Augmented Reality Interaction Design and User Experience of Hand Puppet Historical Museum in Taiwan

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Abstract

Museum is a physical space for preserving cultural heritage and historical records. Due to the rapid development in global technology, information, communication, and digital technology over the last century, users have been enabled to explore museums via multiple approaches. As a result, the traditional museum experience is being challenged and undergoing transformation. Hand puppetry is one of ten Taiwanese arts with the potential to be listed in UNESCO's Representative List of Intangible Cultural Heritage of Humanity. In addition to development of human resources and educational promotion, passing down heritages in more widely acceptable ways is critical to preservation of this traditional art in modern times.

Thus, this study uses the display space in Li Tien-Lu Hand Puppet Historical Museum as the experimental field. By integrating iBeacon sensor technology and virtual reality technology into creation of a new experience of the hand puppetry culture, this study attempts to investigate the exploring behaviors and action strategies of visitors under the navigation of games. While seeking a balance between traditional display of artifacts and use of digital instruments, this study expects to facilitate two-way and spontaneous interactions between the museum and visitors. After implementation of the system, the ease of use of the system, user behaviors, and preferences are also analyzed. Finally, a gamifying museum with mixed reality experience design model is proposed.

Keywords: hand puppet; Gamifying museum; augmented reality; experience model.
1. Introduction

Li Lien-lu Hand Puppet Historical Museum in Sanzhi District, Taiwán, was established in 1996 by the late hand puppet master, Li Tien-lu, with an objective to promote and preserve the traditional art of hand puppetry. It is also the first museum of the hand puppet art in Taiwan. Based on the exhibits and spaces in this museum, we conducted an in-depth analysis of puppets, puppet heads, helmets, and performance stages, and then collaborated with this hand puppet historical museum to develop an interactive game app that integrates interactive designs and gamifying elements and uses radio frequency transmission technology (iBeacon) and cloud technology to provide a new mixed reality experience of the museum. The research results had been published in Traditional art, interactive technology, gamifying cloud: Cross-cultural hybrid puppetry new experience (Lin, Shih, & Wu, 2015).

Using technologies to provide interactive experiences has become a trend among major museums in the world that are seeking to create a stronger advantage through innovative operations (Ferrara & Sapia, 2013). For instance, British Museum is using virtual reality to attract adolescents who are generally less interested in historical objects. The museum has adopted a brand new way of promoting learning of historical objects by creating a virtual reality environment that allows young students to explore how objects were used in the Bronze Age (British Museum, 2015). The National Slate Museum in North Wales is the first in the world to apply iBeacon technology across the entire museum. In this museum, visitors are enabled to discover more about the collections using their own mobile devices. The 25 iBeacons deployed around the museum can offer individualized and real-time navigation as they walk around the museum. This technology can also be flexibly applied to support docent-led tours or voice navigations (National Slate Museum, 2014). The National Palace Museum in Taiwan uses a human-machine interactive device to display the Dwelling in the Fuchun Mountains. With this interactive device, visitors will be guided to discover delicate but unnoticeable composition details in the painting. The application of this technology embodies an integration of contemporary arts and classical arts and can increase visitors’ understanding and pleasure of appreciating static exhibits (National Palace Museum, 2011).

The above examples manifest that development of mixed reality interactions in museums is currently based on application of technologies and multimedia. However, little research has probed into the appropriateness of integrating technologies into museum navigation or the value of new visitor experiences that can be brought by the integration (Davies, 2001; Pérez-Sanagustín, Parra, Verdugo, García-Galleguillos, & Nussbaum, 2016; Sylaiou, Mania, Karoulis, & White, 2010). In this study, we will begin by designing a mixed reality exhibition
environment to examine the interactive process of the navigation. Through measurement of system usability, observation of operational behaviors of users, and visitor preferences, we will further analyze the mixed reality experience model that integrates the concept of gamifying museum and evaluate visitors’ experiences. The results can contribute to creation of new experiences of the hand puppet culture, continuous innovation of the museum, and better implementation of multimedia technologies in the future.

