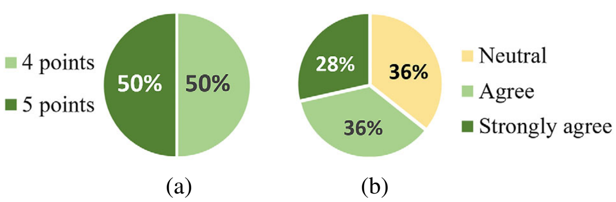

FIGURE 11 Statistics of UX in induction part: (a) How attractive do you think the experimental process is to you? (b) As the interaction progressed, do you feel that your understanding of this painting is gradually deepening?

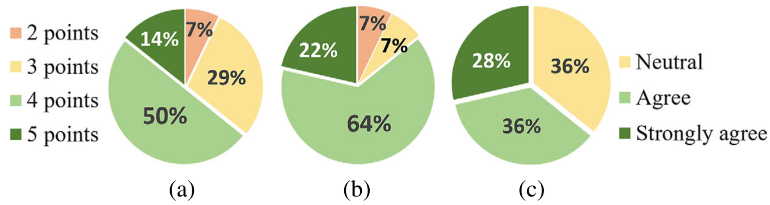

FIGURE 12 Statistics of user experience in interaction part: (a) Please rate the speed of feedback during the operation. (b) Please rate the naturality of the interaction in. (c) Does the water you just operated remind you of the river in the painting?

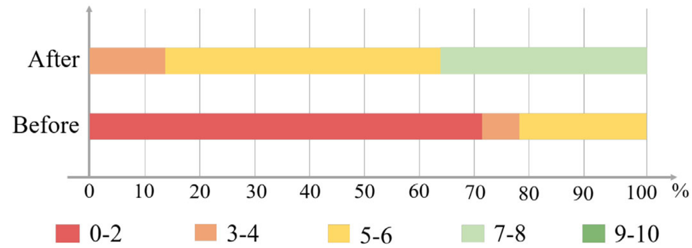

FIGURE 13 Comparison of users' self-evaluation of context cognition before and after the interaction

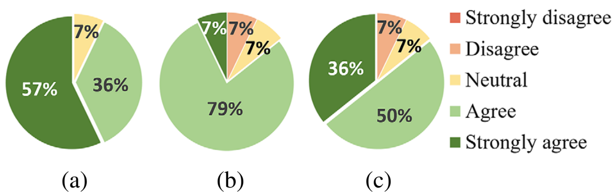

FIGURE 14 Statistics of user experience in imagination part: (a) After this experience, do you think your impression of this painting is more specific and vivid? (b) Do you think you know more about this painting after this experience? (c) Do you think this experience has narrowed the distance between you and the painting, and eliminated some sense of strangeness?

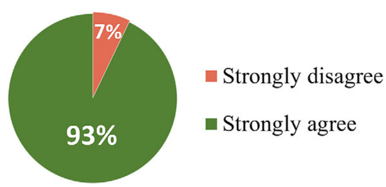

FIGURE 15 User feedback about applicable scenarios: Would you support to use such an interactive device in museums, exhibitions, and other scenes to help display exhibits?

5.2.4 | Imagination

Specially, question No. 11 and No. 12 were in the questionnaires before and after the experience respectively. The statistic results of these two questions in Figure 13 evident that participants' self-evaluation of understanding about the painting became deeper. Furthermore, the participants who weren't familiar with the painting before interaction performed greater improvements. The results show that this system effectively helped users building their understanding and cognition of the context.

According to Figure 14, 93% of users became more familiar with the context, while all users had more specific and vivid impressions of the painting after the experience. The results are shown in Figure 15. Ninety three percentage of users agreed that this system to be used in museums and exhibitions. The results also illustrate the advantages of water-mediated interaction compared to traditional painting display in terms of affinity and positive establishment of users' understanding of the painting.

In summary, the user test results are consistent with the design expectations. The system designed based on the proposed water-mediated interaction design model could eliminate the distance and narrow the boundary between users and context.

6 | CONCLUSION

The proposed context-based water-mediated interaction design model aims to eliminate the boundary between users and context. One water-mediated interaction system is designed based on the proposed model. The experiments conducted indicated that the water-mediated interaction system can achieve an immersive experience and effective connection between users and the context. This article focuses on exploring the design mode of water interaction and the corresponding user experience model, and obtain effective design and experience model verification in 15 test users. In the future, when expanding the water interaction paradigm to system-level application solutions, for example, applications for children[22] or people with disabilities, the interaction model would be improved and the water interaction paradigm will be expanded to more people when conducting functional-level and system-level tests. Besides, due to the transparency character of water and the limitation of space, the border of the interface would affect the experience. We would take it as a future work and adjust the experience of context to weaken the effect of border of interface.

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ORCID
Yingying She https://orcid.org/0000-0002-6770-4622
Baorong Yang https://orcid.org/0000-0002-2896-2506

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AUTHOR BIOGRAPHIES

Weiyue Lin is currently a graduate student at the School of Software and Microelectronics, Peking University. She received her bachelor's degree of digital media technology in 2021 from Xiamen University. Her research interests include user experience, human computer interaction, and mixed reality.

Haoran Hong is currently a master course student at Graduate School of Frontier Sciences, the University of Tokyo, Chiba, Japan. He received his bachelor's degree of digital media technology in 2021 from Xiamen University. His research interests include human computer interaction, media art, and extended reality.

Yingying She is an associate professor at School of Film, Xiamen University, China. She received her PhD degree in computer science in 2011 from Concordia University, Canada. Her research interests include human computer interaction, virtual reality, social robot, and computer graphics.

Baorong Yang is an assistant professor at the College of Computer Engineering, Jimei University, China. She received her PhD degree in computer science and technology in 2020 from Xiamen University. Her research interests include human computer interaction, virtual reality, and computer graphics.

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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