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Mobile Exhibition Guide System Using Multi-Channel Energy Detection of Near-Ultrasonic Signals

비가청 고주파음역을 활용한

전시가이드 시스템의 구현

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Abstract

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This thesis presents a new method for exhibition guide systems, an application for mobile devices that utilizes near-ultrasonic sound waves as communication signals. This system substitutes existing museum or gallery guide systems that use technologies such as infrared sensors, QR codes, RFID, or any other manual input. In the proposed system, a near-field tweeter speaker stands near each piece of artwork and transmits mixed tones in the inaudible frequency range. The receiver application filters interfering noise and pinpoints the signal coming from the nearest artwork, identifies the artwork, and requests the corresponding information from the data server. This process is done automatically and seamlessly, requiring no input from the user. Experiments show that the method is highly accurate and robust to noise, indicating its potential applications to other areas such as indoor positioning systems. In addition, a case study shows that the proposed system is favorable in many aspects compared to existing guide systems.

Keywords: Near-ultrasonic; Inaudible frequency; Exhibition guide; Audio interface;

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Chapter 1. Introduction

1.1 Background

The extreme growths in amount and variety of information, as well as the necessity of organizing them have led the development of identification and tracking systems. Along with the advancement of the sensor technology, these systems have integrated deeply in people's lives nowadays. We scan barcodes upon purchasing goods, tag RFID-based chips to pay public transportation fares [1], and scan QR codes [2] with smart phones near the bus stations to check the transport schedules. Such scenarios are common examples that we can find in our everyday lives. Thus, we can say that we are living in a world of ubiquitous sensor network, and it is no exaggeration to say that these identification or tracking systems have infinite possibilities to be utilized in variety of areas [3].

Museums or galleries, the environments where exhibit and manage thousands of artworks are no exception for utilizing these systems. Especially, to provide exhibition visitors with detailed information about the artworks automatically, it is essential for those environments to establish the identification systems.

Most museum visitors appreciate information that accompanies the artworks, such as the descriptions or histories of the artworks. Thus, museums use a couple of traditional form of guides to provide such supplementary information. The first channel is using the paper-based pamphlets or brochures. They are basically printed materials with text and pictures, providing information in passive form. The second channel is carried by people, who are called as the docents or the curators. They are people who are experts in art histories with high level of artwork related knowledge. Usually, at certain scheduled time, the docents or curators lead the group of visitors and take a tour of the exhibition. In this tour, the group stops in every artwork spot and is provided with detailed information about the artworks. The bidirectional communication is available in this form of guides, so in case a visitor has a question about the artworks, it can be handled instantly by the expert. This can be considered as a definite advantage of the human-based guide systems. However, mechanical audio guide systems are rapidly replacing human guides as the docents lack in immediacy, availability, and have high operating costs [4]. Additionally, some visitors can claim that as the human guide "announces" the same level of information to the group, it is not possible to satisfy everyone in the group with having different knowledge levels about the exhibition.

The first mechanical guide system used the cassette tapes with recorded narration voices. In the system, the visitor manipulates manually to play/stop the tape to obtain the information in aural form [5]. The next generation system utilized compact discs (CD) instead of cassette tapes. Nowadays, the system is nearly standardized as using the key-pressing devices, by assigning every artwork with individual number codes [6]. There are even commercial systems providing a total solution of implementing these mechanical guide systems including the infrastructure installation, such as the Sennheiser's GuidePort system [7] or systems from Antenna International [8].

1.2 Motivation and Objectives

As mentioned above, the mechanical audio guides in museums or galleries are very common and easy to find nowadays. Examples of typical recent mechanical audio guide systems are shown in Figure 1.1. Usually these systems are comprised of digital devices housed in a small plastic cases and work by pressing physical buttons. When a visitor enters a certain numeric code assigned to the artwork, the system retrieves the related content by using the IR (Infrared) sensor technology and provides it back to the user in an auditory and/or visual form.

Figure 1.1: Examples of typical exhibition audio guide system (Adapted from reference [7] [9])

This is a common scenario for visitors who want to look at the artworks in a museum. However, it is possible for users to find this ordinary system frustrating, as they need to enter numbers every time they need information about the artworks they are interested in, and also usually visitors have to pay certain fee to use them. As an alternative, more recently introduced systems use RFID, NFC or QR codes, enabling an easier and faster identification of artworks. However, these systems basically provide point-to-point user interfaces due to their close-by contact mechanism, and thus users may have to wait in line to have a clear line of sight of the corresponding codes. Also, these systems require additional actions such as swiping/tagging (RFID, NFC), or holding (QR codes) for users, creating the need for explicit interactions.

In order to overcome the abovementioned problems, this thesis proposes an effective interaction method for museum guides using near-ultrasonic sound waves on mobile devices. The near-ultrasound is the sound region which has frequency ranging from 18,000 to above. This sound region is also called as the Very High Frequency (VHF) or inaudible high frequency. Usually it is inaudible to human ears but audible to most of consumer grade audio playing/recording equipment.

There are several advantages to our approach. First, since this system is designed to work as an application for mobile devices, the visitor’s own device is used as the receiver device. This removes the necessity of other external devices and results in cost reduction and a maintenance-free environment for museums and also leads to the possibility of creating a new business model by making the paid app, such as substituting the admission fee for the price of the app. Second, the system utilizes the radiation property of sound waves, which enables point-to-multipoint communication between an artwork and simultaneous users. Third, as smart devices have large LCD screens, we can provide users with visual information using rich media, such as videos or pictures, in addition to basic audio. Finally, the automatic detection of the artwork nearest to the user’ s device enables the user to become free of having to explicitly input information, which is an important feature of ubiquitous computing technology as it attempts to merge computational artifacts smoothly with the world of physical artifacts [10] .

The objective of this thesis is to propose a more robust exhibition guide system using sound waves as the identification/tracking signals, as well as having following properties;

(1) Low cost implementation by freeing the necessity of additional devices
(2) High compatibility by not utilizing additional sensors/devices
(3) Minimizing explicit interactions
(4) Providing point-to-multipoint interface, handling multiple users simultaneously

Unlike using the light, it is difficult to control the radiation of the sound waves. So when using it for the identification system as the triggering signal, it is inevitable to confront interference and errors. Thus, we present novel methods for preventing them by establishing several filters and different signal modulation technique in this thesis.

1.3 Thesis Organization

The rest of the thesis is organized as follows: In Chapter 2, we present existing methods and applications related to our work, and define the limitations of them. In the following Chapter 3, we explain our proposed system in detail. We then present the experimental procedures, results and the case study to show the feasibility of the proposed system in Chapter 4, followed by directions for the discussion and future work in Chapter 5. This thesis concludes in Chapter 6.

Chapter 2. Related Work

2.1 Mobile-Based Exhibition Guides

There are numerous cases of museums or exhibitions utilizing smart mobile devices for their guide systems. Comparing to the traditional manual key-pressing “audio guide” systems, these mobile-based systems can provide additional visual feedback to users by utilizing their large, high-resolution LCD screens, enhancing the user experience.

The mobile-based exhibition guide systems can be categorized into two groups (Table 2.1);

(1) Passive systems which require users’ manual input

(2) Active systems providing automated information delivery
utilizing the sensor network.

System Category	Utilized Method
Passive Systems	Manual Key Pressing, Content Hierarchy Browsing, etc.
Active Systems	GPS, RFID, QR code, Augmented Reality, Ultrasound, Bluetooth, etc.

Table 2.1: The classification of mechanical exhibition guide systems

Recently, some museums provide their own mobile applications. Such applications usually are in the passive form, in the format of artwork archives (i.e. encyclopedia style) and do not provide interactive, efficient communication for users. These systems can be considered as the “digitalized pamphlets or brochures”, and they usually require manual input or additional procedures such as number entry or manual searching in lists of artwork names to identify the target artwork.

Although these systems are not able to provide automated information delivery to users, still they are possible to provide more organized interface compared to the paper-based guides, as well as videos and audio information which are not possible to be utilized in traditional paper form. The Like-o-meter in the PEACH project [11] and the research of Celentano et al. [12] focuses on efficient user interface and organized information hierarchy in digitalized guide applications. In the Like-o-meter application, both “Like “and “Dislike” buttons exist in the interface. If the user responds with “Like” button to the shown information, the system provides with detailed information while it stops and recommends other activity if the user has responded with “Dislike”. By this method, user can obtain information that fits his/her knowledge level and preference. Celentano et al. suggests the efficient design principles and content structure of mobile app-based guide system interface. They suggested a way to establish standards to contents grouping by categorizing their characteristics, and processed a usability test as well.

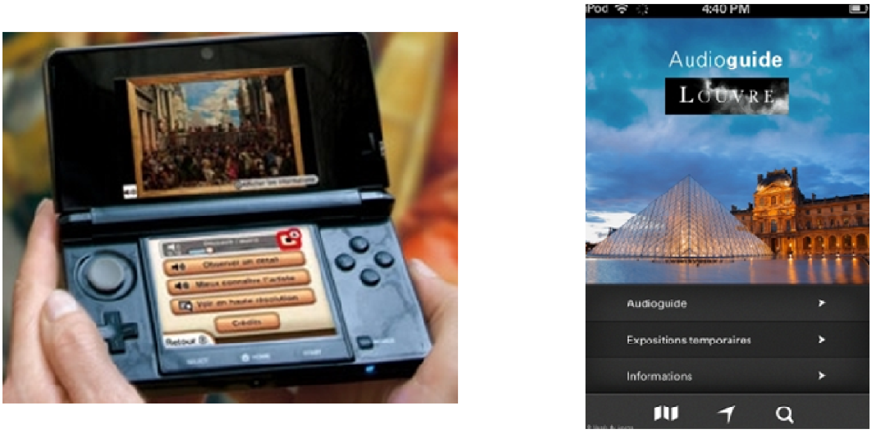

Figure 2.1: Exhibition guide applications of Louvre museum (Adapted from reference [13])

The Figure 2.1 shows the Louvre museum guide systems. They provide their guide systems in three ways. First, the traditional mechanical exhibition guide system, second, the app-based guide application for smart mobile device, and finally, a Nintendo 3DS based guide [14]. Utilizing the divided-screen characteristic of the Nintendo 3DS, users can select the information from the “Navigation” tab located in the touch screen below, and see the corresponding information including text, picture, and even 3D modeling graphics on some dimensional artwork in the upper screen of the device.

The passive systems have advantage in low cost in implementation since the infrastructure installation is not necessary, which is a benefit for the hosts of the exhibitions. However, they lack in terms of effective information delivery as they require explicit interaction to users. This leads to the problem that it makes users to interact with the guide system, not with the artworks.

This misleads the basic principle of the exhibition guide systems, which is to help users focus the artworks. To overcome this limitation, numerous research and methods on the active systems have been proposed.

The active systems utilize various types of integrated or additional sensors with the mobile devices. By this, it enables half-automatic or full-automatic information delivery to users by identifying or tracking them. This result of this enables the bidirectional communication establishment as well as the implicit interaction interface provided to users. And also, it becomes possible to provide additional interactive features in the system.

The Scan and Tilt [15] system is an interactive museum guide on mobile devices, which uses the device's accelerometer as well as external RFID transmitters and additional RFID receivers on devices. The RFID reader equipment is installed in certain spots of the exhibition. The information is obtained by scanning RFID sensors near the artworks. The users then use tilting gestures to control and navigate the application interface. The Hippie [16] system has similar idea, but instead of RFID it utilizes additional IR(Infrared) receivers attached to users' devices. The IR signal transmitters are installed in the entrances of rooms and provide the information of the room when the user enters the zone. Both RFID and IR are commonly used technology and also provide low cost of sensors, but recent smart mobile devices usually do not have such sensors integrated. This leads to the necessity the dedicated devices or additional sensors/devices attached to users' typical smart mobile devices.

The PhoneGuide system by Bruns et al. uses Bluetooth technology with Nokia’s Symbian OS to create the digital exhibition guide system [17]. This system can be categorized as an indoor localization/positioning system rather than an identification system. Several Bluetooth beacons create a virtual grid that divides the exhibition space. Then, the system recognizes the users’ coarse location. Using neural networks, the mapping of artworks is done and the information of the nearest artwork to the user shows up on the screen of the device. However, the Bluetooth technology requires the pairing process in order to communicate between the devices for the first time, which are a time-consuming process that takes several seconds. Also due to its diverse technology versions, it lacks in terms of compatibility.

There are some approaches implementing augmented reality technology into the museums [18]. The LISTEN concept of Terrenghi & Zimmerman adapted tailored audio augmented reality based technology in art museums [19]. Users in the exhibition wore wireless headphones. Meanwhile, interactive 3-dimensional audio was emitted through virtual sound sources in the room. Through this, personalized and contextual audio information about the exhibits is provided to the visitors. The project of Bimber et al. utilized computer graphics and augmented reality techniques and provided projected overlays on the background with customizable image adjustments, such as color and intensity [20]. Through this process, the image could be dynamically rendered in real-time, resulting in the integration of visual information directly into the artwork.

Schmalstieg & Wargner used see-through augmented reality that provided interaction with augmented exhibits in museums [21]. Using Pocket PC PDA cameras, the devices showed the real environment image on the screen on one layer. On top of that, another layer with virtual elements was overlaid. This makes the users' device act as a "magic lens", providing users with additional information that they cannot see in the real world. Improving this system's performance and concept, Miyashita utilized additional marker objects, tracking the camera and rotation sensors of the device [22]. This resulted in creating a "hybrid" museum user tracking/guiding technology.

These methods are basically the same concept of visual augmented reality technology that utilizes GPS and accelerometer sensor of smart devices in outside environment. But since it is not possible to utilize the GPS location indoors, the common property of abovementioned methods is that they all have additional technology establishment to track the users. Those are usually certain "marks" or "spots" which are installed in real-environment, to let the device for tracking the location of the users. However, some are claimed to cause visual disturbance [23]. In terms of visual disturbance, the Blatannkoden Project [24] has the same issue since it uses QR codes as "visual markers". It is a mobile game in the museum for treasure hunt using QR codes, and is designed for young students aged from 11 to 14 to provide entertainment in exhibitions. QR codes were installed in the Norsk Telemuseum. The secret answers which can be obtained after scanning the QR codes provided answers to a sequence of riddles. Utilizing the built-in cameras of users' own mobile devices, the children could find the answers through the QR codes inside the exhibition.

The Navilog system is a computer vision-based mobile guide system [25]. The visitor simply takes the picture of the environment by the smart tablet device and selects the region of interest. After that, the system detects the certain region of the image, then show the corresponding information back to the user's device. This system removes the risk of visual disturbance since it is using image processing instead of establishing markers or APs for localization. However, the processes of taking pictures and selecting certain region of the image cause explicit interaction.

2.2 Methods Utilizing Near-Ultrasound

Near-ultrasonic signals are used in some applications, taking advantage of its inaudibility. Shopkick [26][27] and SonicNotify [28] are both commercial applications that use similar technology to the system in this thesis. Basically, these systems act as identification systems and provide targeted marketing services. The radiation feature of the sound waves enables point-to-multipoint interface, unlike other close-by contact mechanism based systems.

The Shopkick system is installed in various areas of retail shops. In this system, a satellite speaker called as a “beacon” generates a certain range of inaudible frequency tones and it works as the transmitter. A smartphone works as the receiver and decodes the tone, then shows the according messages. While identification is done by the near-ultrasonic signal, the message/information retrieval is done by the other network channels, such as 3G, LTE, or Wi-Fi. Through these messages, users obtain benefits such as merchandise/service discount coupons.

SonicNotify also uses similar technology, but also provides a framework that can be utilized and customized by the users. As a result, even small retail shop owners who are not familiar with computer technology can create their own SonicNotify system easily.

The DingDong system [29] from LG Uplus is also for the targeted-marketing service and has the same concept as the Shopkick. Nonetheless, instead of using the near-ultrasound for transmitting data, this system utilizes tone in near-infrasonic region. The near-infrasound is the sound wave that has frequency near 20 Hz, around the bottom limit of human hearing range [30]. Just like the near-ultrasound, the near-infrasound is inaudible to most human, but audible to most electronic devices. But unlike near-ultrasound, the long exposure to infrasound has possibility to cause vibroacoustic disease due to its high diffractiveness [31].

Another example of near-ultrasound application is Yamaha's Infosound, which works as an advertising application by mixing certain inaudible tones to the original television sound [32].

