
Experiences with RFID-based interactive learning in museums

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Abstract: Tourism plays an important role in the economies of many countries. Tourism can secure employment, foreign exchange earnings, investment and regional development. To attract more tourists and local visitors, many stakeholders such as natural parks, museums, art galleries, hotels and restaurants provide personalised services to meet individual needs. With the increasing number of tourists comes an increased demand for guides at education-oriented leisure centers. Each provided needs unique way to present their services. In this study, these educational leisure centres are coarsely divided into art and science. This paper introduces the architecture of the proposed guide system including a PDA-based recommendation guide for art museums and an Radiofrequency identification-based interactive learning system using collaborative filtering technology for science and engineering education. Evaluations of the two systems reveal that the system inspires and nurtures visitors' interest in science and arts.

Keywords: collaborative filtering; data mining; digital learning; guide system; learning assistant service; RFID.

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1 Introduction

One purpose of museums and galleries is to improve the awareness for a particular subject, provide inspiration and general education. Many such facilities do not sufficiently manage to captivate the audience and visitors consequently do not return. One problem is that there may be a lack of trained guides. Guides are sometimes only offered at certain times and only for groups of visitors. A good guide can make all the difference between a mediocre and a memorable museum experience as a talented guide is able to captivate the audience with their stories.

One solution often adopted is to let visitors borrow devices including headsets, handhold controllers and audio playback devices. Pre-recorded records are then used to present exhibition-related introductions to the visitors. However, static audio is not interactive and may be too uninteresting for very young visitors with a short concentration span. Another problem is that some visiting routes may be blocked by visitors grouped around other popular exhibitions.

Although most people are aware of the importance of science, students often find science boring and uninteresting as traditional textbooks only provide static information. Students who achieve better usually have practical experiences related to the subject or have been exposed to interactive learning tools.

In order to make the museum guide experience more dynamic, multimedia content and tests (learning objects) designed by educators who are experts in the specific domains is combined with an interactive learning assistant. The learning assistant is based on a visitor's personal profile (Youji, Wakita and Yano, 2002; Puntheeranurak and Tsuji, 2005; Tan, Yao and Xu, 2006; Chen et al., 2007), radiofrequency identification (RFID) technology, where each visitor carries a card with an embedded RFID tag with a unique identification number, collaborative filtering and a history of learning records are combined to provide a personalised learning service (Brown, Bovey and Chen, 1997; Kim et al., 2004; Huang and Tsai, 2005). Therefore, a learning system based on RFID is proposed to provide personalised learning service for promoting science education development. The service is called the *Hands-Free Interaction Guide System*.

Users obtain learning materials and questions using their RFID-equipped membership card by touching the sensor installed at the viewing kiosks (Bellotti, Berta and Margarone, 2002) to obtain the personalised learning service. The system provides a route recommendation derived from the user's browsing history (Davies et al., 2001; Facer et al., 2004; Derntl and Hummel, 2005). This system has been in active use at the National Science Education Center (NTSEC) in Taipei, Taiwan, since October 2007.

Museums or exhibition centres often set a series of routes through the exhibits (Derntl and Hummel, 2005). Consequently, popular exhibits may become congested with too many visitors. To tackle these limitations, a guide system running on handheld devices is proposed. The proposed guide system recommends exhibitions to users by the means of data mining.

This paper is structured as follows. Section 2 introduces the motivation and selected components of interest from two systems. The strategy for generating personalised interactive contents by collaborate filtering is illustrated in the third section together with a brief introduction to RFID technology and architectures. Section 4 presents an evaluation of the 'Hands-Free Interaction Guide System' based on the visitors of different age groups. Some recommendations about 'Li Mei-Shu Guide System' are also presented in the section. Section 5 concludes the paper.

2 Motivation and technologies

Kiosks and handheld devices are two useful platforms for providing information to users. They can be used both indoor and outdoor and with both static and dynamic exhibitions.