2. Literature Review

2.1 System Usability Scale
System usability scale (SUS) has been extensively applied to test of products, system programs, functional interfaces, and websites. Through quantitative analysis, it can produce reliable results with a sample of at least 12 people. It is a user experience-centered research method (Brooke, 1996). Consisting of 10 items, SUS can objectively evaluate a product or a system’s performance on usability and learnability. Previous research has found among nearly 500 studies of consumption or business related issues that the average SUS score is 68. This suggests that a product or system with a SUS score above 68 ranks above at least 50% of all the products or systems compared. Hence, SUS can be used as an indicator of both user acceptance and usability (Bangor, 2009). However, the original wording of the SUS 10 items may be interpreted differently from individual to individual (Lewis & Sauro, 2009). In addition to adding auxiliary explanations depending on participant needs, researchers are advised to use qualitative data such as behavioral observations and preference survey results while using the SUS. This can help them obtain substantive views and suggestions from subsequent modifications of the product or system.

2.2 Observation of operating behaviors
Behavioral observation is a method of collecting first-hand, nonverbal behavioral data from users through observation of causes and effects and continuous tracking of further development. Given a sample of 5 users, this method can capture up to 85% of behavioral phenomena. If given 15 users, this method can capture nearly 100%. With the increase of the sample size, more repeated problems can be detected. Hence, it is not necessary to use a large sample to identify common problems or behavioral phenomena (Nielsen & Landauer, 1993). Museum visitors’ behaviors are mainly affected by the environmental factors of the museum. Even if museum visitors come from widely varying backgrounds, their behaviors generally conform to expectable models (Falk & Dierking, 1992). In other words, if museum operators
have better understanding of the expectable behaviors of their visitors, they can provide more satisfactory services. However, visiting route, lighting, content explanation, large interactive facilities, color, and atmosphere are still considered the primary environmental factors that affect museum visitors’ behaviors. As to the behaviors of visitors in museums that provide individualized multimedia-based navigation, more research is needed.

2.3 Preference for traditional display or digital interactions

In today’s museum exhibition practice, application of technologies is so prevalent that new display methods or devices are being invented from time to time (Hashim, Taib, & Alias, 2014). The goal is certainly to deepen visitors’ impressions and induce their responses, and further recontextualize exhibits for audiences (Waidacher, 2001). Exhibit type is one of the important factors affecting visitor behaviors.

Traditionally, museum exhibits are classified by text, post, cabinet size, lighting style, circulation route of the audience (Neal, 1976; Piccablotto, Aghemo, Pellegrino, Iacomussi, & Radis, 2015) or by presentation method (i.e. static or dynamic)(Miles, 1982). With increasing application of technologies, more and more museums classify their exhibits by presentation technology into lighting, audio, visual, and computer (Bell, 1991; Piccablotto et al., 2015). According to the Natural History Museum in London, the benefits of using multimedia to aid exhibition include (1) attract visitors, (2) retain visitors’ attention, (3) arouse visitors’ existing knowledge, (4) diffuse information to visitors, (5) encourage responses, and (6) provide feedbacks (Gosling, 1981).

While traditional display methods have their irreplaceable value, using technologies to add value to museum exhibitions has become a trend (Eghbal-Azar, Merkt, Bahnmueller, & Schwan, 2016). However, little research has evaluated the appropriateness of integrating digital technologies into traditional display methods. Through a survey of visitor preferences for display methods, museums can predict visitor responses and choices and further plan a suitable design of mixed reality to provide visitors the best display of exhibits and services.

3. Design Process

3.1 Building a mixed reality interactive exhibition hall

In this study, the research site was the left exhibition hall on the second floor of Li Tien-lu Hand Puppet Historical Museum. There were about 30 display cabinets of different types in this exhibition area. After evaluation with our design concept and research needs, we selected only 12 cabinets to install iBeacon and designed the circulation route for visitors based on pre-arranged tasks (see Figure 1). Our design was to allow visitors to engage in a series of
interactive games after installing a specially-designed APP on their own mobile device or a public mobile device borrowed from the service counter. The ending of the game would vary depending on visitors’ choice in each stage, so the gamifying museum could be more interesting and bring a new experience of the hand puppet culture to visitors.