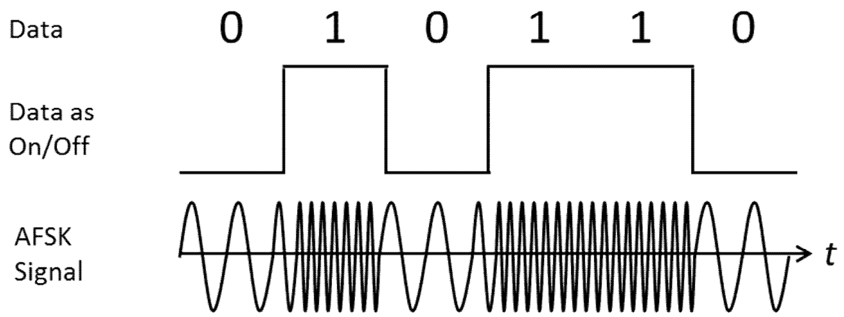

Figure 2.2: An example of data using Audio Frequency Shift Keying

A commonly used method to transmit data in such systems is Audio Frequency Shift Keying (AFSK). As shown in Figure 2.2, it utilizes two frequencies to transmit data [33]. One frequency represents ones and the remaining frequency represents zeros. By turning these frequencies on and off, binary data can be transmitted through inaudible audio.

Another similar system is the Arentz [34][35] method, which uses one frequency with pulse length modulation. Because this modulation technique only utilizes one frequency channel, it has advantage of saving the bandwidth by 50 percent compared to the AFSK.

These methods transmit data sequentially and have special ‘start’ and ‘stop’ signals that indicate the beginning and end of the transmission. In the case of errors, a retransmission is needed, which requires the establishment of a correction or synchronization procedure, such as an Automatic Repeat re-Quest (ARQ) system. Implementing such procedures makes the system increasingly complex and hard to implement.

2.3 Exhibition Guide System Utilizing Near-Ultrasound

The Smartguide is a similar museum guide system to the system in this thesis, which uses near-ultrasonic tones as the exhibit identifying method [23]. The Smartguide system is mainly composed of two parts: 1) a VHF sound emitter called beacons and 2) a mobile application that serves as the client. When a user passes by an emitter, the device receives the encoded tone and decodes it, then provides the relevant information back to the user by retrieving information via the Wi-Fi or cellular network.

But since the system only uses two signals using aforementioned Audio Frequency Shift Keying (AFSK) for encoding the tone, the tone is dependent to the time domain, which leads to an error when the signal has missing or erroneous data while transmitting. Every bit has 26 ms of duration, so to transmit 8-bit data takes total time of 208 ms.

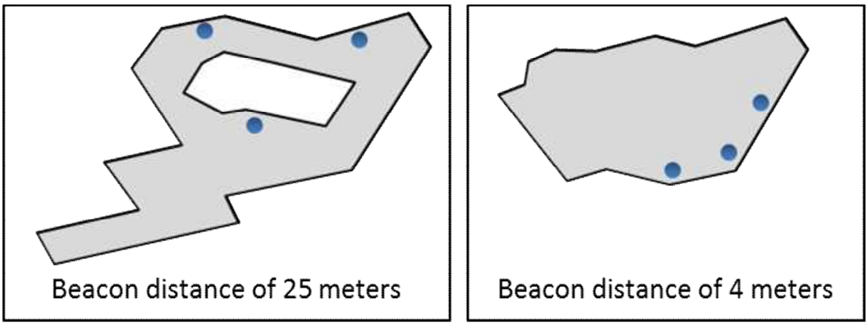

Figure 2.3: Transmitter locations of Smartguide system experiment on two different floors with different transmitter distances (Redrawn from reference [23])

Also it has a high error rate due to the interference of other signal beacons and confronts scalability issues. As shown in Figure 2.3, during the experiment in Deutsches Transrapid museum, they installed total of six beacons in two floors. On one floor the transmitters were installed at intervals of 25 meters, and four meters in another floor. To minimize interference, they did not establish an ARQ algorithm, however implemented to give random delay time ranging from 20 ms to 525 ms to all transmitters.

In addition, the Smartguide system receives information on all the artworks in a given space. The user then manually selects the information that is relevant to the artwork he/she is interested in. In this thesis, we propose a system that automates the above process, requiring no input from the user and successfully detecting the nearest artwork.

In the next Chapter, we present a concept that is the key to implementing an identification system for exhibitions that utilizes near-ultrasonic sound waves and improves on the limitations of the previous studies.

Chapter 3. Research Method

3.1 Near-Ultrasound

The human audible frequency is known to range from 20 Hz to 20,000 Hz [36]. But generally most adults aged over 20 are only able to detect frequencies up to 18,000 Hz, as the ability to hear high-pitched sounds reduces gradually as people get older [37][38]. There are a number of researches about age-associated high frequency hearing loss [39] [40].

Percentile	10%	25%	50%	75%	90%
Age (Years)	Upper Limit Frequency (kHz)				
10-19	19.3	18.4	17.2	15.7	15.0
20-29	18.0	17.1	15.9	14.9	13.8
30-39	16.6	15.2	14.5	13.6	12.4
40-49	14.6	13.8	12.9	11.8	10.6
50-59	13.2	12.2	11.0	9.6	8.2
60-69	11.2	9.9	8.3	5.3	1.8

Table 3.1: The average upper limit frequency of human hearing by percentile [38]

In our proposed system, we focus on the inability to sense high frequency sounds and take advantage of this.

Although most people cannot hear frequencies that are higher than 18,000 Hz, many modern mobile devices can detect sounds up to 20,000 Hz or even higher. To testify the feasibility of near-ultrasound on smart devices, A small experiment with several smart devices from four major brands (Apple iPhone 4S, iPhone 5, iPad 2, Samsung Galaxy S3, Galaxy Note, LG Optimus G and HTC Nexus One) was conducted.

Using a Focal CMS-40 speaker which is able to play the frequency from 60 Hz to 28,000 Hz at +/- 3dB, 40 sinusoids at intervals of 50 Hz from 18,000 to 20,000 Hz were generated simultaneously. Each receiving mobile device was placed 50 cm in front of the speaker. Using the integrated audio recording application for the each device, we recorded the sound for two seconds. The sample rate of the devices was all set to 44,100 Hz. After analyzing the frequency components of the recorded sound files on MATLAB, the two examples of the results are shown below.

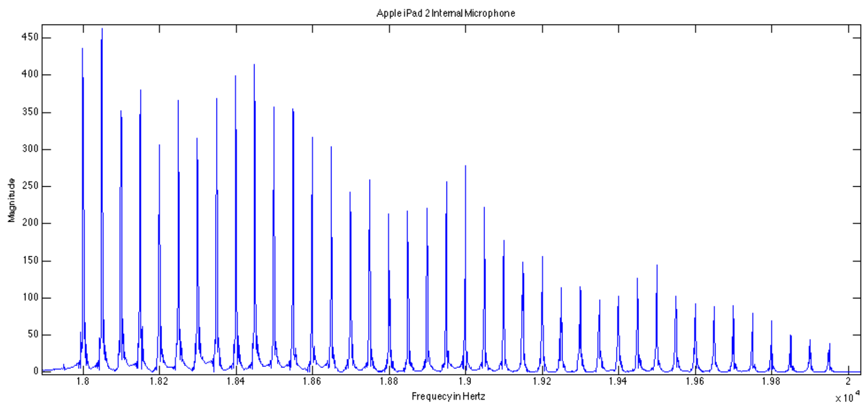

Figure 3.1: 40 channel peaks received by internal microphone of Apple iPad2

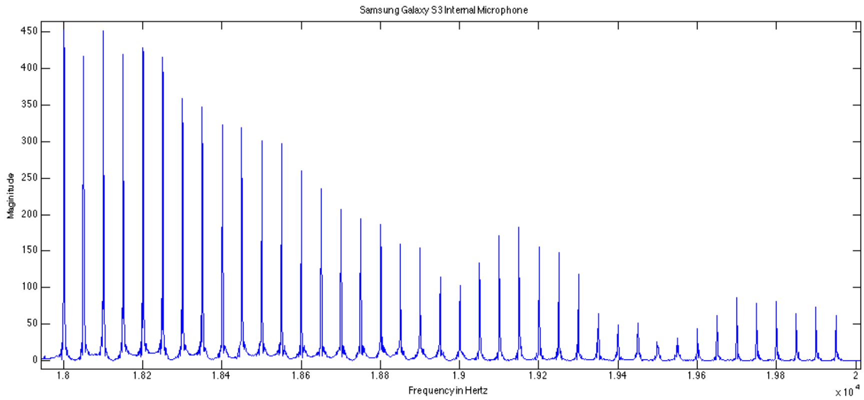

Figure 3.2: 40 channel peaks received by internal microphone of Samsung Galaxy S3

As shown in Figure 3.1 and 3.2, there are differences in level of received energy in each region due to the different frequency response properties of internal microphones, but still it is able to detect the "peak" of the regions. Rest of devices only varied the energy value, and all were able to detect near-ultrasound.

3.2 System Configuration

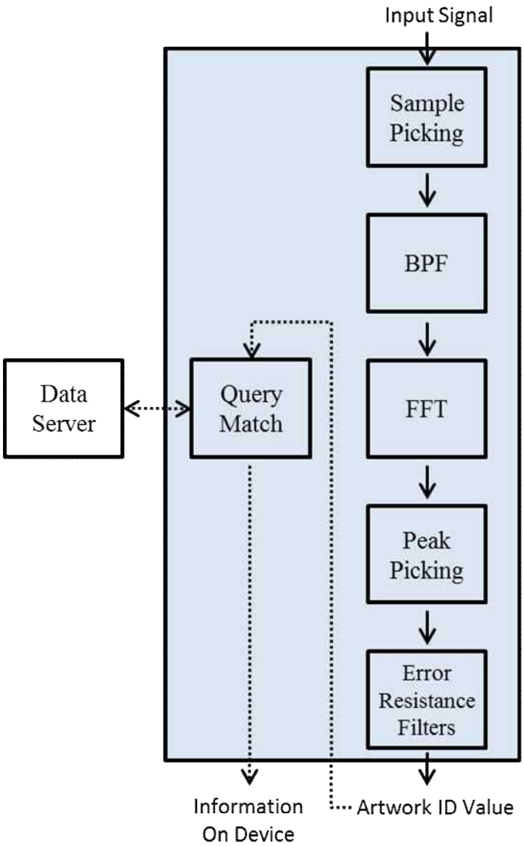

Figure 3.3: System flow diagram

The system utilizes two kinds of communication channels. One that uses near-ultrasonic tones is used for identifying the artworks, and another channel that uses Wi-Fi network to retrieve according information of the ID. The basic system flow diagram is shown in Figure 3.3.

The system is composed of four main components as shown in Figure 3.4. First, each artwork has a small tweeter speaker that generates an audio signal in the inaudible range. Second, the Pyroelectric Infrared (PIR) sensor attached to Arduino boards beneath the speaker detects human motions and generates tones to be received by the receiver. PIR sensors are used to minimize unnecessary signals and reduce interference with other signals. Third, the application on a smart device receives the signal via its internal microphone and decodes the tone. In the final process, the application sends the detected artwork ID to the server using the WI-FI network. The server then looks for the corresponding information about the artwork in the database, and sends it back to the application. Because IDs are assigned uniquely to the artworks, the inaudible signal from the tweeter speaker is only used as a “trigger” signal and does not contain any artwork data itself.

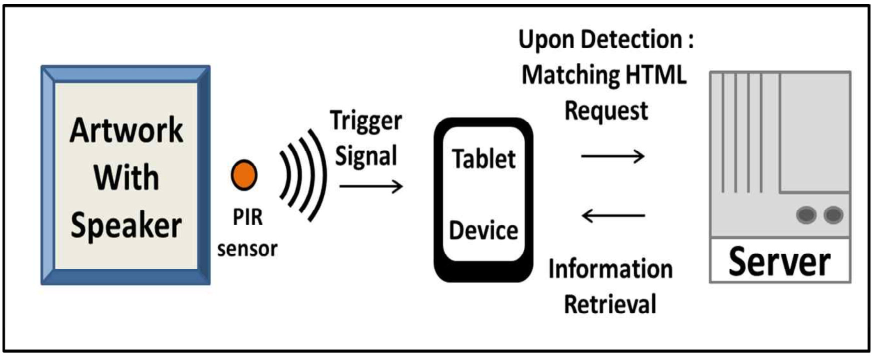

Figure 3.4: The four main components of the system

3.3 Implementation

The system was developed using Pure Data[1] to generate high frequency sound signals, and iOS SDK 5, to implement the receiver app on iOS.

Our guide system uses 40 pre-determined frequency channels in the human-inaudible range, between 18,100 Hz and 20,000 Hz. These 40 frequency channels act as binary on/off signals to transmit data from a transmitter to the mobile device. These signals are then processed to filter interference from other transmitters and pinpoint the signal coming from the transmitter that is nearest to the mobile device. In contrast to methods such as Audio Frequency Shift Keying, our method of transmitting data is easy to implement as it does not require syncing of the transmission and receiver devices.

The Transmitter

Pure Data, a programming environment for audio and video processing, was used to generate the 40 signals. These signals were pure sine waves having frequency values as one of the pre-determined 40 frequencies. In the perspective of the receiver, these 40 frequencies were the "channels" to listen to. These signals were sent in 400 ms pulses (Figure 3.5), which acted as another basic precaution for interference from other signals in addition to the PIR sensors. 8 channels are used to transfer a complete "message" that

[1] Pure Data. http://www.puredata.info.

identifies a unique artwork. Thus, the same messages are redundantly transmitted 5 times, simultaneously, to reduce error. Therefore, 5 copies of an 8-bit message are sent in one pulse to the mobile device. With 8 bits of information it is possible to identify 255 different artworks (2^8 – 1 combinations, since it is impossible to identify a signal with all zeros). The basic structure of the tone resembles the combination of the on/off keying (OOK) [41] and multi-frequency signaling (MF) [42] technique.

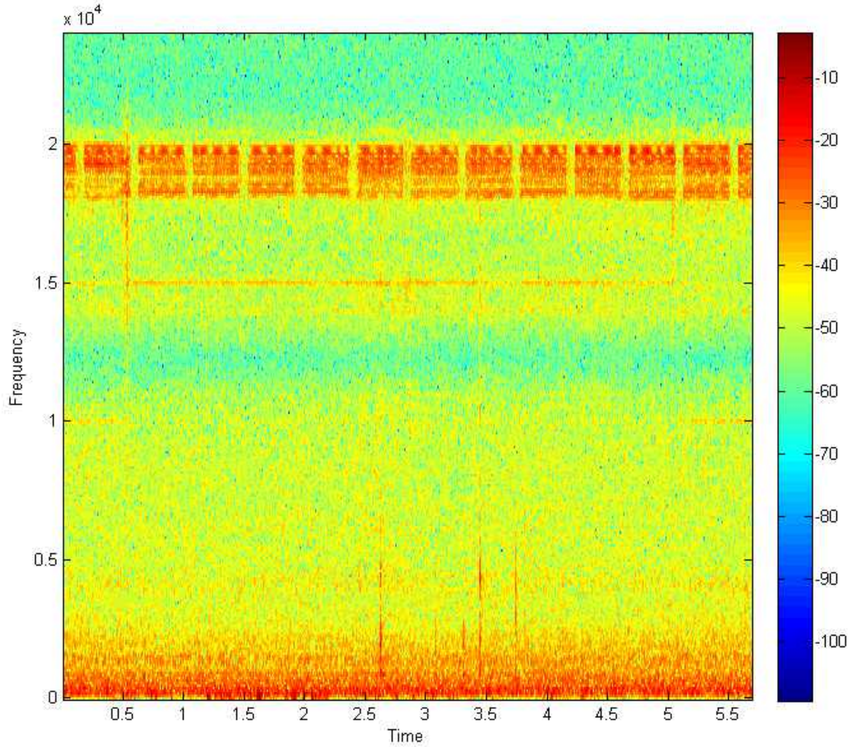

Figure 3.5: Magnitude spectrogram of the tone. X axis stands for time, Y axis stands for frequency. Each signal pulse has a length of 400 ms and 50 ms of interval

Figure 3.7 illustrates an example of a transmitted signal. The data, or message, being transmitted is “01011001”, which is the identification code of a particular artwork. The message requires 8 channels, or frequencies, to transmit at once. Here, the second, fourth, fifth, and eighth channels are activated, thus producing the “01011001” message. These first eight channels correspond to a complete message indicated by Set 1 in the Figure.