The goal of the system is to make science and art education more attractive. Visitors are not always able to be given a guided tour at the education centre. However, the learning outcome is related to the skills of the guides that explain the exhibitions. In order to provide a self-learning environment, interactive kiosk were designed to provide relevant content according to age when the visitors are browsing by themselves. The objective was to replace the manual guide. Guides use various pedagogical strategies to make the contents interesting. Different age groups are approached differently and students are asked questions to stimulate the learning process. In order to provide personalised learning, RFID technology is used to associate each user with a unique identification.

Tourists may expect inspiration and fun instead of pure knowledge when visiting art museums. In order to guarantee that most tourists can enjoy the stories behind artwork some tools are needed to help them browse the background and provide related information of exhibitions when they want to gain a deeper understanding about specific exhibitions. In order to make operations of the system as friendly as possible, RFID technology is exploited to bridge artefacts, their background stories and related artefacts. Moreover, the handheld device approach is especially suitable for space constrained venues where there is no space for information kiosks in the vicinity of the artefacts. The small assistants are portable and the approach scales unlike information kiosks that can only be used by one person at the time. In our implementation, PDA were used as the handheld platform.

2.1 Radio frequency identification

The RFID technology emerged in the 1980s (Haverkamp and Gauch, 1998; Landt, 2005). RFID comprises a reader and a tag. The reader receives the identity of an object from the embedded tag wirelessly using radio waves and then compares it with the corresponding identification stored in the database. When a match is found, detailed information is retrieved.

Owing to its wide applicability, convenience, wireless information transmission, robustness to the environment and the possibility of performing multiple reads and writes, RFID technology has been successfully applied in a diverse set of domains, including logistics, healthcare, small value payment, education, business or science and personal ID (Weinstein, 2005; Roussos, 2006). Wal-Mart is one well-known case. Researchers have also experimented with embedding a small capsule containing a RFID tag in the arm for physical access control.

In our implementation, an embedded RFID membership card is used to uniquely identify visitors. A trial card is also provided to occasional visitors, but with limited functionality as it cannot be used to gather personalised information and browsing history. When the visitors touch the kiosk sensor with their cards collaborative filtering is used to make recommendations (Billsus and Pazzani, 1998). Collaborative filtering is different to rule-based mining and classification (Wen and He, 2006; Xi-Zheng, 2007). Our science education centre implementation has a range of interactive displays, such as simple electric circuits, vacuum discharge and solar batteries. Some of the displays are permanent and others are only on display temporarily for a particular theme or exhibition.

Similarly, in our Li Mei-Shu art gallery guide system a PDA equipped with a RFID reader receives the identification from the vicinity of the artefact. Tourist holds the device close to the tag, and then the detailed contents of the exhibition are downloaded via a wireless network or a local database. This arrangement makes changes simple and cost-effective, especially for exhibitions that are modified frequently.

2.2 Collaborative filtering

Collaborative filtering (CF; Claypool et al., 1999; Gokhale et al., 1999; Good et al., 1999) utilises the browsing profile of visitors as building blocks for making recommendations. Such information is gained by the browsing activities of visitors who have similar or related interests and learning behaviours. Item-based filtering is used in the current implementation. The purpose of the adopted methodology is to connect different science subjects based on visitor selections and educators' pre-defined rules based on their teaching experiences. The selection records of visitors can be used to establish associations between subjects.

For example, the interactivity kiosk collects visitors' responses to a learning test, that is, wrong or right answer (Haverkamp and Gauch, 1998; Zaiane, 2002; Furukawa et al., 2003; Ponnusamy and Gopal, 2006). After connecting each subject covered by the visitors, their learning habits are estimated. Thus, the methodology can retrieve a relationship to other subjects when the visitor is learning a specific subject.