Figure 1. The visitor circulation route in the mixed reality space

3.2 Research subjects and methods

The subjects were participants in a two-day Hand Puppet Workshop held on Aug 1~2, 2015. The participants included 20 teachers and 8 students at junior high or elementary school level. On the first day of the workshop, participants were first introduced to hand puppets created using 3D scanning and printing technologies. On the second day, they were taken to visit Li Tien-lu Hand Puppet Historical Museum, where the museum docent first gave them an introduction of the museum and basic skills of hand puppetry. Later, they were asked to fill out a pre-test questionnaire called “Preferences for Museum Exhibits”. The survey result could provide an insight into their opinions about the types of exhibits in museum and be used for subsequent analyses. To minimize human interference, the number of visitors in each exhibition space had to be controlled. The participants were divided into three groups, and the three groups had to take turns to experience the interactive mixed reality APP using a Tablet PC or mobile device. Each group would be accompanied by an observer, who would record the various behaviors of the participants as they used the navigation system. After all the three
groups finished the experimental tour, they were asked to fill out a post-test questionnaire consisting of the SUS and questions that required them to provide descriptive suggestions based on personal experiences and perceptions.

3.3 Research instruments

The instruments used in this study included the SUS, a behavioral observation scale, and a preference questionnaire. The SUS is a 10-item questionnaire developed by John Brooke. In each item, there are five response options, from “strongly agree” to “strongly disagree”.

The behavioral observation scale is intended to observe the types of behaviors that may arise during the system usability assessment (Lin & Fan, 2013). In this study, these behaviors were classified into “operational mistake”, “misunderstand the question”, “hesitate during operation”, “fail to accomplish”, “raise questions”, “system problems”, “failed trials”, and “cabinet search model” which was added to record participants’ performance in the mixed reality space. These behavioral types were respectively explained in Table 1. Participants’ behaviors were recorded using a checklist.

Table 1. Definition of behavioral types in the mixed reality space

<table>
<thead>
<tr>
<th>Code</th>
<th>Type</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Operational mistake</td>
<td>The user does not follow the suggested operational procedure.</td>
</tr>
<tr>
<td>B</td>
<td>Misunderstand the question</td>
<td>The user’s actions do not conform to the task instruction.</td>
</tr>
<tr>
<td>C</td>
<td>Hesitate in operation</td>
<td>The user stays in the same screen and ceases his/her operation for more than 3 seconds; The user’s facial expression shows that he/she is in confusion.</td>
</tr>
<tr>
<td>D</td>
<td>Fail to accomplish</td>
<td>The user terminates the task before accomplishing it.</td>
</tr>
<tr>
<td>E</td>
<td>Raise questions</td>
<td>The user feels unable to carry on the task and seeks assistance by asking questions.</td>
</tr>
<tr>
<td>F</td>
<td>System problems</td>
<td>The system shows error messages or gives abnormal responses due to network or system problems.</td>
</tr>
<tr>
<td>G</td>
<td>Failed trials</td>
<td>The user randomly clicks on items that are not directly related to the task. This clearly shows that the user does not know what the next step he/she should take and simply attempt to solve it through trials.</td>
</tr>
</tbody>
</table>
The user searches for the next sensor-embedded cabinet by number.

The user searches for the next sensor-embedded cabinet by instructions on the APP.

The user searches for the next sensor-embedded cabinet by following others.

The preference questionnaire was intended to understand participants' preferences for the “traditional display” model and the “digital interactions” model as well as expectations for services that a digital museum navigation system should offer. This questionnaire was designed based on the Interactive Experience Model proposed by Falk & Dierking (1992) and previous research’s views on traditional display and digital display of exhibits (Neal, 1976, Miles, 1982, James Bell, 1991, & Gosling, 1981). It consists of 11 items, including (1) intuitively understand the content of the exhibition; (2) understand the details of the exhibition; (3) see the real collections; (4) have in-depth understanding of the exhibition, (5) see the collections freely, (6) see the collections in interesting ways, (7) have strong visual experiences; (8) novel experiences are available in the exhibition; (9) share with others easily, (10) search for needed information easily, and (11) the exhibition offers high interactivity. All the items were designed to be rated on a five-point Likert scale.

4. Results

4.1 Analysis of SUS results

The SUS items were rated on a five-point Likert scale, from 1 point to 5 points. The odd-numbered items were positive questions. For these items, the score contribution was the scale position minus 1. The even-numbered items were negative questions. For these items, the score contribution was 5 minus the scale position. The overall SUS score was obtained by multiplying the sum of the score contributions by 2.5. This SUS score ranged between 0~100. The mean score for each item and the overall SUS score are shown in Table 2.