To handle errors during transmission, the same message is transmitted four more times using higher frequencies. The next eight frequencies, or channels, are then used to transmit the same data. This is repeated until all 40 channels are used. Thus, the same message is redundantly sent 5 times with each pulse.

The advantage of using 40 frequency channels of signals is that the data is transmitted as a whole, rather than a sequence of bits. Each pulse from the tweeter speaker unit (Figure 3.6) contains all the data that is needed to identify the artwork.

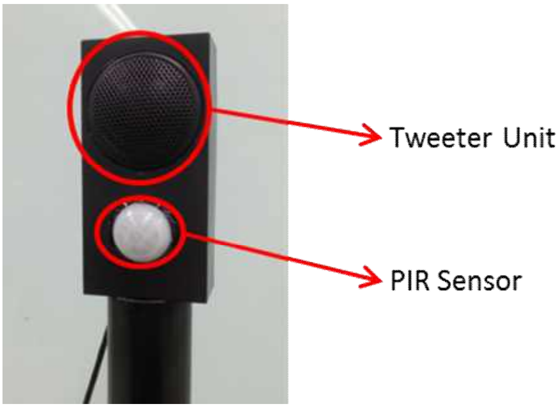

Figure 3.6: Transmitter components

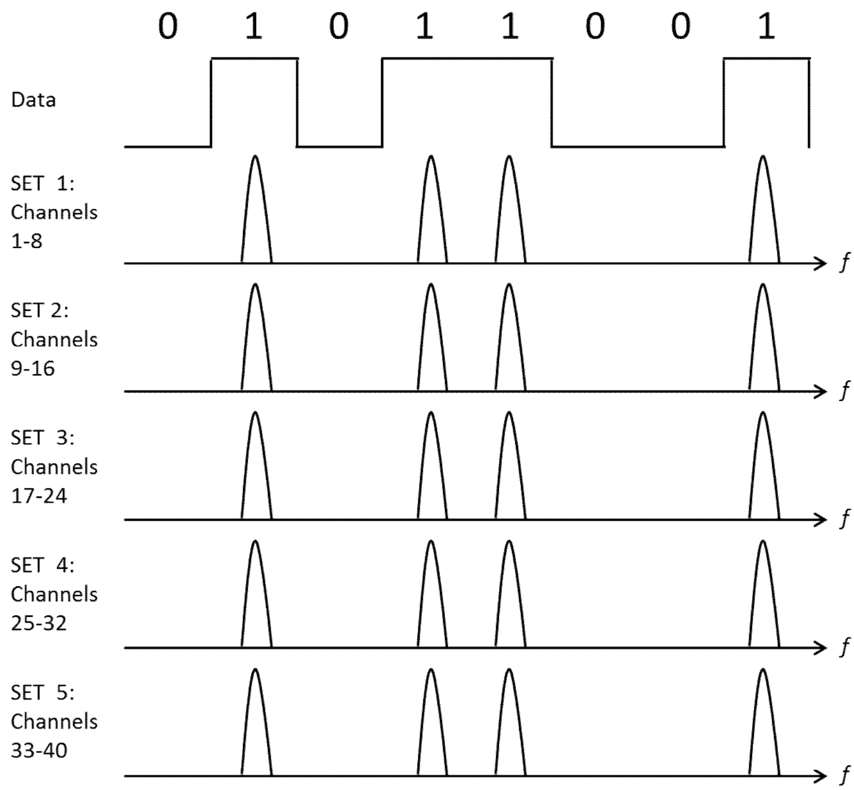

Figure 3.7: Example of a message sent by the transmitter using 40 frequency channels

The output signal from Pure Data was connected to the tweeter speaker units. A 20-watt stereo amplifier with a Tripath TA2020 IC chip was utilized for amplifying these passive tweeter units.

Pyroelectric Infrared (PIR) sensors (Figure 3.6) were placed below each tweeter speaker unit to detect movement, which triggers several pulses of the artwork identification signal. These PIR sensors are controlled by Arduino UNO boards.

The Receiver

With the iOS SDK, we implemented a mobile application that listened to sound frequencies in the inaudible range and analyzed the incoming 8-bit message. To analyze the energy of the sound detected from the mobile device's microphone, we used the Fast Fourier Transform (FFT) in Apple's vDSP portion of the Xcode Accelerate Framework. This process enables the conversion of the incoming sound signal from the time-domain to the frequency-domain, making the signal analyzable by the device.

The incoming sound is passed through a high-pass filter to eliminate ambient noise and any other noise sources within the normal hearing range. We designed the filter to ignore all sound peak data under 18,000 Hz. Through the Fast Fourier Transform, energy spikes at the predetermined frequency channels are detected. The list of predetermined frequency channels are in Table 3.2. They are the center frequencies of FFT bins, selected 40 out of 43 channels in range of 18,100 Hz to 20,000 Hz. The FFT resolution was set to 1024 at the sample rate of 44,100 Hz. Interfering signals from nearby artworks were eliminated as much as possible by having an energy threshold for a channel to be considered activated.

Channel Number	Frequency	BIN	Channel Number	Frequency	BIN
1	18130	421	21	18992	441
2	18174	422	22	19035	442
3	18217	423	23	19078	443
4	18260	424	24	19121	444
5	18303	425	25	19164	445
6	18346	426	26	19207	446
7	18389	427	27	19250	447
8	18432	428	28	19293	448
9	18475	429	29	19336	449
10	18518	430	30	19379	450
11	18561	431	31	19422	451
12	18604	432	32	19466	452
13	18647	433	33	19509	453
14	18690	434	34	19552	454
15	18733	435	35	19595	455
16	18776	436	36	19638	456
17	18820	437	37	19681	457
18	18863	438	38	19724	458
19	18906	439	39	19767	459
20	18949	440	40	19810	460

Table 3.2: The list of 40 channels used at FFT size of 1024

Figure 3.8 illustrates an example of the data received via one pulse of a signal by the transmitter. The majority bit is used to predict the transmitted signal. In this example, the predicted message would correctly be "01011001" despite having errors in Sets 3 and 4. However, there are additional precautions in predicting the message by sampling the incoming pulses until three consecutive samplings have matching messages. Each sampling interval was 50 ms, so one pulse from the transmitter could be sampled multiple times by the receiver.

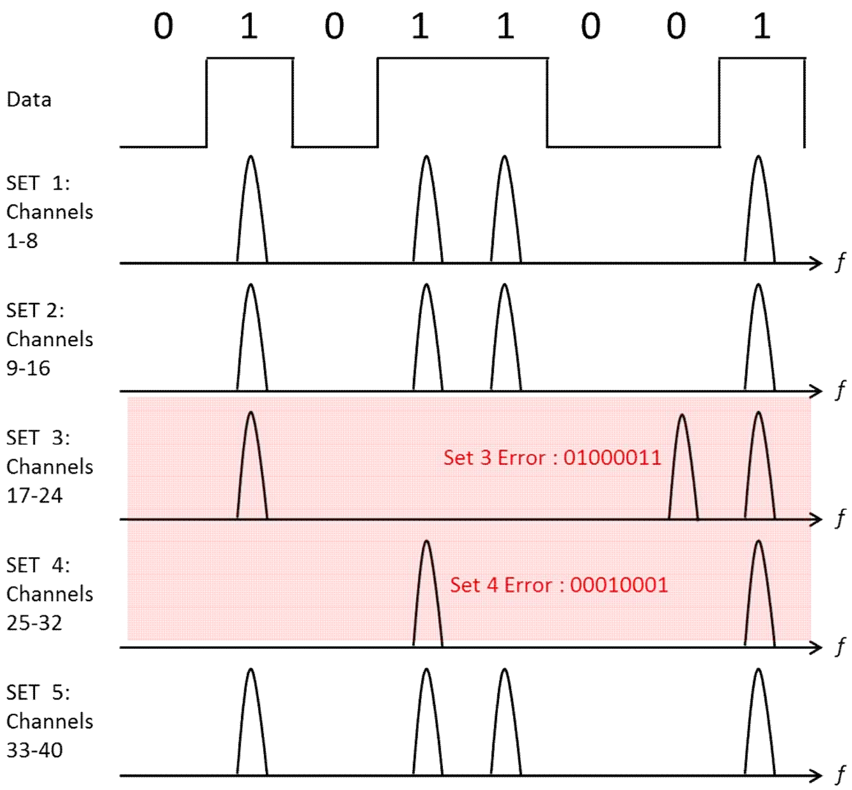

Figure 3.8: Example of a message received by the receiver with errors

During our research we found that higher frequency channels tended to be weaker in terms of transmitting power. Thus, higher frequencies were less reliable compared to the lower frequency channels. Thus, when doing a majority bit vote, frequency Sets 4 and 5 had less "voting power" and were assigned a vote value of 0.8. Sets 1 and 2 were reliable frequencies as they were in lower range, and were given a vote value of 1.2.

As described above, the system has deliberate redundancies to minimize errors and be robust to interfering signals from nearby artworks.

Once the artwork ID was identified, the according information on the artwork was displayed on the mobile device. The data transmission is done via the Wi-Fi network. The data server was designed as a standard HTTP web server using the open source Apache HTTP server project.

Chapter 4. Experiments

4.1 Performance Test

We performed several tests in various conditions of interference to examine the feasibility and the error rate of the proposed system. We set up our equipment in a quiet rectangular room with dimensions of 5m x 12m. Using an Extech 407750 sound level meter, the environmental noise level of the room was measured to be around 44 to 50 dB (A). We chose the "distance between the artworks" and the "layout of artworks" as the two variables of our experiments. We defined the "artwork observation spot" to be 150cm away from the artwork while directly facing it.

Four Lanzar TCS-1 one-inch tweeter speaker units were used as the signal transmitters and played the role of artworks. Since the system only utilizes near-ultrasonic frequencies, we used these tweeter speakers, which had a frequency response of ranging from 2,500 to 24,000 Hz. Also the small size of the unit is an advantage as it is easier to be "hidden" in installations, minimizing its presence in the exhibitions. The tweeter units were installed on steel stands that were 100cm high. In these experiments, the PIR sensors on the transmitters were all disabled and designed to generate constant signal instead of using the pulses. This was to create the worst-case scenario, in which all signals from multiple speakers are generated simultaneously and interfering with each other. Also, the sound levels of the transmitters were restricted to a maximum of 65 dB (A).

We had two people (simulating other visitors) to walk freely around the artworks and block the communication between the mobile device and the transmitter. Tests were considered a success if the system detected the front facing artwork, and a failure if it detected nearby artworks or failed to detect anything at all.

4.1.1 Distance Experiment

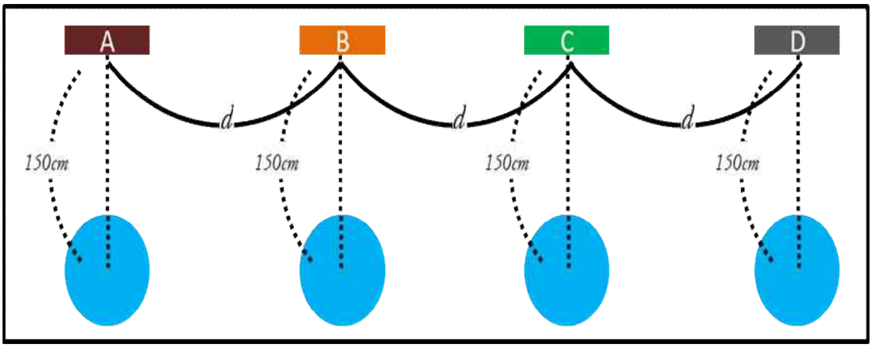

Figure 4.1: Artworks arranged horizontally. Variable *d* is the distance between the artworks. The distance between the artwork and the user is set to 150 cm

Four transmitter units were placed horizontally against the wall. We experimented with three distances – 50 cm, 100 cm, and 150 cm – to investigate the robustness of the system (Figure 4.1). For each distance, we conducted 20 attempts to detect the artwork. Each attempt was done in front of one of four transmitters, randomly. The blue circle in Figure 4.1 shows the standing point. In between each attempt, the artwork codes that the speakers were transmitting were also randomized. The results of this experiment are shown in Table 4.1. The results show that the interference and distance between the artworks are inversely proportional, as we expected. The chance of picking a different signal other than the artwork in front decreases as the distance becomes farther.

Distance	50 cm	100 cm	150 cm
Accuracy	55 %	95 %	100 %

Table 4.1: Success rate of artwork detection when artworks are laid out horizontally.

4.1.2 Position Experiment

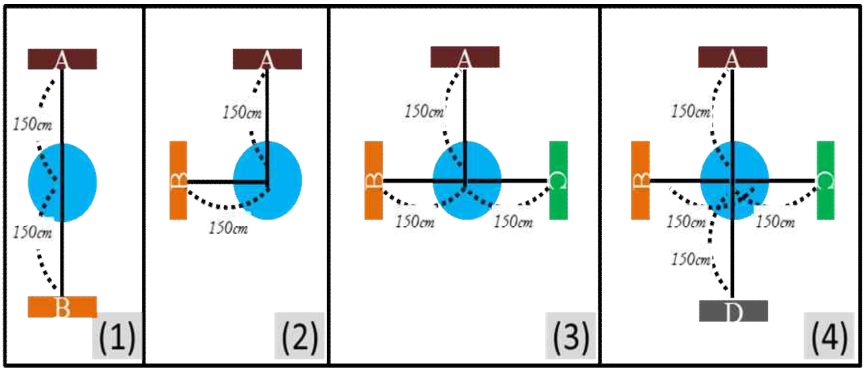

Figure 4.2: Artwork placements in various positions

To simulate worst case scenarios that cause high interferences among the signals, we placed the artworks in four different configurations (Figure 4.2);

(1) Two artworks facing each other

(2) Two artworks placed at a right angle

(3) Three artworks positioned in the shape of a square bracket,

(4) Four artworks in a cross shape

For each configuration, we stood on the artwork observation spot (highlighted in blue circle in Figure 4.2) and faced each artwork ten times. The artwork identification code was randomized before each measurement. Table 4.2 shows the detection accuracy.

Config. / Target	1	2	3	4
A	100 %	90 %	100 %	100 %
B	100 %	100 %	80 %	90 %
C	-	-	100 %	100 %
D	-	-	-	100 %

Table 4.2: Success rate of detection in various artwork configurations.

Contrary to our expectations that the second experiment would suffer from interferences and lead to massive error, the results show that our system successfully detects the target artworks in all configurations. A possible explanation is that because high frequency sounds are extremely directional, the user’s body acted as a “sound shield” against other interfering signals from reaching the mobile device.

4.2 Case Study

4.2.1 Experiment Setup

To let users test and evaluate our system in real-world conditions, we set up our equipment in the Seoul National University, Museum of Art. The system was installed in the “Love Impossible” exhibition. We measured the venue for any noise in the frequency region between 18,000 and 20,000 Hz before installing the system, as we had found that some elevators and electric ballasts create constant noise approximately at 19,000 Hz. The environment did not have any constant noise in the near-ultrasound frequency region, so the experiment was conducted without any calibration process.

Six signal transmitters with PIR sensors installed on 100-cm high steel stands were setup in the exhibition as shown in Figure 4.3. These transmitters were assigned to five paintings, one installation art, and one media art. The transmitters were designed to detect visitor movements using PIR sensors, deciding whether or not to generate the signal. Each movement detection triggered 400 ms of the tone pulse.

Figure 4.3: The system installation in Museum of Art, Seoul National University. Artworks blurred due to museum policy

The Automatic/Manual systems

Two museum guide applications were developed to be evaluated by the users. One application was the Manual System, which required explicit artwork IDs as input to retrieve the artwork information. This type of interface is very common in museums. On every artwork, a three digit number was attached and made visible to users. As the user entered the number on the Manual System, the information of corresponding artwork showed up on the screen.

The other application was the proposed system, but was referred to as the Automatic System in the case study. As described in previous sections, the system was designed to automatically retrieve information of the corresponding artwork the user was standing in front of. Both applications were developed to run on Apples' iPad devices.

Participants

We recruited 12 participants (ages 20-60, 7 male, 5 female) to take part in the case study. 9 people were aged below 30, 1 person between 30 and 50 years, and 2 people were above 50. Most of them were familiar with using the iPad device since they all claimed to own smartphones or tablets.

In our case study, the participants were provided with Apple iPad devices with the two guide applications before entering the exhibition. They were asked to freely roam the exhibition area but were required to view the exhibition at least twice, once with each application. The sequence of using whether Manual/Automatic applications was randomized. After exiting the exhibition, the participants were asked to fill out a survey.