The following equation is used for calculating the similarity of learning efficiency between subjects:

$$\text{sim}(a, b) = \text{corr}_{ab} = \frac{\sum_{j=1}^N (p_{aj} - \bar{p}_a)(p_{bj} - \bar{p}_b)}{\sqrt{\sum_{j=1}^N (p_{aj} - \bar{p}_a)^2} \sqrt{\sum_{j=1}^N (p_{bj} - \bar{p}_b)^2}}, \quad (1)$$

where p_{aj} represents subject a 's rating by visitor j and \bar{p}_a is the mean rating across all visitors. Then, the most suitable subject to be recommended is:

$$\text{Score}(c, j) = \frac{\sum_{i \in H} (p_{ij} - \bar{p}_i) \times \text{sim}(c, i)}{\sum_{i \in H} \text{sim}(c, i)}. \quad (2)$$

As illustrated in Table 1, subjects viewed by the visitor are assigned 1 while the subjects are assigned 0 if they were not viewed. In this example, there is a high similarity of learning between subjects B and E. Therefore, any visitor who viewed subject B but has not viewed subject E should be recommended subject E. After the recommendations are calculated, the system suggests that visitor 5 views subject E after viewing subject B.

The system can also employ prefixed rules based on the recommendation of educators and exhibition managers. This may be useful for suggesting browsing routes for new exhibitions that lack a browsing history. The browsing records of visitors and their positions have to be continually monitored for the suggestions to be valuable (Bahl and Padmanabhan, 2000).

The Li Mei-Shu Guide System employs a similar strategy. Usually, galleries position fine arts according to different categories such as photographic collections, Chinese ink-water paintings, oil paintings or ancient architectures in different zones. Alternatively, artefacts from different categories are mixed and presented together to form some particular theme. The shortest routing path for browsing exhibitions has become an important topic. The main goal of the recommendation system is to customise better routes for visitors.

While browsing exhibitions in one zone, a tourist may miss some particular artists' works belonging to different themes but with similar characteristics. A better guide route is therefore recommended based on item-based CF method.

The exhibit centre first gathers all the information about what the tourists have viewed. Then the relationships between the browsed items can be identified. More related exhibitions can therefore be recommended to the tourists when they browse particular items. The CF method first identifies tourists with similar interests in exhibitions as the target user. The recommendation is then issued assuming that the groups of visitors have similar interests in exhibitions. The CF method continues identifying the correlations between items within the visitors' groups. Once the correlations have been found, potential exhibitions are recommended to the visitors. The preference similarity of exhibitions between the visitors is calculated as in Equations (1) and (2), where p_{aj} is user a 's rating of exhibition j and \bar{p}_a is the mean rating of the exhibitions.

Table 2 illustrates the CF method. Exhibitions browsed by a user are marked with 1; otherwise it is marked with 0. According to this table, tourist A has high preference similarity to tourist D. Hence, any exhibition browsed by tourist A not yet browsed by tourist D should be recommended to tourist D.

Table 1 Example of collaborative filtering

	<i>Visitor 1</i>	<i>Visitor 2</i>	<i>Visitor 3</i>	<i>Visitor 4</i>	<i>Visitor 5</i>
Subject A	0	1	0	0	1
Subject B	1	1	0	1	1
Subject C	0	0	1	0	0
Subject D	1	0	0	0	0
Subject E	1	1	0	1	0

Table 2 Another example of collaborative filtering

	<i>People</i>	<i>Scenery</i>	<i>Bird</i>	<i>Flower</i>	<i>Mountain</i>
Tourist A	1	1	0	0	1
Tourist B	0	1	0	1	1
Tourist C	0	0	1	0	0
Tourist D	1	1	0	0	0
Tourist E	1	0	0	1	0

3 System components and architecture

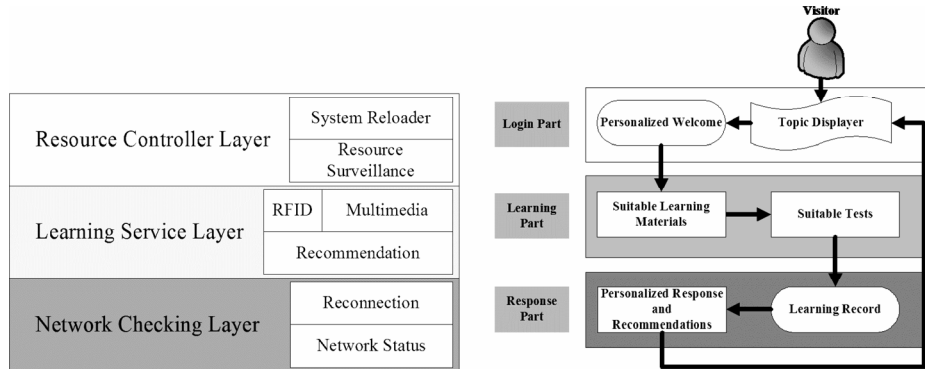
3.1 *The Hands-Free Interaction Guide System*