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
<th>SUS Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>I think that I would like to use this system frequently.</td>
<td>4.1</td>
</tr>
<tr>
<td>2.</td>
<td>I found the system unnecessarily complex.</td>
<td>2.5</td>
</tr>
<tr>
<td>3.</td>
<td>I though the system was easy to use.</td>
<td>3.9</td>
</tr>
<tr>
<td>4.</td>
<td>I think that I would need the support of a technical person to be able to use this system.</td>
<td>3.2</td>
</tr>
</tbody>
</table>

Table 2. SUS results
5. I found the various functions in this system were well integrated. 3.8
6. I thought there was too much inconsistency in this system. 2.4
7. I would imagine that most people would learn to use this system very quickly. 4.3
8. I found the system very cumbersome to use. 2.3
9. I felt very confident using the system. 4.3
10. I needed to learn a lot of things before I could get going with this system. 2.4

**Overall SUS score** 68.8

The overall SUS score was 68.8, or 52% after converted to a percentage. This suggests that the system's usability score was higher than the average 68 points (50%), and integrating mixed reality technology into Li Tien-lu Hand Puppet Historical Museum was acceptable by visitors.

Among the odd-numbered positive items, Item 7 (I would imagine that most people would learn to use this system very quickly) and Item 9 (I felt very confident using the system) received the highest average score, indicating using Tablet PC or other mobile devices as a medium of mixed reality interactive navigation is appropriate, because visitors can operate the APP based on their past experience of using the devices and become familiar with the gamifying museum model quickly. Using a familiar carrier device for navigation is critical to the SUS score. It can reduce anxiety and fear in users when using a new system and allow them to experience the system with confidence.

Among the odd-numbered positive items, Item 4 (I think that I would need the support of a technical person to be able to use this system) received the highest score, indicating that when integrating a technological innovation into the mixed reality space of museum, whether visitors can intuitively get involved in the interactions is important. The experience model should be self-descriptive. It should be designed in a way that allows users to know how to operate the system in their first use of the system. It should enable first-time users to identify or perceive through self-system the attributes, cultural factors, value, functionality, practicality, and other information the designers have intended to express by the system’s design and interface (Almquist & Lupton, 2010). When the self-descriptive property of the system conforms to user perceptions, users will engage in voluntary exploration of the museum. Even without occasional or additional explanation or assistance, they can naturally gain the experiences that the mixed reality space is designed to offer.
4.2 Observation of operational behaviors

Users’ behaviors of operating the system were classified into 10 types as listed in Table 1. Each user might have multiple behavioral models in the mixed reality space. Through calculation of the frequency of each type of behavior, the strengths and weaknesses of the system could be identified. The result could fill the gap of the SUS in capturing the usability of each system function. The frequency statistics are illustrated in Figure 2.

![Frequency of each behavior](image)

Figure 2. Illustration of frequency of each type of user behavior

From the 28 participants, it was found that “search by number” and “raise questions” occurred more frequently. Hence, the causes of these two types of behaviors had to be examined.

In the mixed reality exhibition space, the tasks were arranged with consideration of the locations of the cabinets. Users were expected to visit the cabinets according to the order of tasks. The mobile APP would provide users the number of the next cabinet to visit. Users had to find the correct cabinet before they could move on to the next game. This shows that users’ decision over moving route and behavior of moving were affected many times by the instructions given by the APP. They unknowingly followed the circulation route we have originally designed for the gamifying museum. This design of circulation route could be a reference for exhibition designers to overcome the difficulty of navigating visitors in large exhibition spaces or spaces without a specific movement direction. However, this model also reduced users’ exploration of the museum. Users would habitually follow the instructions offered by the APP. They seldom had exploratory behavior or stopped at certain objects out of curiosity. In the future, the directions on circulation route should be progressively reduced to provide users an opportunity to choose exhibits to appreciate and explore on their own.
The question raising behavior occurred as many as 41 times. This is consistent with the relatively high score for SUS Item 4 (I think that I would need the support of a technical person to be able to use this system). This implies that the interface design is not intuitive enough or users were unfamiliar with iBeacon sensing technology. The loading time of data also affected users’ experience and willingness to use. In Akamai and Gomez’s research, nearly half of the users expected that data could be loaded within 2 seconds on their mobile device, and they might lose interest, patience and even become anxious when a site cannot respond in 3 seconds (Jacob, 2011). Therefore, it is necessary to let users have sufficient understanding of the system's operations so as to avoid repeated “question-raising” behaviors. One of the ways is to provide an introduction of the system design before they enter the mixed reality interaction space. Posters, unified verbal explanations or APP-embedded explanations can be used. The “user instruction” should be viewed as a part of the museum experience. This can prevent users from interacting with the museum in a state of confusion.