The Exhibition Area

Figure 4.4 shows the structure of the room, the locations of the artworks and installation points of the transmitters. Paintings 3 to 6 were a series of one artwork, so both transmitters between them transmitted the same artwork code (i.e. all four paintings shared the same artwork ID). The transmitter corresponding to the media art was installed near the viewing spot, which is marked as a red X near artwork number 2 in Figure 4.4. The minimum distance between the transmitters was two meters, the distance that was safe from any errors from controlled experiments. The overall transmitting power was restricted to a maximum of 65 dB (A), the same power used in the previous system performance experiment. With this level of sound power, the maximum distance of detection was about 3.2 meters from the transmitter.

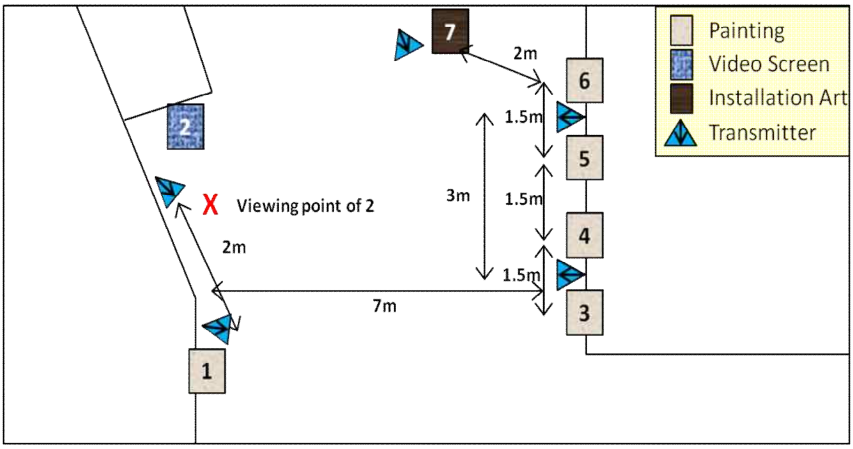

Figure 4.4: Structure and dimensions of the exhibition and locations of the artworks and transmitters. The arrow in the transmitter indicates the direction of the signal

Application Interface

To provide users with artwork information, both manual and the automatic applications had the same artwork information screen. Figure 4.5 shows the artwork information view.

For each artwork detected, the following list of items is provided to users:

- Name of artwork
- Name of artist

- Artwork image (Images of Paintings 3 to 6 were cycled through automatically)
- Narration play / stop button: works manually for both Manual and Automatic Systems
- Description of artwork

In the Automatic System, an additional "Begin Detection" button was added on the top of the screen to start the detecting session.

The basic layout of the information and the types of information provided were benchmarked from the Museum of Modern Art (MoMA) mobile application[2].

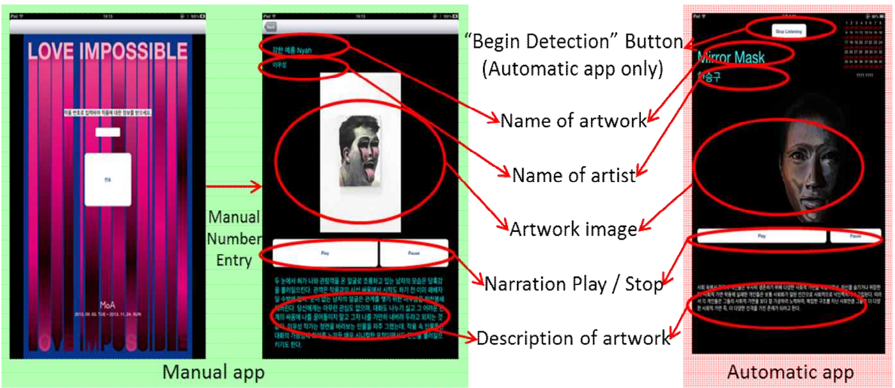

Figure 4.5: Screenshots of the Manual/Automatic Application

[2] MoMA Mobile App. http://www.moma.org/explore/mobile/index.

4.2.2 Case Study Results

After the participants completed the exhibition tour, they were asked to fill out a survey. The first two questions from the survey required users to rate both Automatic and Manual systems on a five-point scale. These two questions compared the Automatic and Manual Systems on the following two aspects:

(1) How easy each system is to use

(2) How each system interferes with user's intention of seamless viewing experience.

Since our case study sample was too small (N = 12) and the distribution of responses was not normally distributed, we used the Wilcoxon Signed-Rank Test to analyze the answers to these two questions. IBM SPSS Statistics version 21 program was used to analyze the data.

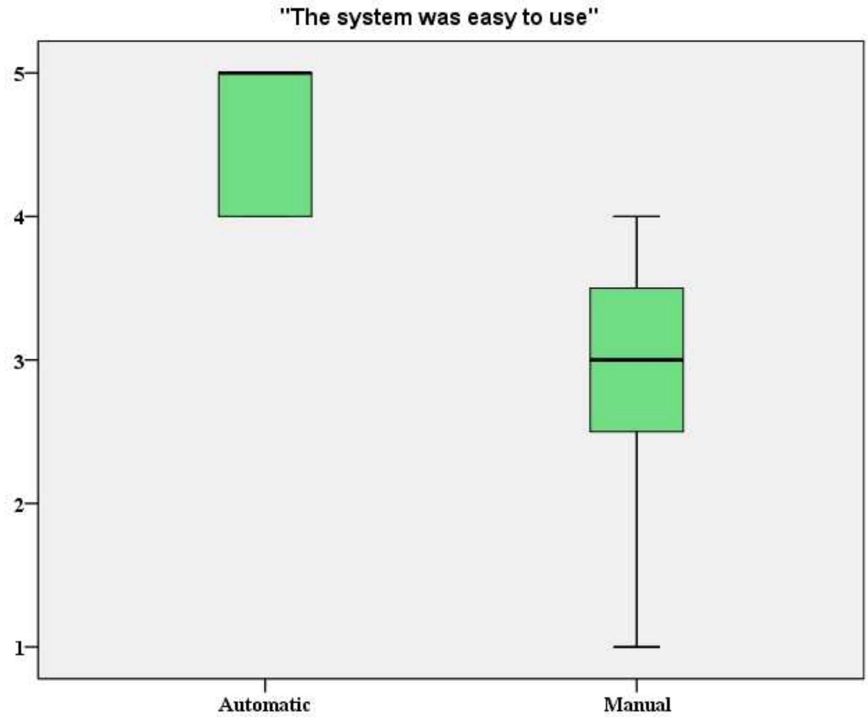

Figure 4.6: Survey result on the question of how easy it was to use the systems

On the question of how easy it was to use the systems, the test indicated that the Automatic System (Mdn = 5) was easier to use than the Manual System (Mdn = 3), Z = -2.979, $p < 0.005$, r = -0.608 (Figure 4.6).

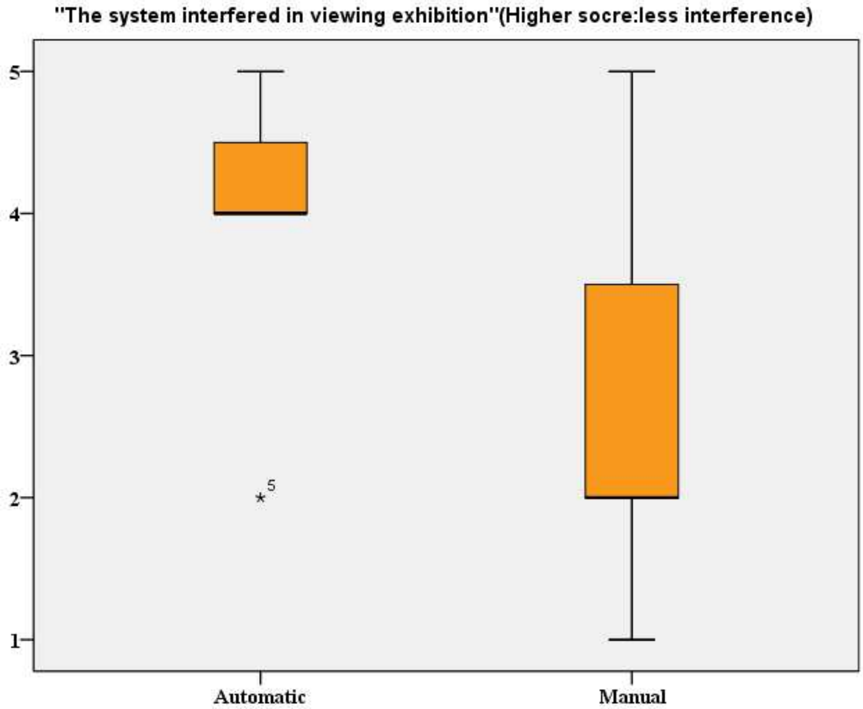

Figure 4.7: Survey result on the question of how interfering the system was in being immersed in the exhibition. Higher score indicates less interference. Sample 5 is shown as an outlier

On how interfering the system was while focusing on viewing the exhibition (higher scores indicate less interference), the test indicated that the Automatic System (Mdn = 4) was less interfering than the Manual System (Mdn = 2), $Z = -2.086$, $p < 0.005$, $r = -0.426$ (Figure 4.7). The sample number 5 is shown as an outlier. The person claimed that the automatic system was annoying since the system automatically changes the viewing information as he/she approaches to artworks.

The following two questions in the survey were phrased in a way so that the participants rated only the Automatic System relative to the Manual System by directly comparing the two on a 5-point scale. A '3' indicated equality between the two systems, '5' indicated that the Automatic System was significantly more effective, and '1' indicated that the Manual System was significantly more effective (Figure 4.8).

For the question "Compared to the Manual System, how helpful was the Automatic System in viewing the exhibition?": 7 people (58.3%) responded that the Automatic System was significantly more effective; 4 people (33.3%) responded that the Automatic System was slightly more effective; and 1 person (8.3%) responded that the two systems were equal.

For the question "Compared to the Manual System, how satisfied are you with the Automatic System?": 4 people (33.3%) responded that the Automatic System was significantly more effective; 7 people (58%) responded that the Automatic System was slightly more effective; and 1 person (8.3%) responded that the two systems were equal.

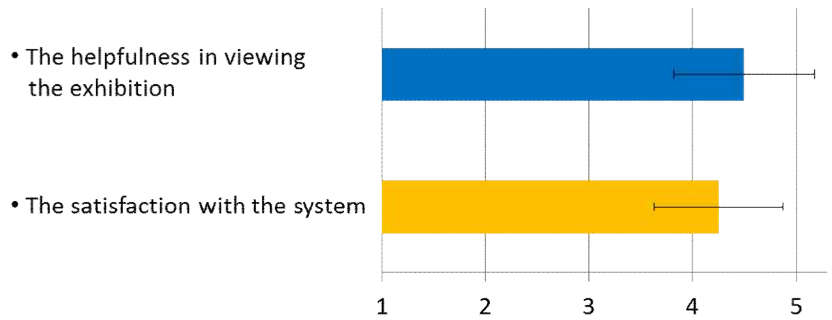

Figure 4.8: Mean responses for rating the Automatic system compared to the

Manual system (Score 1 = the Manual system is more effective, 3 = they are equal and 5 = the Automatic system is more effective). Error bars show standard deviations

The next two questions were asked in typical 5-point Likert scale, of which 1 stands for “strongly disagree” and 5 stands for “strongly agree” (Figure 4.9). When asked about the frequency of errors of the Automatic System, 2 people (16.7%) reported no errors at all (Strongly disagree); 6 people (50%) reported no errors (Disagree); 2 people reported neutral; and 2 people reported occasional errors (Agree); and zero person reported extreme errors (Strongly Agree). Participants were not asked explicitly count the number of errors or disturbances, as we wanted the participants to focus on viewing the exhibition while using the two systems naturally.

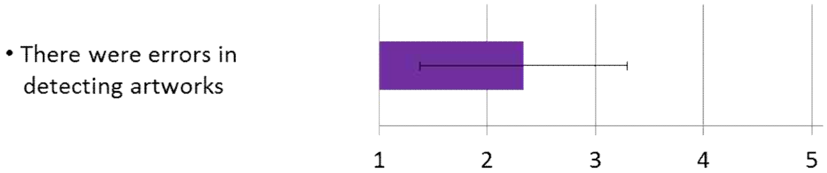

Figure 4.9: Mean responses for rating the Automatic system (Score 1 = strongly disagree, 5 = strongly agree). Error bars show standard deviations

In the next question, we asked about any disturbing sounds recognized related to the transmitter of the Automatic system. 11 people out of 12 responded with no disturbances. However, one person reported several disturbances. The person was the youngest participant in the group. While exhibiting, the participants knew the system utilizes "sound waves" since there were speakers installed in the exhibition. But none of them had any experience of being exposed to near-ultrasound, having no idea what it is, and how it sounds like.

For the last question, "For your next visit, which system would you choose to use and why?", ten out of twelve participants chose the Automatic System and responded very positively to the performance and the concept of the system. However, there were participants who preferred the Manual System, (Including the outlier in Figure 4.7) stating that the Automatic System was distracting and at times annoying because it updated the information automatically as the user moved to another artwork and did not let the users manipulate or change the information themselves. Those participants responded that they wanted to have control over when, where, and which information to view.

Another feedback about the Automatic System from the participants included, "It was convenient because I did not have to input the artwork ID", "It would have been better if it detected the artwork faster", and "It would be better if the speakers (referring to the transmitters) were out of eyesight".

The feedback about the faster detection demand, we assume that it is because of the little delay before generating the transmitting signal, caused by the PIR sensors. While detecting human movement and then triggering the generation of the tone, there does exist approximately 400 ms of the delay in the process.

Chapter 5. Discussion and Future Work

So far, we have proposed a new method for exhibition guide systems, using near-ultrasonic signals. Here we discuss some issues and future directions of the system.

Because the system is using near-ultrasonic tones as the communication signal, the current system has some limitations. The primary barrier that the system confronts is its sensitivity to the energy of incoming signals. During our research, we found that the microphone's ability to pick up higher frequencies drastically decreased as the distance between the device and the sound source increased, beginning with the highest of the higher frequencies. Also, although the extreme directionality of the near-ultrasound helped the accuracy in the above experiments as proven in our "artwork position experiment", it could also be a weakness of the system. For instance, objects that block the path of the mobile device and the sound transmitter for more than a few seconds can also block the incoming sound signal to the mobile device. However, the current system functions well with objects blocking the path of the signal for a brief moment (i.e. person walking in between the artwork and the device).

We assume that the fundamental solution to this problem is changing the transmitter location. During our research, the transmitters were installed at a height of 100cm from the ground, about the waist height of an adult. We have tested placing transmitters on the floor, and on the wall facing 45 degrees downward as well. The installation on the wall performed the best and showed the most robust results even if multiple users are on the same spot. However, it is much more difficult to install the system due to the wires and cables. The solution is left to as future work, and we expect better results with this in scenarios of crowded places.

On another note, although sound with frequencies above 18,000 Hz is known to be inaudible for most adults, they can be audible and annoying to children and animals [38], and may even cause hearing damage [43]. Even during the case study, the youngest participant aged at 24, claimed that he could definitely hear something coming out from the tweeter unit. Because of this issue, controlling the sound level and finding the optimal decibels of signal tone, as well as shifting the current utilized frequency range (18,100 to 20,000 Hz) to higher range will be crucial for use in the real-world.

Additionally, the current system is able to handle up to only 255 (2^8 -1) identifiers since the system uses 8-bit binary transmission. But to be utilized in real museum situations this number is would not be enough to handle every artwork ID. By expanding channels, more than 8-bit binary transmission will be available (i.e. 80 channels makes 16-bit binary transmission possible; handling up to 65,535 (2^16 -1) IDs).

The Manual/Automatic applications used in the case study, both applications are designed to play the narration manually upon users' touch of a button. But some participants wished that the narration would play automatically as the system detects the artwork, while others responded that they prefer the current way, since the automatic playing narration would cause distraction and be annoying to them. Opinions diverged on this issue. Also, we found out that there are artwork knowledge level gaps among the visitors. So we assume that by adding menus reflecting various types of users' preferences such as automatic narration on/off, different description text or narration regarding the knowledge level, would lead to a better system, improving the user experience.

Chapter 6. Conclusion

In this thesis, we proposed an exhibition guide system using inaudible near-ultrasonic sound waves, which enables to provide implicit, seamless interactions in museums or galleries and could also replace traditional methods.