To ensure adaptability, expansibility and stability, the Hands-Free Interaction Guide System has been divided into two components, namely the interactive kiosks and the central server. Our implementation covers 20 different science subjects distributed across three floors. Each interactive kiosk covers a single subject. These 20 kiosks are connected to a single central server that collects all the browsing records and calculates personal learning profiles for the visitors. The personal learning history can later be accessed from the website using a membership account.

Physical constraints forced us to use wireless network connections for most of the interactive kiosks. Consequently, to ensure stability and high quality of service a three-layer control design was adopted to prevent the learning service from crashing. As illustrated in Figure 1, the network reconnection checking module is located at the first layer to ensure that all connections are running correctly. The module attempts to reconnect to the server cyclically whenever a network connection is broken. A reconnection module is deployed in the network checking layer to resolve wireless network interruptions, prevent resource exhaustion and prevent wireless devices from overheating.

Network failures usually occur unpredictably. Still, the service kiosk must maintain the users' learning records. The reconnection module therefore notifies the learning service layer that uploads the learning records once the connection is available. This procedure guarantees that visitors can retrieve their records despite network failures.

Figure 1 The architecture of the Hands-Free Interactive Guide System (left) and the system flow (right)



The network checking layer ensures a stable and robust connection. In the second layer, the learning service provides teaching materials and tests according to the visitor's profile. Every kiosk is equipped with an embedded RFID reader near its screen. The reader senses the RFID tag that is embedded in the visitor's member card for verifying the visitor's profile that is received from the server. The server recommendation engine selects suitable learning materials. For each subject, there are three levels of learning materials. Each level comprises unique multimedia contents and tests. Visitors view the contents using a trackball or a touch panel. In total, the system contains 60 independent digital learning objects (20 kiosks have three levels each). The system automatically selects a suitable level according to the visitor's profile, but the visitor can also choose a different level manually. Figure 2 shows the visitors' name after login and the user may select the level manually. After the visitor has watched the media, the system asks the visitor three questions to assess the learning behaviour. These personal records are stored on the server and used for subsequent recommendations.

Although steps are taken to ensure a stable network link, the system may run out of CPU resources. To overcome this problem, a resource controller is implemented in the third layer. This controller cyclically monitors the system resource and restarts the learning service when the resource utilisation exceeds a given threshold. Through experimentation, 80% of CPU usage sustained for 20 sec was found to be a suitable threshold.

This three-layer design is shown in Figure 1. Each layer is subdivided into several sub-objects. The first layer comprises the reconnection and network status monitor. The RFID, multimedia and recommendation modules are implemented on the interactive kiosks and the server. The third layer contains the system reloader that restarts the service and resource surveillance that invokes the reloader.

The main service is located in the learning service layer. In this layer, the personalised learning procedure is designed by educators and provided automatically by the server. The learning system architecture is shown in Figure 1 (left). It is divided into three main parts, namely login, learning and response. The components enclosed by rectangles and ellipses are located on kiosk and server, respectively. Initially, visitors log into the system using their member card.

Figure 2 Screenshots from the information kiosk: (a) welcome, (b) celebration, (c) level selection, (d) video, (e) learning test, (f) recommendation, (g) learning record and (h) visitor's response



When the visitor is logged in, a personalised welcome message is sent from the server. It is generated according to the unique ID containing the visitor's name and customised message, for example, birthday, Christmas greeting, etc. The server also identifies the materials and tests that are most suitable for the visitor. The learning record is sent to

the server and stored. The interactive kiosk will then switch to the welcome screen to await the next visitor. The process is illustrated in the Figure 1 (right).