4.3 The preference questionnaire
Below shows the users’ preferences for the two types of museum exhibition models, namely “traditional display” and “digital interactions”. All the items were rated on a five-point Likert scale. The first and last three items ordered by average score are as follows:

Table 3. Analysis of user preferences for the traditional display model and digital interaction model

<table>
<thead>
<tr>
<th></th>
<th>Preferred factors of digital interactions</th>
<th>Average score</th>
</tr>
</thead>
<tbody>
<tr>
<td>First three factor</td>
<td>See the collections in interesting ways</td>
<td>4.4</td>
</tr>
<tr>
<td></td>
<td>Novel experiences are available in the exhibition</td>
<td>4.3</td>
</tr>
<tr>
<td></td>
<td>The exhibition offers high interactivity</td>
<td>4.2</td>
</tr>
<tr>
<td>Last three factors</td>
<td>Share with others easily</td>
<td>3.7</td>
</tr>
<tr>
<td></td>
<td>See the real collections</td>
<td>3.6</td>
</tr>
<tr>
<td></td>
<td>See the collections freely</td>
<td>3.5</td>
</tr>
<tr>
<td>First three factor</td>
<td>Preferred factors of traditional display</td>
<td>Average score</td>
</tr>
<tr>
<td></td>
<td>See the collections freely</td>
<td>4.7</td>
</tr>
<tr>
<td></td>
<td>See the real collections</td>
<td>4.5</td>
</tr>
<tr>
<td></td>
<td>Intuitively understand the content of the exhibition</td>
<td>4.2</td>
</tr>
</tbody>
</table>
As shown in Table 3, there is a complementary nature between the traditional display model and the digital interactions model. Presenting real objects in the exhibition can increase the value of attending a museum for visitors and shorten the distance between visitors and collections and even the entire museum. Hence, in application of mixed reality in museum exhibition, the focus can be placed on the core advantages of each exhibition model. The advantages of the traditional display model include “See the collections freely”, “See the real collections”, and “Intuitively understand the content of the exhibition”. The advantages of the digital interactions model include “See the collections in interesting ways”, “Novel experiences are available in the exhibition”, and “The exhibition offers high interactivity”. Exhibition designers can use these six items as a guideline to design an optimal combination of virtual and reality elements in the exhibition space and bring the best exhibition and services to visitors.

As to the digital museum navigation system, users’ evaluation on a five-point Likert scale is as follows: 4.54 points for building a virtual map, 4.46 points for building a cross-domain platform, 4.18 points for recording data in the cloud. All the scores were higher than the average 3 points. For future developers of digital navigation systems, these items can be viewed as the required functions or the functions to be added in the systems.

5. Conclusion and Suggestion
In this study, we used the SUS, the behavioral observation scale, and a preferences questionnaire to explore the appropriateness of a mixed reality exhibition model implemented in a hand puppet historical museum. The findings are summarized as follows. These findings can be a reference for other museums when planning to implement the mixed reality navigation model.

(1) The SUS test showed that the gamifying museum navigation model implemented in Li Tien-lu Hand Puppet Historical Museum was a mixed reality navigation technology accepted by users.

(2) The gamifying museum navigation model affected users’ decision over moving route. It could be used as a basis of circulation route design. However, it could also reduce users’ spontaneous exploration of the museum.
(3) Before implementation of any technological innovation, it is necessary to inform users of how the system works first. Otherwise, users may raise questions repeatedly. Hence, it is advised to view “user instructions” as an integral part of users’ museum experience. This can avoid them from interacting with mixed reality in a state of confusion.

(4) The traditional display model and the digital interactions model are complementary. Hence, the core advantages of the two models can be emphasized in the application of mixed reality in museum exhibition. The advantages of the traditional display model include “See the collections freely”, “See the real collections”, and “Intuitively understand the content of the exhibition”. The advantages of the digital interactions model include “See the collections in interesting ways”, “Novel experiences are available in the exhibition”, and “The exhibition offers high interactivity”. These advantages can be utilized to design an optimal combination of virtual and reality elements for visitors.
References