We have developed and tested our prototype, which is a new approach to exhibition guide systems. We have proposed an improved system by implementing a new signal design compared to the previous related work, as well as conducting complete experiments and a case study. The experiments conducted in various configurations showed the robustness of the system against other interfering signals and noises. A case study also showed that the participants favored the proposed system to existing systems and that it was not only easier to use but also helped stay focused in viewing the exhibition. Future work will be dedicated to improve the proposed system by considering and resolving some existing issues that we have mentioned previously.

As the purpose of museum guide systems is to help visitors enjoy exhibitions with useful information and history about the artworks, we believe that the method in this study could result in significant benefits. And also, we expect to stimulate further research in the field of the museum informatics.

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초 록

정보사회의 발달과 유비쿼터스 컴퓨팅이 강조되는 이 시대에서는 유비쿼터스 센서 네트워크(Ubiqutous Sensor Network)이 인간의 주변을 이루고 있다. 식별(Identification) 시스템 혹은 추적(Tracking)으로 불리는 시스템은, RFID나 적외선(Infrared) 등의 기술을 활용하며 다양한 분야에서 활용되고 있다.

이러한 시스템을 필요로 하는 분야는 너무나 다양하며, 미술관 내지는 박물관의 전시(Exhibition) 가이드 시스템 분야도 예외가 될 수 없다.

전시 가이드 시스템은 오래된 역사를 가지고 있으며, 전통적으로는 도슨트(Docent) 내지는 큐레이터(Curator) 라는 명칭의 인력이 방문객들에게 정보 전달을 하는 것이 일반적이다. 하지만 기술의 발전에 따라 인력을 대체하는 기계가 등장하게 되었다. 현재는 모바일 기기의 발전으로 인하여 모바일 앱(App), 각종 센서를 이용하는 시스템 등으로 플랫폼 이동이 벌어지고 있으며, 다양한 형태로 변화, 발전하고 있다.

본 연구에서는 추가적인 센서의 활용이 아닌, 모든 모바일

디바이스가 가지고 있는 기본적인 장치인 마이크와 스피커 만을 사용하여 비가청 초음파 근접대역(Near-ultrasound region)의 음파를 활용하는 전시 가이드 용 식별 시스템을 제안한다. 이러한 방식의 활용으로, 자연스러운 상호작용(Imlpicit interaction)을 가진, 기존 시스템 대비 높은 편의성을 가지고, 추가적인 장치의 구축이 필요하지 않아 높은 호환성 및 낮은 구축 비용이 드는 장점을 가진 시스템의 구현을 연구 목표로 한다.

본 연구에서는 기존에 진행된 연구에서 해결하지 못한, 음파(Sound wave)의 특성으로 생기는 간섭을 극복할 수 있는 음파 신호의 방식을 제안하며, 핵심 시스템을 제안한다. 이후 성능 실험과 사용성 평가를 진행하며, 결과를 통해 연구를 검증한다.

주요어: 비가청 주파수, 전시 가이드, 식별 시스템
학　번: 2012-22465

공학석사 학위논문

Mobile Exhibition Guide System Using Multi-Channel Energy Detection of Near-Ultrasonic Signals

비가청 고주파음역을 활용한

전시가이드 시스템의 구현

2014 년 2 월

서울대학교 대학원

융합과학부 디지털정보융합전공

신 종 규

Abstract

Mobile Exhibition Guide System Using Multi-Channel Energy Detection of Near-Ultrasonic Signals

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This thesis presents a new method for exhibition guide systems, an application for mobile devices that utilizes near-ultrasonic sound waves as communication signals. This system substitutes existing museum or gallery guide systems that use technologies such as infrared sensors, QR codes, RFID, or any other manual input. In the proposed system, a near-field tweeter speaker stands near each piece of artwork and transmits mixed tones in the inaudible frequency range. The receiver application filters interfering noise and pinpoints the signal coming from the nearest artwork, identifies the artwork, and requests the corresponding information from the data server. This process is done automatically and seamlessly, requiring no input from the user. Experiments show that the method is highly accurate and robust to noise, indicating its potential applications to other areas such as indoor positioning systems. In addition, a case study shows that the proposed system is favorable in many aspects compared to existing guide systems.

Keywords: Near-ultrasonic; Inaudible frequency; Exhibition guide; Audio interface;

Student Number: 2012-22465

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Chapter 1. Introduction

1.1 Background

The extreme growths in amount and variety of information, as well as the necessity of organizing them have led the development of identification and tracking systems. Along with the advancement of the sensor technology, these systems have integrated deeply in people's lives nowadays. We scan barcodes upon purchasing goods, tag RFID-based chips to pay public transportation fares [1], and scan QR codes [2] with smart phones near the bus stations to check the transport schedules. Such scenarios are common examples that we can find in our everyday lives. Thus, we can say that we are living in a world of ubiquitous sensor network, and it is no exaggeration to say that these identification or tracking systems have infinite possibilities to be utilized in variety of areas [3].

Museums or galleries, the environments where exhibit and manage thousands of artworks are no exception for utilizing these systems. Especially, to provide exhibition visitors with detailed information about the artworks automatically, it is essential for those environments to establish the identification systems.

Most museum visitors appreciate information that accompanies the artworks, such as the descriptions or histories of the artworks. Thus, museums use a couple of traditional form of guides to provide such supplementary information. The first channel is using the paper-based pamphlets or brochures. They are basically printed materials with text and pictures, providing information in passive form. The second channel is carried by people, who are called as the docents or the curators. They are people who are experts in art histories with high level of artwork related knowledge. Usually, at certain scheduled time, the docents or curators lead the group of visitors and take a tour of the exhibition. In this tour, the group stops in every artwork spot and is provided with detailed information about the artworks. The bidirectional communication is available in this form of guides, so in case a visitor has a question about the artworks, it can be handled instantly by the expert. This can be considered as a definite advantage of the human-based guide systems. However, mechanical audio guide systems are rapidly replacing human guides as the docents lack in immediacy, availability, and have high operating costs [4]. Additionally, some visitors can claim that as the human guide "announces" the same level of information to the group, it is not possible to satisfy everyone in the group with having different knowledge levels about the exhibition.

The first mechanical guide system used the cassette tapes with recorded narration voices. In the system, the visitor manipulates manually to play/stop the tape to obtain the information in aural form [5]. The next generation system utilized compact discs (CD) instead of cassette tapes. Nowadays, the system is nearly standardized as using the key-pressing devices, by assigning every artwork with individual number codes [6]. There are even commercial systems providing a total solution of implementing these mechanical guide systems including the infrastructure installation, such as the Sennheiser's GuidePort system [7] or systems from Antenna International [8].

1.2 Motivation and Objectives

As mentioned above, the mechanical audio guides in museums or galleries are very common and easy to find nowadays. Examples of typical recent mechanical audio guide systems are shown in Figure 1.1. Usually these systems are comprised of digital devices housed in a small plastic cases and work by pressing physical buttons. When a visitor enters a certain numeric code assigned to the artwork, the system retrieves the related content by using the IR (Infrared) sensor technology and provides it back to the user in an auditory and/or visual form.

Figure 1.1: Examples of typical exhibition audio guide system (Adapted from reference [7] [9])

This is a common scenario for visitors who want to look at the artworks in a museum. However, it is possible for users to find this ordinary system frustrating, as they need to enter numbers every time they need information about the artworks they are interested in, and also usually visitors have to pay certain fee to use them. As an alternative, more recently introduced systems use RFID, NFC or QR codes, enabling an easier and faster identification of artworks. However, these systems basically provide point-to-point user interfaces due to their close-by contact mechanism, and thus users may have to wait in line to have a clear line of sight of the corresponding codes. Also, these systems require additional actions such as swiping/tagging (RFID, NFC), or holding (QR codes) for users, creating the need for explicit interactions.

In order to overcome the abovementioned problems, this thesis proposes an effective interaction method for museum guides using near-ultrasonic sound waves on mobile devices. The near-ultrasound is the sound region which has frequency ranging from 18,000 to above. This sound region is also called as the Very High Frequency (VHF) or inaudible high frequency. Usually it is inaudible to human ears but audible to most of consumer grade audio playing/recording equipment.

There are several advantages to our approach. First, since this system is designed to work as an application for mobile devices, the visitor' s own device is used as the receiver device. This removes the necessity of other external devices and results in cost reduction and a maintenance-free environment for museums and also leads to the possibility of creating a new business model by making the paid app, such as substituting the admission fee for the price of the app. Second, the system utilizes the radiation property of sound waves, which enables point-to-multipoint communication between an artwork and simultaneous users. Third, as smart devices have large LCD screens, we can provide users with visual information using rich media, such as videos or pictures, in addition to basic audio. Finally, the automatic detection of the artwork nearest to the user's device enables the user to become free of having to explicitly input information, which is an important feature of ubiquitous computing technology as it attempts to merge computational artifacts smoothly with the world of physical artifacts [10] .

The objective of this thesis is to propose a more robust exhibition guide system using sound waves as the identification/tracking signals, as well as having following properties;

(1) Low cost implementation by freeing the necessity of additional devices
(2) High compatibility by not utilizing additional sensors/devices
(3) Minimizing explicit interactions
(4) Providing point-to-multipoint interface, handling multiple users simultaneously

Unlike using the light, it is difficult to control the radiation of the sound waves. So when using it for the identification system as the triggering signal, it is inevitable to confront interference and errors. Thus, we present novel methods for preventing them by establishing several filters and different signal modulation technique in this thesis.

1.3 Thesis Organization

The rest of the thesis is organized as follows: In Chapter 2, we present existing methods and applications related to our work, and define the limitations of them. In the following Chapter 3, we explain our proposed system in detail. We then present the experimental procedures, results and the case study to show the feasibility of the proposed system in Chapter 4, followed by directions for the discussion and future work in Chapter 5. This thesis concludes in Chapter 6.

Chapter 2. Related Work

2.1 Mobile-Based Exhibition Guides

There are numerous cases of museums or exhibitions utilizing smart mobile devices for their guide systems. Comparing to the traditional manual key-pressing “audio guide” systems, these mobile-based systems can provide additional visual feedback to users by utilizing their large, high-resolution LCD screens, enhancing the user experience.

The mobile-based exhibition guide systems can be categorized into two groups (Table 2.1);

(1) Passive systems which require users’ manual input

(2) Active systems providing automated information delivery
utilizing the sensor network.

System Category	Utilized Method
Passive Systems	Manual Key Pressing, Content Hierarchy Browsing, etc.
Active Systems	GPS, RFID, QR code, Augmented Reality, Ultrasound, Bluetooth, etc.

Table 2.1: The classification of mechanical exhibition guide systems

Recently, some museums provide their own mobile applications. Such applications usually are in the passive form, in the format of artwork archives (i.e. encyclopedia style) and do not provide interactive, efficient communication for users. These systems can be considered as the “digitalized pamphlets or brochures”, and they usually require manual input or additional procedures such as number entry or manual searching in lists of artwork names to identify the target artwork.

Although these systems are not able to provide automated information delivery to users, still they are possible to provide more organized interface compared to the paper-based guides, as well as videos and audio information which are not possible to be utilized in traditional paper form. The Like-o-meter in the PEACH project [11] and the research of Celentano et al. [12] focuses on efficient user interface and organized information hierarchy in digitalized guide applications. In the Like-o-meter application, both “Like “and “Dislike” buttons exist in the interface. If the user responds with “Like” button to the shown information, the system provides with detailed information while it stops and recommends other activity if the user has responded with “Dislike”. By this method, user can obtain information that fits his/her knowledge level and preference. Celentano et al. suggests the efficient design principles and content structure of mobile app-based guide system interface. They suggested a way to establish standards to contents grouping by categorizing their characteristics, and processed a usability test as well.

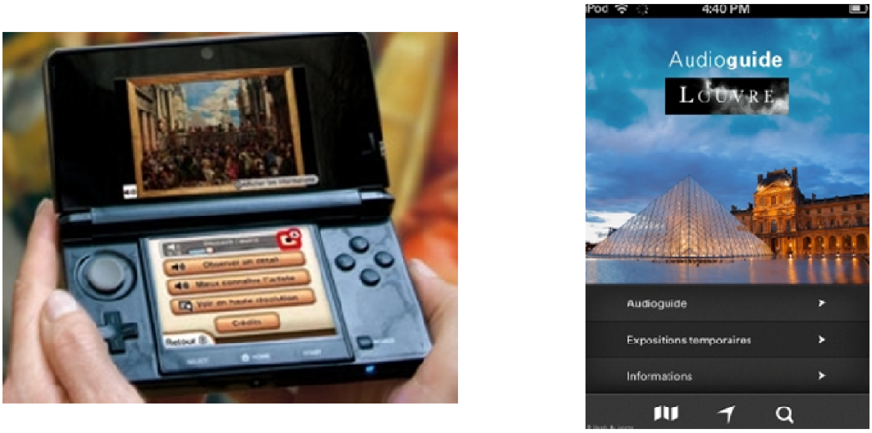

Figure 2.1: Exhibition guide applications of Louvre museum (Adapted from reference [13])

The Figure 2.1 shows the Louvre museum guide systems. They provide their guide systems in three ways. First, the traditional mechanical exhibition guide system, second, the app-based guide application for smart mobile device, and finally, a Nintendo 3DS based guide [14]. Utilizing the divided-screen characteristic of the Nintendo 3DS, users can select the information from the "Navigation" tab located in the touch screen below, and see the corresponding information including text, picture, and even 3D modeling graphics on some dimensional artwork in the upper screen of the device.

The passive systems have advantage in low cost in implementation since the infrastructure installation is not necessary, which is a benefit for the hosts of the exhibitions. However, they lack in terms of effective information delivery as they require explicit interaction to users. This leads to the problem that it makes users to interact with the guide system, not with the artworks.

This misleads the basic principle of the exhibition guide systems, which is to help users focus the artworks. To overcome this limitation, numerous research and methods on the active systems have been proposed.

The active systems utilize various types of integrated or additional sensors with the mobile devices. By this, it enables half-automatic or full-automatic information delivery to users by identifying or tracking them. This result of this enables the bidirectional communication establishment as well as the implicit interaction interface provided to users. And also, it becomes possible to provide additional interactive features in the system.

The Scan and Tilt [15] system is an interactive museum guide on mobile devices, which uses the device's accelerometer as well as external RFID transmitters and additional RFID receivers on devices. The RFID reader equipment is installed in certain spots of the exhibition. The information is obtained by scanning RFID sensors near the artworks. The users then use tilting gestures to control and navigate the application interface. The Hippie [16] system has similar idea, but instead of RFID it utilizes additional IR(Infrared) receivers attached to users' devices. The IR signal transmitters are installed in the entrances of rooms and provide the information of the room when the user enters the zone. Both RFID and IR are commonly used technology and also provide low cost of sensors, but recent smart mobile devices usually do not have such sensors integrated. This leads to the necessity the dedicated devices or additional sensors/devices attached to users' typical smart mobile devices.

The PhoneGuide system by Bruns et al. uses Bluetooth technology with Nokia's Symbian OS to create the digital exhibition guide system [17]. This system can be categorized as an indoor localization/positioning system rather than an identification system. Several Bluetooth beacons create a virtual grid that divides the exhibition space. Then, the system recognizes the users' coarse location. Using neural networks, the mapping of artworks is done and the information of the nearest artwork to the user shows up on the screen of the device. However, the Bluetooth technology requires the pairing process in order to communicate between the devices for the first time, which are a time-consuming process that takes several seconds. Also due to its diverse technology versions, it lacks in terms of compatibility.

There are some approaches implementing augmented reality technology into the museums [18]. The LISTEN concept of Terrenghi & Zimmerman adapted tailored audio augmented reality based technology in art museums [19]. Users in the exhibition wore wireless headphones. Meanwhile, interactive 3-dimensional audio was emitted through virtual sound sources in the room. Through this, personalized and contextual audio information about the exhibits is provided to the visitors. The project of Bimber et al. utilized computer graphics and augmented reality techniques and provided projected overlays on the background with customizable image adjustments, such as color and intensity [20]. Through this process, the image could be dynamically rendered in real-time, resulting in the integration of visual information directly into the artwork.

Schmalstieg & Wargner used see-through augmented reality that provided interaction with augmented exhibits in museums [21]. Using Pocket PC PDA cameras, the devices showed the real environment image on the screen on one layer. On top of that, another layer with virtual elements was overlaid. This makes the users' device act as a "magic lens", providing users with additional information that they cannot see in the real world. Improving this system's performance and concept, Miyashita utilized additional marker objects, tracking the camera and rotation sensors of the device [22]. This resulted in creating a "hybrid" museum user tracking/guiding technology.