The interactive kiosk includes an RFID reader, display and wireless device. Each kiosk pre-stores all the learning materials to avoid any unpredictable crash. Each kiosk stores 60 videos and up to 600 questions. To prevent malicious attacks and damage, each service kiosk is made of resistible materials and the display panel is protected by a transparent plastic plate.

The server stores the visitor's learning history in the learning material database and responds with the recommendations. A single server is capable of serving more than 100 interactive kiosks based on the available network bandwidth and the processing power of the machine. In this specific case, the implemented server only serves 20 kiosks.

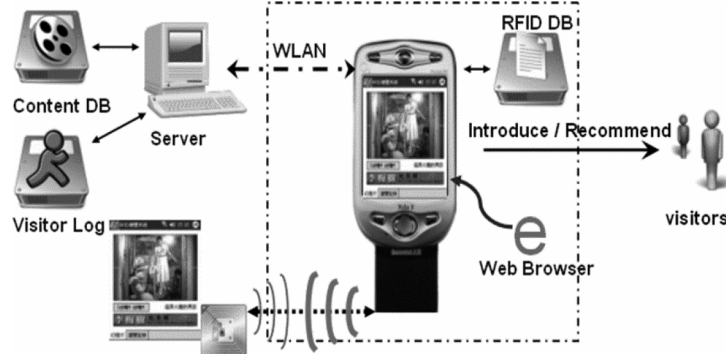
A series of multimedia learning objects were designed in collaboration with a team of educators. An example of the personalised welcome message is shown in Figure 2 (a and b), respectively. The system also retrieves the profile of the current visitor to provide more services as shown in Figure 2b. The kiosk is configured for several celebration events including national birthday celebration, Chinese New Year, father's day, mother's day, Christmas, etc.

The system selects one level from the three available learning materials, depending on the visitor's historical record. Each level contains three different questions that are forwarded to the user after an instructional video is played. The level selection and a teaching example are illustrated in Figure 2 (c and d). These questions are devised by educators. In most cases, the visitors prefer to watch the video with rich anime rather than textual descriptions. Thus, most learning materials are expressed by anime to attract the visitors' attention. However, not every subject can be easily transformed to simple anime and sometimes a few textual materials are still used for learning at some specific exhibitions.

Figure 2e shows the question interface. Responses are stored in the server database. When the learning session is complete, the kiosk retrieves the visitor's e-mail account from the database and asks whether to send the learning records to the visitor. The user can choose whether an e-mail is to be forwarded with information about the visit. A website is provided that allows the visitors to subsequently browse and download visitor-specific items related to their museum visit. These learning histories can later be browsed at home through a web-based interface. Recommendations are shown in Figure 2f. The learning history of the last visit can also be sent via e-mail (see Figure 2g). Figure 2h shows a questionnaire for gathering comments from visitors.

3.2 *Li Mei-Shu Guide System*

A traditional audio-tape guide can only provide static contents. To enhance the quality of interaction, the proposed guide and recommendation system is implemented on a handheld device. The RFID reader, wireless network and EPC class 1 electronic tag allow the PDA-based platform to support a dynamic and interactive learning model. ISO 15693 passive electronic tags are attached to the information plaque of each exhibition. When a user holds the PDA equipped with a RFID reader close to the tag, the detailed contents and recommendations of the exhibition is downloaded via the wireless network or local database. In addition, personal customised guidance is recommended to individuals according to their association rules-based preferences. The following sections describe the components of our system.

Figure 3 The hardware architecture of the Li Mei-Shu Guide System

The architecture of the proposed system is depicted in Figure 3. Two main components in the system include the client-side PDA and the server-side database. The PDA comprises the guide's user interface with a RFID reader. The server-side database maintains the stored visitors' log files.