These methods are basically the same concept of visual augmented reality technology that utilizes GPS and accelerometer sensor of smart devices in outside environment. But since it is not possible to utilize the GPS location indoors, the common property of abovementioned methods is that they all have additional technology establishment to track the users. Those are usually certain "marks" or "spots" which are installed in real-environment, to let the device for tracking the location of the users. However, some are claimed to cause visual disturbance [23]. In terms of visual disturbance, the Blatannkoden Project [24] has the same issue since it uses QR codes as "visual markers". It is a mobile game in the museum for treasure hunt using QR codes, and is designed for young students aged from 11 to 14 to provide entertainment in exhibitions. QR codes were installed in the Norsk Telemuseum. The secret answers which can be obtained after scanning the QR codes provided answers to a sequence of riddles. Utilizing the built-in cameras of users' own mobile devices, the children could find the answers through the QR codes inside the exhibition.

The Navilog system is a computer vision-based mobile guide system [25]. The visitor simply takes the picture of the environment by the smart tablet device and selects the region of interest. After that, the system detects the certain region of the image, then show the corresponding information back to the user's device. This system removes the risk of visual disturbance since it is using image processing instead of establishing markers or APs for localization. However, the processes of taking pictures and selecting certain region of the image cause explicit interaction.

2.2 Methods Utilizing Near-Ultrasound

Near-ultrasonic signals are used in some applications, taking advantage of its inaudibility. Shopkick [26][27] and SonicNotify [28] are both commercial applications that use similar technology to the system in this thesis. Basically, these systems act as identification systems and provide targeted marketing services. The radiation feature of the sound waves enables point-to-multipoint interface, unlike other close-by contact mechanism based systems.

The Shopkick system is installed in various areas of retail shops. In this system, a satellite speaker called as a “beacon” generates a certain range of inaudible frequency tones and it works as the transmitter. A smartphone works as the receiver and decodes the tone, then shows the according messages. While identification is done by the near-ultrasonic signal, the message/information retrieval is done by the other network channels, such as 3G, LTE, or Wi-Fi. Through these messages, users obtain benefits such as merchandise/service discount coupons.

SonicNotify also uses similar technology, but also provides a framework that can be utilized and customized by the users. As a result, even small retail shop owners who are not familiar with computer technology can create their own SonicNotify system easily.

The DingDong system [29] from LG Uplus is also for the targeted-marketing service and has the same concept as the Shopkick. Nonetheless, instead of using the near-ultrasound for transmitting data, this system utilizes tone in near-infrasonic region. The near-infrasound is the sound wave that has frequency near 20 Hz, around the bottom limit of human hearing range [30]. Just like the near-ultrasound, the near-infrasound is inaudible to most human, but audible to most electronic devices. But unlike near-ultrasound, the long exposure to infrasound has possibility to cause vibroacoustic disease due to its high diffractiveness [31].

Another example of near-ultrasound application is Yamaha's Infosound, which works as an advertising application by mixing certain inaudible tones to the original television sound [32].

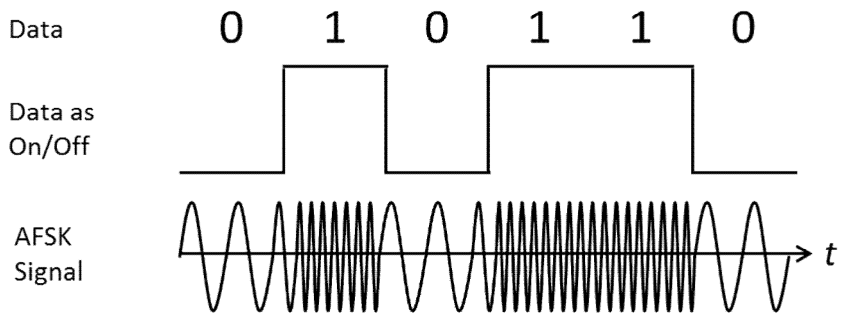

Figure 2.2: An example of data using Audio Frequency Shift Keying

A commonly used method to transmit data in such systems is Audio Frequency Shift Keying (AFSK). As shown in Figure 2.2, it utilizes two frequencies to transmit data [33]. One frequency represents ones and the remaining frequency represents zeros. By turning these frequencies on and off, binary data can be transmitted through inaudible audio.

Another similar system is the Arentz [34][35] method, which uses one frequency with pulse length modulation. Because this modulation technique only utilizes one frequency channel, it has advantage of saving the bandwidth by 50 percent compared to the AFSK.

These methods transmit data sequentially and have special ‘start’ and ‘stop’ signals that indicate the beginning and end of the transmission. In the case of errors, a retransmission is needed, which requires the establishment of a correction or synchronization procedure, such as an Automatic Repeat re-Quest (ARQ) system. Implementing such procedures makes the system increasingly complex and hard to implement.

2.3 Exhibition Guide System Utilizing Near-Ultrasound

The Smartguide is a similar museum guide system to the system in this thesis, which uses near-ultrasonic tones as the exhibit identifying method [23]. The Smartguide system is mainly composed of two parts: 1) a VHF sound emitter called beacons and 2) a mobile application that serves as the client. When a user passes by an emitter, the device receives the encoded tone and decodes it, then provides the relevant information back to the user by retrieving information via the Wi-Fi or cellular network.

But since the system only uses two signals using aforementioned Audio Frequency Shift Keying (AFSK) for encoding the tone, the tone is dependent to the time domain, which leads to an error when the signal has missing or erroneous data while transmitting. Every bit has 26 ms of duration, so to transmit 8-bit data takes total time of 208 ms.

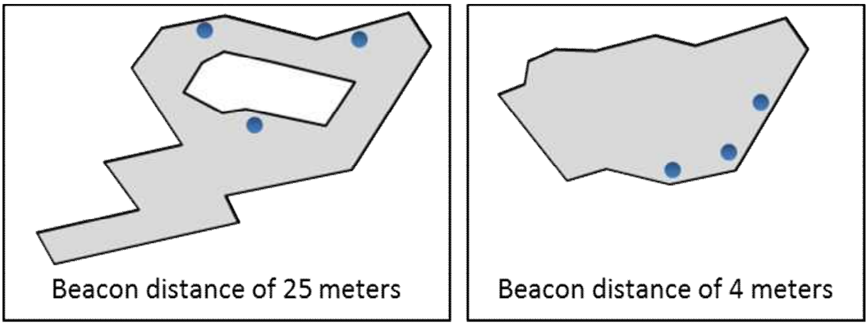

Figure 2.3: Transmitter locations of Smartguide system experiment on two different floors with different transmitter distances (Redrawn from reference [23])

Also it has a high error rate due to the interference of other signal beacons and confronts scalability issues. As shown in Figure 2.3, during the experiment in Deutsches Transrapid museum, they installed total of six beacons in two floors. On one floor the transmitters were installed at intervals of 25 meters, and four meters in another floor. To minimize interference, they did not establish an ARQ algorithm, however implemented to give random delay time ranging from 20 ms to 525 ms to all transmitters.

In addition, the Smartguide system receives information on all the artworks in a given space. The user then manually selects the information that is relevant to the artwork he/she is interested in. In this thesis, we propose a system that automates the above process, requiring no input from the user and successfully detecting the nearest artwork.

In the next Chapter, we present a concept that is the key to implementing an identification system for exhibitions that utilizes near-ultrasonic sound waves and improves on the limitations of the previous studies.

Chapter 3. Research Method

3.1 Near-Ultrasound

The human audible frequency is known to range from 20 Hz to 20,000 Hz [36]. But generally most adults aged over 20 are only able to detect frequencies up to 18,000 Hz, as the ability to hear high-pitched sounds reduces gradually as people get older [37][38]. There are a number of researches about age-associated high frequency hearing loss [39] [40].

Percentile	10%	25%	50%	75%	90%
Age (Years)	Upper Limit Frequency (kHz)				
10-19	19.3	18.4	17.2	15.7	15.0
20-29	18.0	17.1	15.9	14.9	13.8
30-39	16.6	15.2	14.5	13.6	12.4
40-49	14.6	13.8	12.9	11.8	10.6
50-59	13.2	12.2	11.0	9.6	8.2
60-69	11.2	9.9	8.3	5.3	1.8

Table 3.1: The average upper limit frequency of human hearing by percentile [38]

In our proposed system, we focus on the inability to sense high frequency sounds and take advantage of this.

Although most people cannot hear frequencies that are higher than 18,000 Hz, many modern mobile devices can detect sounds up to 20,000 Hz or even higher. To testify the feasibility of near-ultrasound on smart devices, A small experiment with several smart devices from four major brands (Apple iPhone 4S, iPhone 5, iPad 2, Samsung Galaxy S3, Galaxy Note, LG Optimus G and HTC Nexus One) was conducted.

Using a Focal CMS-40 speaker which is able to play the frequency from 60 Hz to 28,000 Hz at +/- 3dB, 40 sinusoids at intervals of 50 Hz from 18,000 to 20,000 Hz were generated simultaneously. Each receiving mobile device was placed 50 cm in front of the speaker. Using the integrated audio recording application for the each device, we recorded the sound for two seconds. The sample rate of the devices was all set to 44,100 Hz. After analyzing the frequency components of the recorded sound files on MATLAB, the two examples of the results are shown below.

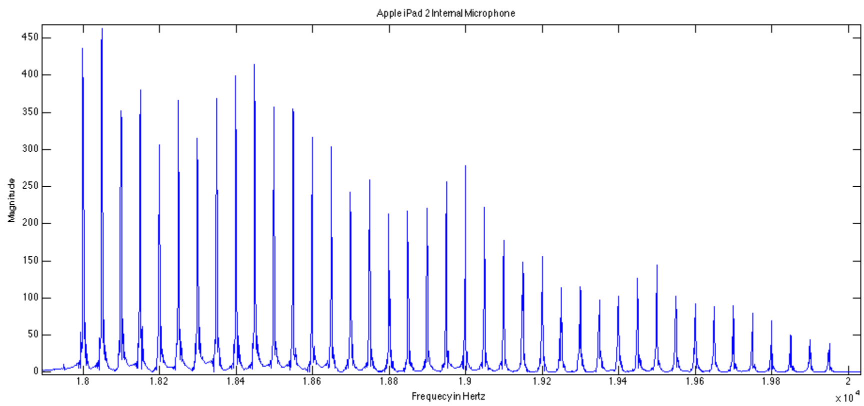

Figure 3.1: 40 channel peaks received by internal microphone of Apple iPad2

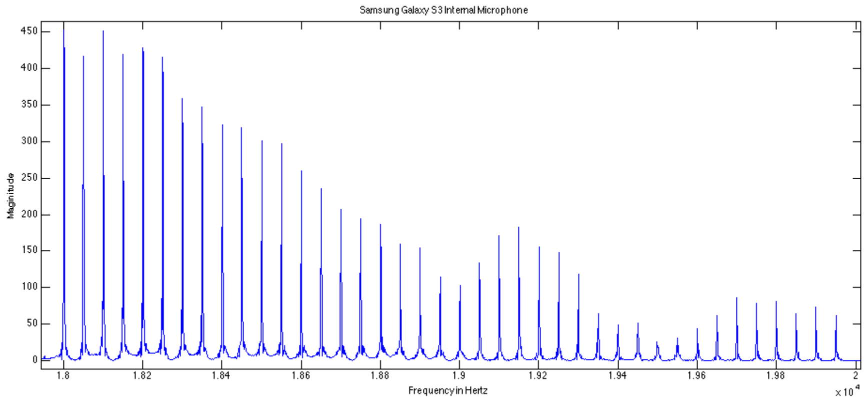

Figure 3.2: 40 channel peaks received by internal microphone of Samsung Galaxy S3

As shown in Figure 3.1 and 3.2, there are differences in level of received energy in each region due to the different frequency response properties of internal microphones, but still it is able to detect the "peak" of the regions. Rest of devices only varied the energy value, and all were able to detect near-ultrasound.

3.2 System Configuration

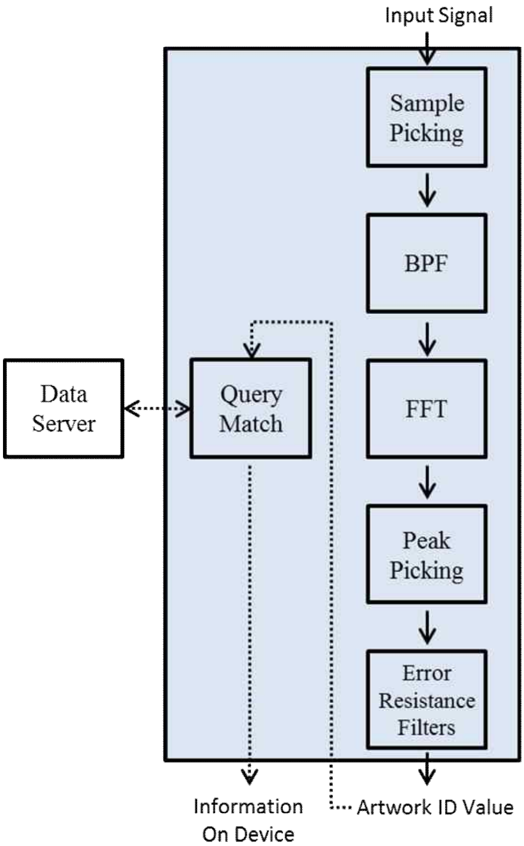

Figure 3.3: System flow diagram

The system utilizes two kinds of communication channels. One that uses near-ultrasonic tones is used for identifying the artworks, and another channel that uses Wi-Fi network to retrieve according information of the ID. The basic system flow diagram is shown in Figure 3.3.

The system is composed of four main components as shown in Figure 3.4. First, each artwork has a small tweeter speaker that generates an audio signal in the inaudible range. Second, the Pyroelectric Infrared (PIR) sensor attached to Arduino boards beneath the speaker detects human motions and generates tones to be received by the receiver. PIR sensors are used to minimize unnecessary signals and reduce interference with other signals. Third, the application on a smart device receives the signal via its internal microphone and decodes the tone. In the final process, the application sends the detected artwork ID to the server using the WI-FI network. The server then looks for the corresponding information about the artwork in the database, and sends it back to the application. Because IDs are assigned uniquely to the artworks, the inaudible signal from the tweeter speaker is only used as a "trigger" signal and does not contain any artwork data itself.

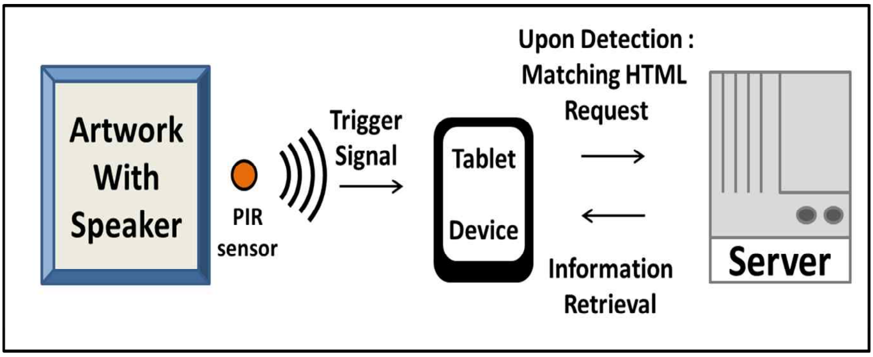

Figure 3.4: The four main components of the system

3.3 Implementation

The system was developed using Pure Data[1] to generate high frequency sound signals, and iOS SDK 5, to implement the receiver app on iOS.

Our guide system uses 40 pre-determined frequency channels in the human-inaudible range, between 18,100 Hz and 20,000 Hz. These 40 frequency channels act as binary on/off signals to transmit data from a transmitter to the mobile device. These signals are then processed to filter interference from other transmitters and pinpoint the signal coming from the transmitter that is nearest to the mobile device. In contrast to methods such as Audio Frequency Shift Keying, our method of transmitting data is easy to implement as it does not require syncing of the transmission and receiver devices.

The Transmitter

Pure Data, a programming environment for audio and video processing, was used to generate the 40 signals. These signals were pure sine waves having frequency values as one of the pre-determined 40 frequencies. In the perspective of the receiver, these 40 frequencies were the "channels" to listen to. These signals were sent in 400 ms pulses (Figure 3.5), which acted as another basic precaution for interference from other signals in addition to the PIR sensors. 8 channels are used to transfer a complete "message" that

[1] Pure Data. http://www.puredata.info.

identifies a unique artwork. Thus, the same messages are redundantly transmitted 5 times, simultaneously, to reduce error. Therefore, 5 copies of an 8-bit message are sent in one pulse to the mobile device. With 8 bits of information it is possible to identify 255 different artworks (2^8 – 1 combinations, since it is impossible to identify a signal with all zeros). The basic structure of the tone resembles the combination of the on/off keying (OOK) [41] and multi-frequency signaling (MF) [42] technique.

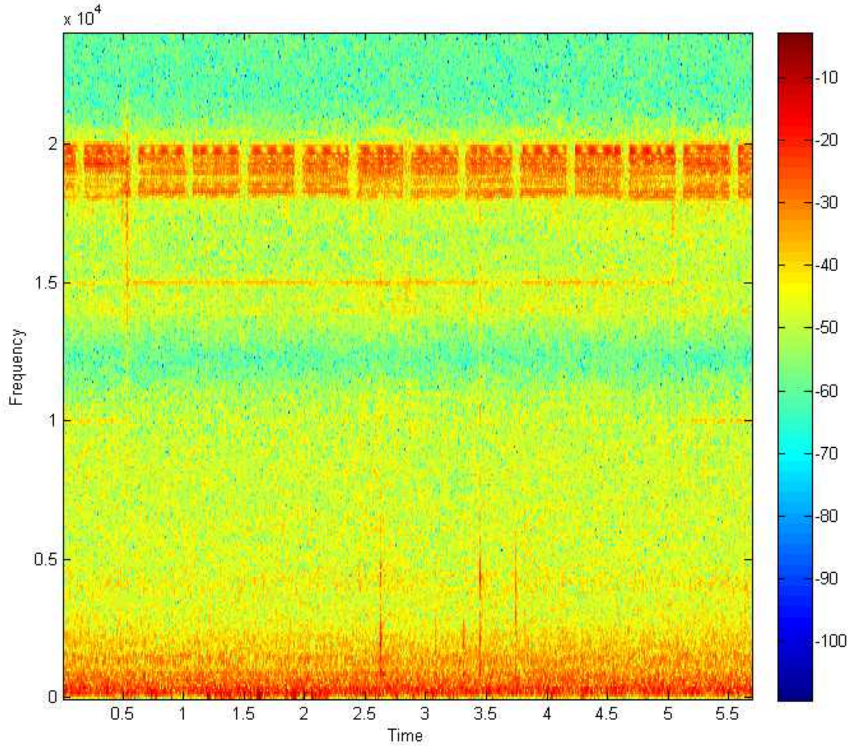

Figure 3.5: Magnitude spectrogram of the tone. X axis stands for time, Y axis stands for frequency. Each signal pulse has a length of 400 ms and 50 ms of interval

Figure 3.7 illustrates an example of a transmitted signal. The data, or message, being transmitted is “01011001”, which is the identification code of a particular artwork. The message requires 8 channels, or frequencies, to transmit at once. Here, the second, fourth, fifth, and eighth channels are activated, thus producing the “01011001” message. These first eight channels correspond to a complete message indicated by Set 1 in the Figure.

To handle errors during transmission, the same message is transmitted four more times using higher frequencies. The next eight frequencies, or channels, are then used to transmit the same data. This is repeated until all 40 channels are used. Thus, the same message is redundantly sent 5 times with each pulse.

The advantage of using 40 frequency channels of signals is that the data is transmitted as a whole, rather than a sequence of bits. Each pulse from the tweeter speaker unit (Figure 3.6) contains all the data that is needed to identify the artwork.

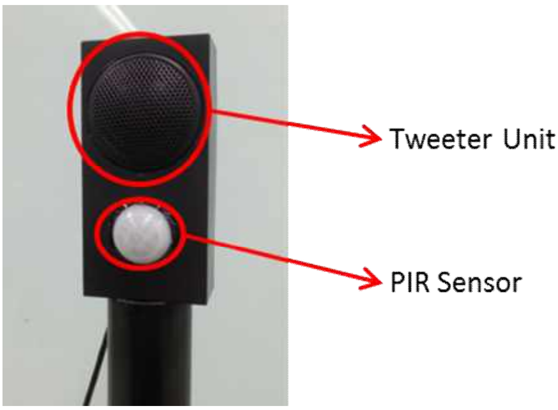

Figure 3.6: Transmitter components

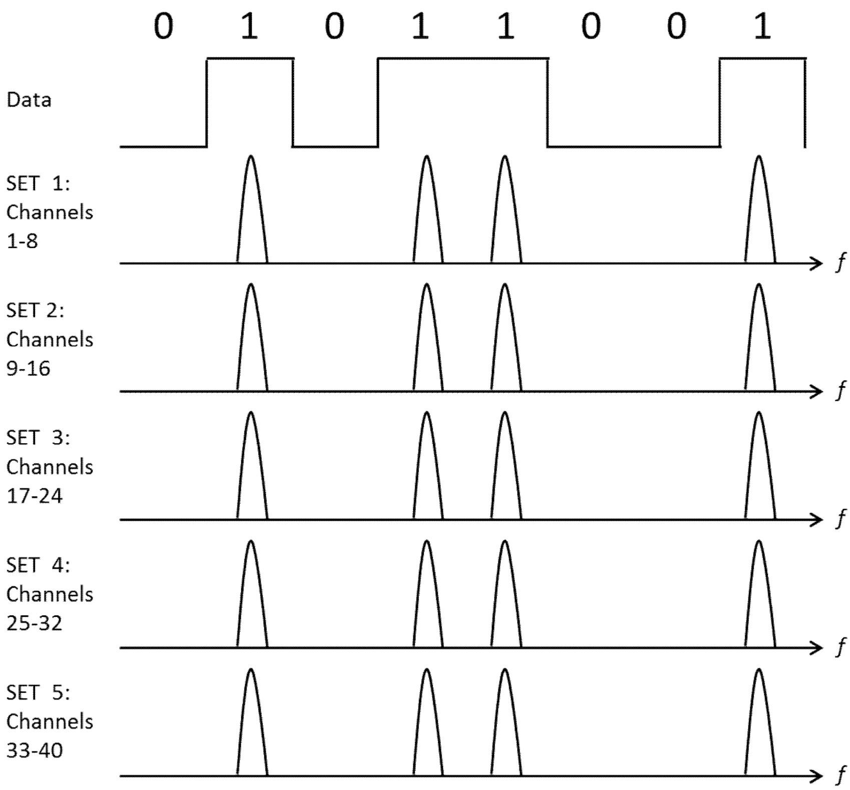

Figure 3.7: Example of a message sent by the transmitter using 40 frequency channels

The output signal from Pure Data was connected to the tweeter speaker units. A 20-watt stereo amplifier with a Tripath TA2020 IC chip was utilized for amplifying these passive tweeter units.

Pyroelectric Infrared (PIR) sensors (Figure 3.6) were placed below each tweeter speaker unit to detect movement, which triggers several pulses of the artwork identification signal. These PIR sensors are controlled by Arduino UNO boards.

The Receiver

With the iOS SDK, we implemented a mobile application that listened to sound frequencies in the inaudible range and analyzed the incoming 8-bit message. To analyze the energy of the sound detected from the mobile device's microphone, we used the Fast Fourier Transform (FFT) in Apple's vDSP portion of the Xcode Accelerate Framework. This process enables the conversion of the incoming sound signal from the time-domain to the frequency-domain, making the signal analyzable by the device.

The incoming sound is passed through a high-pass filter to eliminate ambient noise and any other noise sources within the normal hearing range. We designed the filter to ignore all sound peak data under 18,000 Hz. Through the Fast Fourier Transform, energy spikes at the predetermined frequency channels are detected. The list of predetermined frequency channels are in Table 3.2. They are the center frequencies of FFT bins, selected 40 out of 43 channels in range of 18,100 Hz to 20,000 Hz. The FFT resolution was set to 1024 at the sample rate of 44,100 Hz. Interfering signals from nearby artworks were eliminated as much as possible by having an energy threshold for a channel to be considered activated.

Channel Number	Frequency	BIN	Channel Number	Frequency	BIN
1	18130	421	21	18992	441
2	18174	422	22	19035	442
3	18217	423	23	19078	443
4	18260	424	24	19121	444
5	18303	425	25	19164	445
6	18346	426	26	19207	446
7	18389	427	27	19250	447
8	18432	428	28	19293	448
9	18475	429	29	19336	449
10	18518	430	30	19379	450
11	18561	431	31	19422	451
12	18604	432	32	19466	452
13	18647	433	33	19509	453
14	18690	434	34	19552	454
15	18733	435	35	19595	455
16	18776	436	36	19638	456
17	18820	437	37	19681	457
18	18863	438	38	19724	458
19	18906	439	39	19767	459
20	18949	440	40	19810	460

Table 3.2: The list of 40 channels used at FFT size of 1024

Figure 3.8 illustrates an example of the data received via one pulse of a signal by the transmitter. The majority bit is used to predict the transmitted signal. In this example, the predicted message would correctly be "01011001" despite having errors in Sets 3 and 4. However, there are additional precautions in predicting the message by sampling the incoming pulses until three consecutive samplings have matching messages. Each sampling interval was 50 ms, so one pulse from the transmitter could be sampled multiple times by the receiver.

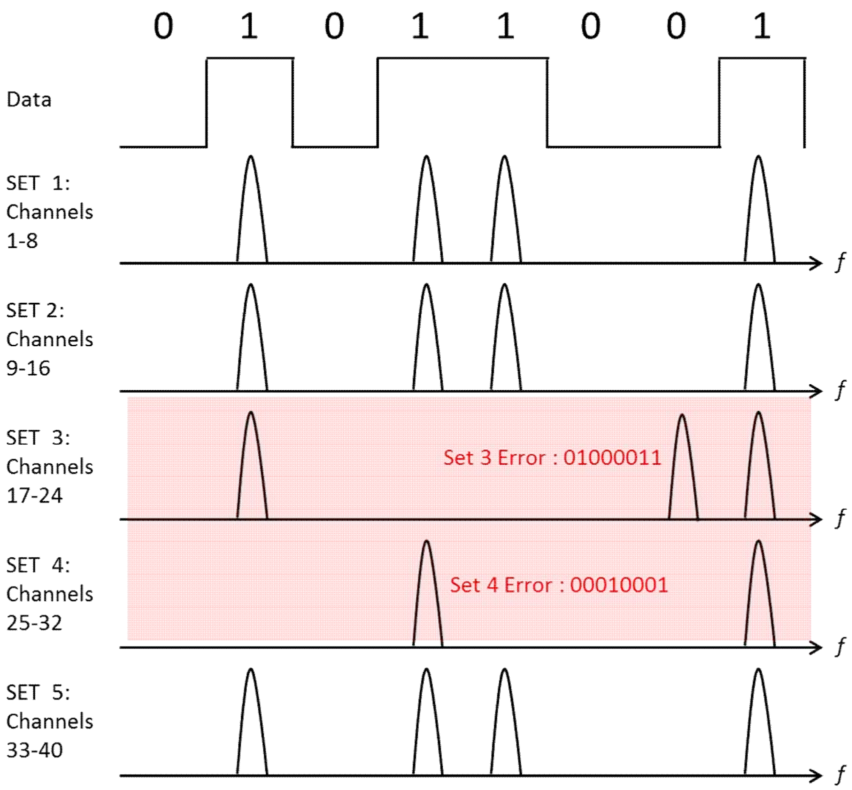

Figure 3.8: Example of a message received by the receiver with errors

During our research we found that higher frequency channels tended to be weaker in terms of transmitting power. Thus, higher frequencies were less reliable compared to the lower frequency channels. Thus, when doing a majority bit vote, frequency Sets 4 and 5 had less "voting power" and were assigned a vote value of 0.8. Sets 1 and 2 were reliable frequencies as they were in lower range, and were given a vote value of 1.2.

As described above, the system has deliberate redundancies to minimize errors and be robust to interfering signals from nearby artworks.

Once the artwork ID was identified, the according information on the artwork was displayed on the mobile device. The data transmission is done via the Wi-Fi network. The data server was designed as a standard HTTP web server using the open source Apache HTTP server project.

Chapter 4. Experiments

4.1 Performance Test

We performed several tests in various conditions of interference to examine the feasibility and the error rate of the proposed system. We set up our equipment in a quiet rectangular room with dimensions of 5m x 12m. Using an Extech 407750 sound level meter, the environmental noise level of the room was measured to be around 44 to 50 dB (A). We chose the "distance between the artworks" and the "layout of artworks" as the two variables of our experiments. We defined the "artwork observation spot" to be 150cm away from the artwork while directly facing it.

Four Lanzar TCS-1 one-inch tweeter speaker units were used as the signal transmitters and played the role of artworks. Since the system only utilizes near-ultrasonic frequencies, we used these tweeter speakers, which had a frequency response of ranging from 2,500 to 24,000 Hz. Also the small size of the unit is an advantage as it is easier to be "hidden" in installations, minimizing its presence in the exhibitions. The tweeter units were installed on steel stands that were 100cm high. In these experiments, the PIR sensors on the transmitters were all disabled and designed to generate constant signal instead of using the pulses. This was to create the worst-case scenario, in which all signals from multiple speakers are generated simultaneously and interfering with each other. Also, the sound levels of the transmitters were restricted to a maximum of 65 dB (A).

We had two people (simulating other visitors) to walk freely around the artworks and block the communication between the mobile device and the transmitter. Tests were considered a success if the system detected the front facing artwork, and a failure if it detected nearby artworks or failed to detect anything at all.

4.1.1 Distance Experiment

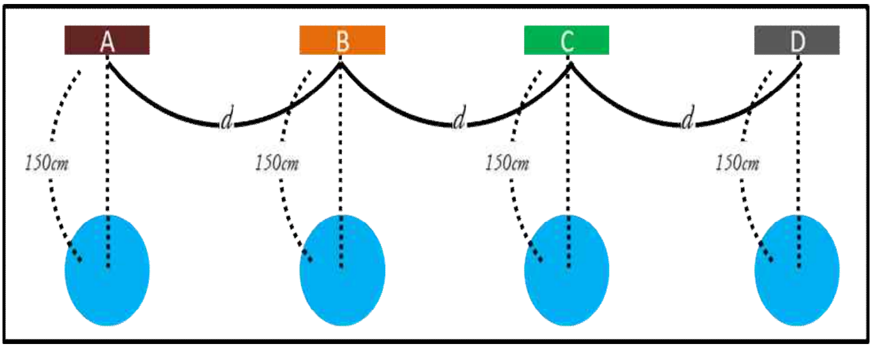

Figure 4.1: Artworks arranged horizontally. Variable *d* is the distance between the artworks. The distance between the artwork and the user is set to 150 cm

Four transmitter units were placed horizontally against the wall. We experimented with three distances – 50 cm, 100 cm, and 150 cm – to investigate the robustness of the system (Figure 4.1). For each distance, we conducted 20 attempts to detect the artwork. Each attempt was done in front of one of four transmitters, randomly. The blue circle in Figure 4.1 shows the standing point. In between each attempt, the artwork codes that the speakers were transmitting were also randomized. The results of this experiment are shown in Table 4.1. The results show that the interference and distance between the artworks are inversely proportional, as we expected. The chance of picking a different signal other than the artwork in front decreases as the distance becomes farther.

Distance	50 cm	100 cm	150 cm
Accuracy	55 %	95 %	100 %

Table 4.1: Success rate of artwork detection when artworks are laid out horizontally.

4.1.2 Position Experiment

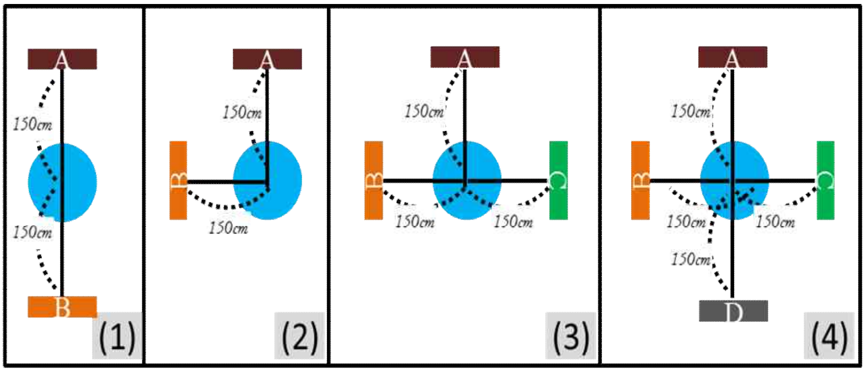

Figure 4.2: Artwork placements in various positions

To simulate worst case scenarios that cause high interferences among the signals, we placed the artworks in four different configurations (Figure 4.2);

(1) Two artworks facing each other

(2) Two artworks placed at a right angle

(3) Three artworks positioned in the shape of a square bracket,

(4) Four artworks in a cross shape

For each configuration, we stood on the artwork observation spot (highlighted in blue circle in Figure 4.2) and faced each artwork ten times. The artwork identification code was randomized before each measurement. Table 4.2 shows the detection accuracy.