3.2.1 The PDA-based guide system

The PDA system shown in Figure 4 (left) comprises eight modules. The corresponding functions include the *RFID reader module*, which emits radio waves for reading the passive electronic tag. The tag ID is read as the identification to the exhibition. The *RFID identification module* sends control command to the RFID reader module. When the RFID reader receives the response messages and identifies the corresponding ID, the relevant contents can be accessed directly from the local database or downloaded from the mobile communication module. Next, the *RFID middleware mapping module* identifies the ID of the exhibition obtained from the RFID identification module. The *wireless/mobile communication module* transmits data from the server to the PDA through GSM, WLAN, Bluetooth or 3G. Then, the *guide content storage module* saves the optimal guide route information and contents in advance such that a fast fetch for the detailed explanation of contents is possible. Next, the *guide content display module* presents the contents to the users such as textual introductions and multimedia. The *guide activity monitor module* records the users' routes and the browsed exhibitions. A suggested route of additional items to browse is recommended by the proposed recommendation model. Finally, the *guide interaction module* is the user interface of the proposed mobile guide system. All the exhibitions and related information are presented in this module.

3.2.2 Server functionalities of the guide system

There are five modules in the backend as shown in Figure 4 (right), namely the *network communication module* that communicates information and multimedia contents between the network communication module and the mobile communication module on the PDA.

Next, the *guide content repository module* stores the exhibition contents, related multimedia data and special exhibition programmes. Then, the *data mining module* finds association rules based on the visitors' browsing records. The recommendations are made according to these association rules. Next, the *video streaming module* encodes the multimedia data as video streams and then transmits them to the PDA. Finally, the *guide activity log repository module* maintains and manages the overall system.

The guide system is developed in Embedded Visual C++ 4.0 and runs in a PDA Windows Mobile environment. The proposed system provides four languages including:

- 1 Chinese
- 2 Taiwanese
- 3 English
- 4 Japanese.

After selecting the language, users enter the guide system from the main screen as shown in Figure 5a.

Figure 4 The modules of the PDA guide system (left) and the guide system modules (right)

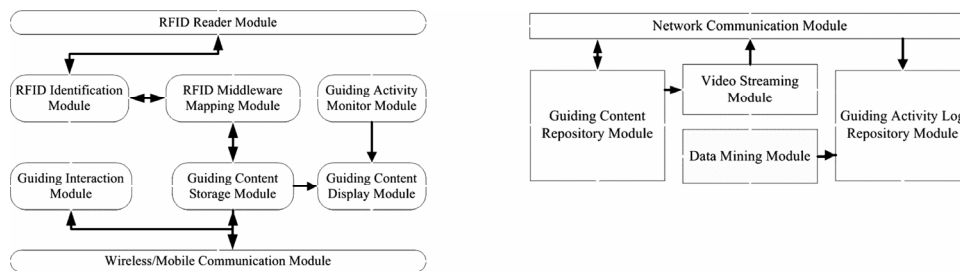


Figure 5 The user interface of the proposed guide system deployed in the Li Mei-Shu memorial gallery

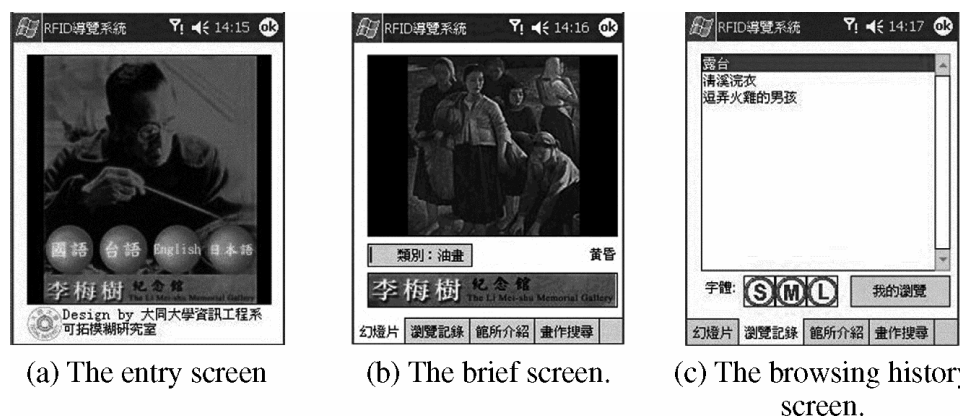


Figure 5 The user interface of the proposed guide system deployed in the Li Mei-Shu memorial gallery (continued)



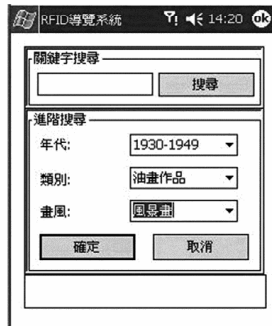
(d) The related exhibition.



(e) The video introduction.



(f) Sort by painted year.



(g) The search by keyword or features.



(h) The background story for painting.

4 System evaluation

The system has been deployed since October 2007. During the period, the system has been used for almost 8000 sessions. To assess the performance of the system, statistics were collected from October to December 2007 to reflect usage statistics for each interactive kiosk and the learning performance associated with different age groups.

4.1 The usage frequency for the interactivity kiosks

Figure 6 (a and b) shows the usage frequencies for the system. Figure 6a shows that most members visit the fourth kiosk mostly. The reason is that this interactive kiosk is near the entrance. Some kiosks are less used and this may be because of their textual interface that is less attractive. The result shown in Figure 6a implies that most visitors are likely to get a superficial understanding through quick and casual observation rather than to learn a specific subject during their visit to the museum. Another interesting observation is that the tenth to the fourteenth kiosks provide similar statistics that may arise from their closeness of installation and the related subjects to each other. A visitor browsing one

kiosk may continue to find related subjects of interest at the neighbouring kiosks. Therefore, suggested subjects should be presented on kiosks in close vicinity with the related subjects. Moreover, the relationship between subjects should be taken as an important factor when establishing recommendations and routing rules. Compared with Figure 6b, which shows the usage statistics for non-members, most non-members preferred the sixteenth and nineteenth kiosks that cover vacuum discharge and conservation of angular momentum. Vacuum discharge shows a vacuum ball that contains electricity light and conservation of angular momentum shows a rotating plate that the visitor can stand on to experience the angular momentum. Obviously, those two exhibitions have more interactive and interesting effects for visitors. These statistics may verify that most visitors are not serious about learning new subjects but are only interested in being amused. Therefore, we should design more special and learnable exhibitions to attract non-member visitors.

The statistics reveal that non-members are more interested in dazzling exhibitions than the members. One reason for this may be that members want a deeper understanding of a specific subject. The results tell us that more dazzling and interacting exhibitions are needed if we want to get the general public interested in science. The most used kiosk is the vacuum discharge and the least popular kiosk is the dangerous of our environment because it is conspicuously located and the materials used are more conventional than the other items on display.

Figure 6 Usage statistics for members (top) and non-members (bottom)

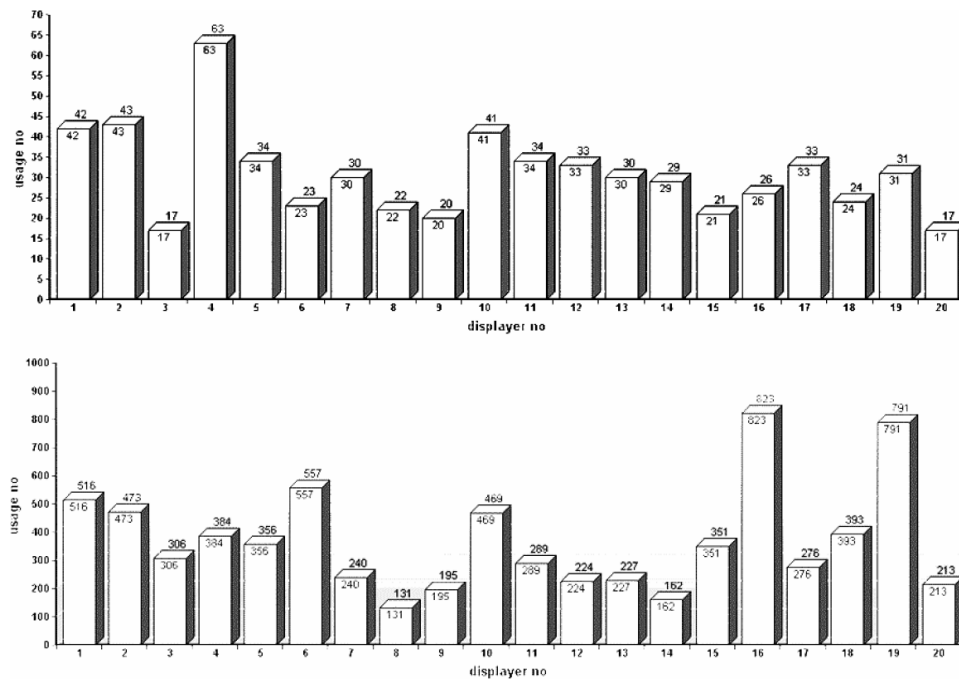
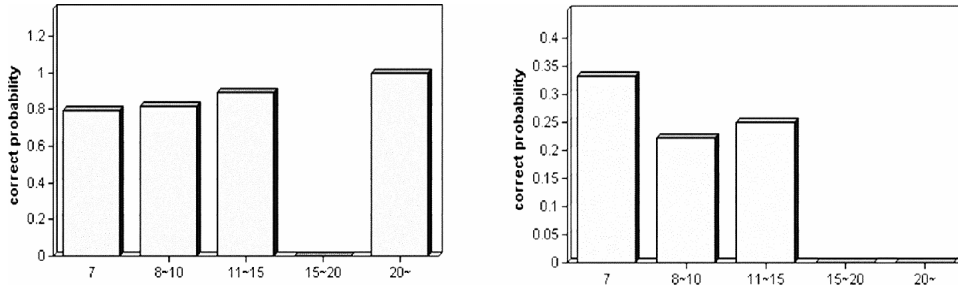


Figure 7 The superior (left) and inferior learning performances (right)

4.2 The learning performance in different age groups

Figure 7 presents the ratio of correct answers. The right plot shows that the rate of correct answers from the students of ages from 15 to 20 is zero. This suggests that the system does not appeal to students in this age segment. However, another explanation is that the educational strategy of NTSEC focuses on elementary and junior high school students; therefore, not many high school students showed activities in the database. Moreover, the questions are easy for the age group of 20 and up and the correct answer rate is high.

The results for every other age segment display a high correct learning rate of more than 80%. This suggests that the materials are suitable for both children and adults. According to Figure 7 (right), students younger than 15 still make some mistakes after having viewed the learning materials. Based on this result, the material was reviewed. It was found that the vocabulary is too complex and does not match the vocabulary level of the young children. This material is currently being revised to such that it is more suitable for younger visitors.

4.3 Recommendations

When the first time we introduced Li Mei-Shu Guide System to tourists whose ages ranged from 15 to 60, most of the users agreed that they can operate the system without any pre-assistance even when they have never used the system before. The result indicates that our layout and operation flow is satisfactory. Some visitors suggest that brighter screen and a louder voice should be considered owing to the limited display space.

5 Conclusions and future work

This paper presented two guide systems that are used in dissimilar environments. These two systems have been adopted for more than 1 year in two museums. The ‘Hands-Free Interaction Guide System’ is a personalised learning assisting system based on RFID technology and recommendation mining method. Educators have endorsed the system. Future work includes combining RFID with a camera for personalised capture, remote

teaching, in-door location for social contact and routing recommendations. A touch panel will be adapted for a richer interactive experience. Providing the learning interface and agent into the visitor's cell phone for better personal learning is being considered for future design.

In the Li Mei-Shu Guide System, visitors view exhibition-related multimedia contents on PDA equipped with RFID readers. The exhibition centre gathers the visitors' information based on the interactions between the PDA and the server and the records are used for making recommendations to prospective visitors. In order to provide more mobility, the system has been transferred to the cellular phone platform with quick response (QR) code using web technology now. Visitors can download detailed contents from the internet by decoding the address that is encoded in the QR code picture using a pre-installed QR code decoder in many cell phones. In the future, we will use the gathered information from the visitor's browsing history to provide real-time online interactive platform for tourists with similar interests.

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