Config. / Target	1	2	3	4
A	100 %	90 %	100 %	100 %
B	100 %	100 %	80 %	90 %
C	-	-	100 %	100 %
D	-	-	-	100 %

Table 4.2: Success rate of detection in various artwork configurations.

Contrary to our expectations that the second experiment would suffer from interferences and lead to massive error, the results show that our system successfully detects the target artworks in all configurations. A possible explanation is that because high frequency sounds are extremely directional, the user’s body acted as a “sound shield” against other interfering signals from reaching the mobile device.

4.2 Case Study

4.2.1 Experiment Setup

To let users test and evaluate our system in real-world conditions, we set up our equipment in the Seoul National University, Museum of Art. The system was installed in the “Love Impossible” exhibition. We measured the venue for any noise in the frequency region between 18,000 and 20,000 Hz before installing the system, as we had found that some elevators and electric ballasts create constant noise approximately at 19,000 Hz. The environment did not have any constant noise in the near-ultrasound frequency region, so the experiment was conducted without any calibration process.

Six signal transmitters with PIR sensors installed on 100-cm high steel stands were setup in the exhibition as shown in Figure 4.3. These transmitters were assigned to five paintings, one installation art, and one media art. The transmitters were designed to detect visitor movements using PIR sensors, deciding whether or not to generate the signal. Each movement detection triggered 400 ms of the tone pulse.

Figure 4.3: The system installation in Museum of Art, Seoul National University. Artworks blurred due to museum policy

The Automatic/Manual systems

Two museum guide applications were developed to be evaluated by the users. One application was the Manual System, which required explicit artwork IDs as input to retrieve the artwork information. This type of interface is very common in museums. On every artwork, a three digit number was attached and made visible to users. As the user entered the number on the Manual System, the information of corresponding artwork showed up on the screen.

The other application was the proposed system, but was referred to as the Automatic System in the case study. As described in previous sections, the system was designed to automatically retrieve information of the corresponding artwork the user was standing in front of. Both applications were developed to run on Apples' iPad devices.

Participants

We recruited 12 participants (ages 20-60, 7 male, 5 female) to take part in the case study. 9 people were aged below 30, 1 person between 30 and 50 years, and 2 people were above 50. Most of them were familiar with using the iPad device since they all claimed to own smartphones or tablets.

In our case study, the participants were provided with Apple iPad devices with the two guide applications before entering the exhibition. They were asked to freely roam the exhibition area but were required to view the exhibition at least twice, once with each application. The sequence of using whether Manual/Automatic applications was randomized. After exiting the exhibition, the participants were asked to fill out a survey.

The Exhibition Area

Figure 4.4 shows the structure of the room, the locations of the artworks and installation points of the transmitters. Paintings 3 to 6 were a series of one artwork, so both transmitters between them transmitted the same artwork code (i.e. all four paintings shared the same artwork ID). The transmitter corresponding to the media art was installed near the viewing spot, which is marked as a red X near artwork number 2 in Figure 4.4. The minimum distance between the transmitters was two meters, the distance that was safe from any errors from controlled experiments. The overall transmitting power was restricted to a maximum of 65 dB (A), the same power used in the previous system performance experiment. With this level of sound power, the maximum distance of detection was about 3.2 meters from the transmitter.

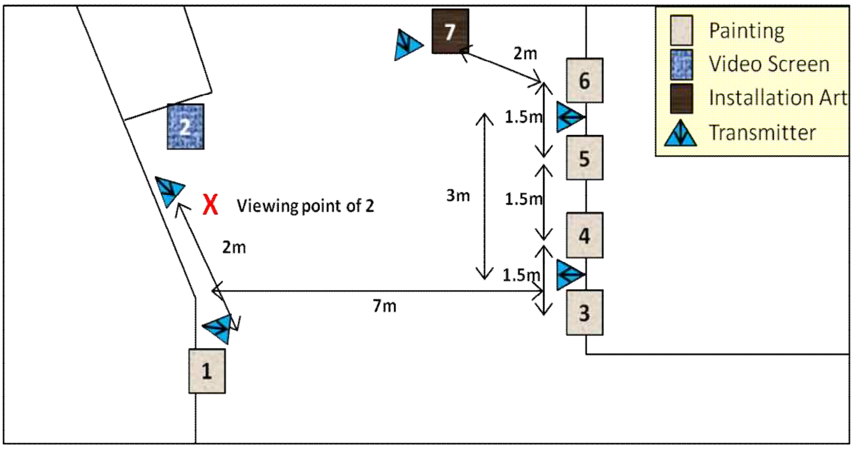

Figure 4.4: Structure and dimensions of the exhibition and locations of the artworks and transmitters. The arrow in the transmitter indicates the direction of the signal

Application Interface

To provide users with artwork information, both manual and the automatic applications had the same artwork information screen. Figure 4.5 shows the artwork information view.

For each artwork detected, the following list of items is provided to users:

- Name of artwork
- Name of artist

- Artwork image (Images of Paintings 3 to 6 were cycled through automatically)
- Narration play / stop button: works manually for both Manual and Automatic Systems
- Description of artwork

In the Automatic System, an additional "Begin Detection" button was added on the top of the screen to start the detecting session.

The basic layout of the information and the types of information provided were benchmarked from the Museum of Modern Art (MoMA) mobile application[2].

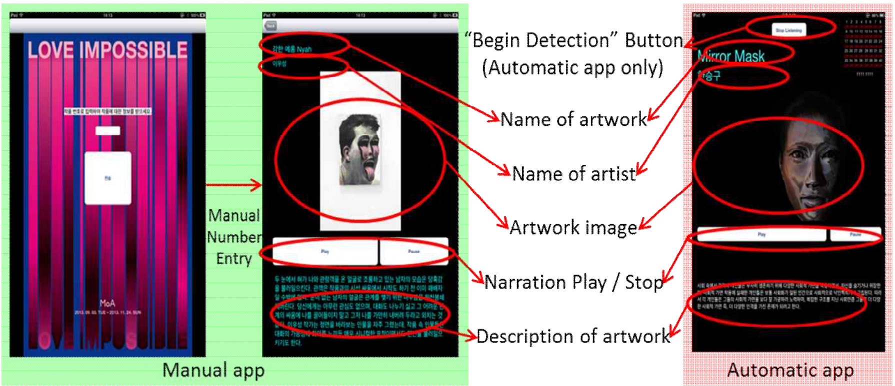

Figure 4.5: Screenshots of the Manual/Automatic Application

[2] MoMA Mobile App. http://www.moma.org/explore/mobile/index.

4.2.2 Case Study Results

After the participants completed the exhibition tour, they were asked to fill out a survey. The first two questions from the survey required users to rate both Automatic and Manual systems on a five-point scale. These two questions compared the Automatic and Manual Systems on the following two aspects:

(1) How easy each system is to use

(2) How each system interferes with user's intention of seamless viewing experience.

Since our case study sample was too small (N = 12) and the distribution of responses was not normally distributed, we used the Wilcoxon Signed-Rank Test to analyze the answers to these two questions. IBM SPSS Statistics version 21 program was used to analyze the data.

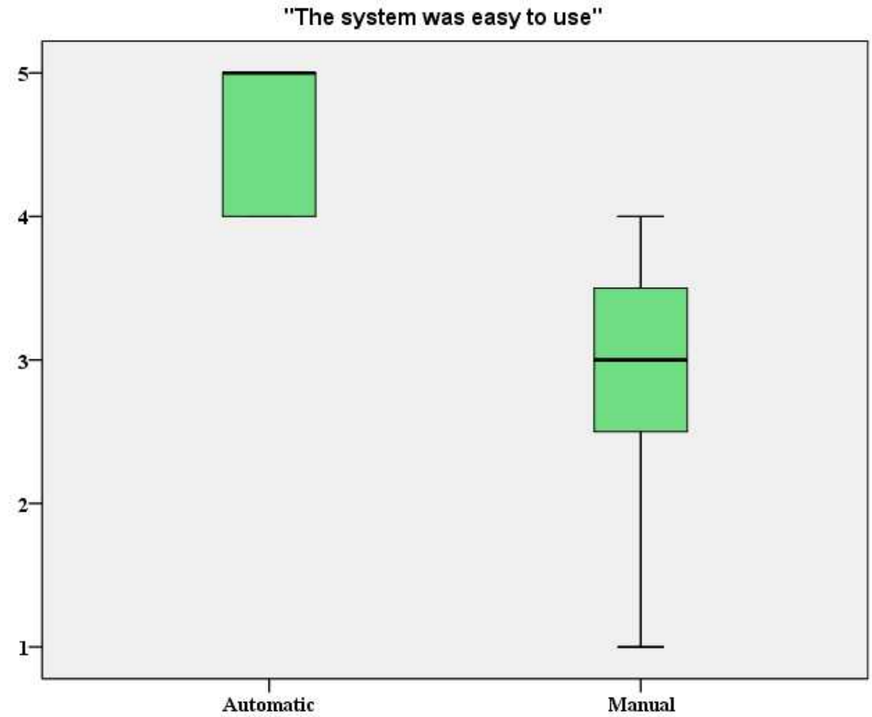

Figure 4.6: Survey result on the question of how easy it was to use the systems

On the question of how easy it was to use the systems, the test indicated that the Automatic System (Mdn = 5) was easier to use than the Manual System (Mdn = 3), Z = -2.979, $p < 0.005$, r = -0.608 (Figure 4.6).

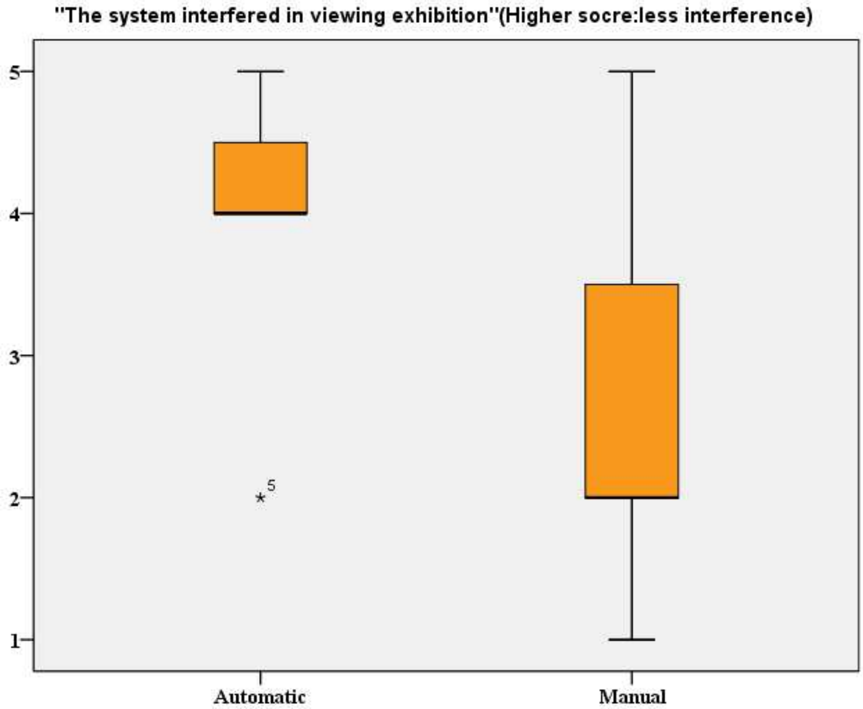

Figure 4.7: Survey result on the question of how interfering the system was in being immersed in the exhibition. Higher score indicates less interference. Sample 5 is shown as an outlier

On how interfering the system was while focusing on viewing the exhibition (higher scores indicate less interference), the test indicated that the Automatic System (Mdn = 4) was less interfering than the Manual System (Mdn = 2), $Z = -2.086$, $p < 0.005$, $r = -0.426$ (Figure 4.7). The sample number 5 is shown as an outlier. The person claimed that the automatic system was annoying since the system automatically changes the viewing information as he/she approaches to artworks.

The following two questions in the survey were phrased in a way so that the participants rated only the Automatic System relative to the Manual System by directly comparing the two on a 5-point scale. A '3' indicated equality between the two systems, '5' indicated that the Automatic System was significantly more effective, and '1' indicated that the Manual System was significantly more effective (Figure 4.8).

For the question "Compared to the Manual System, how helpful was the Automatic System in viewing the exhibition?": 7 people (58.3%) responded that the Automatic System was significantly more effective; 4 people (33.3%) responded that the Automatic System was slightly more effective; and 1 person (8.3%) responded that the two systems were equal.

For the question "Compared to the Manual System, how satisfied are you with the Automatic System?": 4 people (33.3%) responded that the Automatic System was significantly more effective; 7 people (58%) responded that the Automatic System was slightly more effective; and 1 person (8.3%) responded that the two systems were equal.

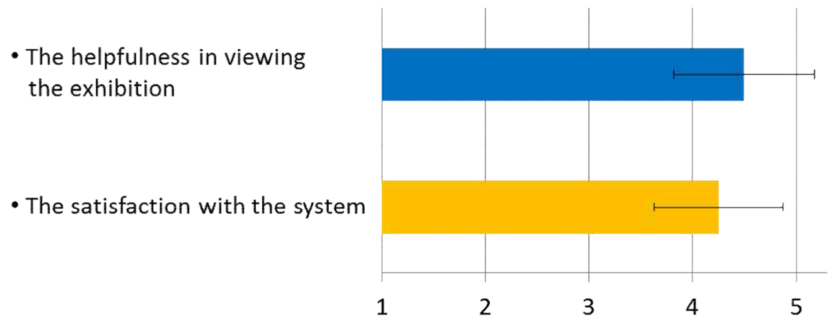

Figure 4.8: Mean responses for rating the Automatic system compared to the

Manual system (Score 1 = the Manual system is more effective, 3 = they are equal and 5 = the Automatic system is more effective). Error bars show standard deviations

The next two questions were asked in typical 5-point Likert scale, of which 1 stands for "strongly disagree" and 5 stands for "strongly agree" (Figure 4.9). When asked about the frequency of errors of the Automatic System, 2 people (16.7%) reported no errors at all (Strongly disagree); 6 people (50%) reported no errors (Disagree); 2 people reported neutral; and 2 people reported occasional errors (Agree); and zero person reported extreme errors (Strongly Agree). Participants were not asked explicitly count the number of errors or disturbances, as we wanted the participants to focus on viewing the exhibition while using the two systems naturally.

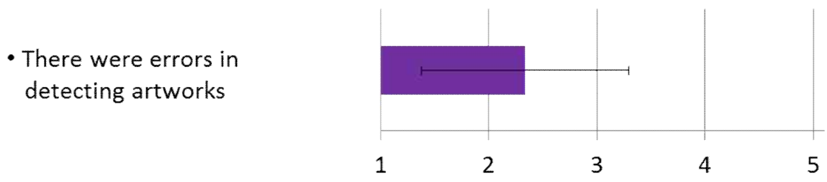

Figure 4.9: Mean responses for rating the Automatic system (Score 1 = strongly disagree, 5 = strongly agree). Error bars show standard deviations

In the next question, we asked about any disturbing sounds recognized related to the transmitter of the Automatic system. 11 people out of 12 responded with no disturbances. However, one person reported several disturbances. The person was the youngest participant in the group. While exhibiting, the participants knew the system utilizes “sound waves” since there were speakers installed in the exhibition. But none of them had any experience of being exposed to near-ultrasound, having no idea what it is, and how it sounds like.

For the last question, “For your next visit, which system would you choose to use and why?”, ten out of twelve participants chose the Automatic System and responded very positively to the performance and the concept of the system. However, there were participants who preferred the Manual System, (Including the outlier in Figure 4.7) stating that the Automatic System was distracting and at times annoying because it updated the information automatically as the user moved to another artwork and did not let the users manipulate or change the information themselves. Those participants responded that they wanted to have control over when, where, and which information to view.

Another feedback about the Automatic System from the participants included, “It was convenient because I did not have to input the artwork ID”, “It would have been better if it detected the artwork faster”, and “It would be better if the speakers (referring to the transmitters) were out of eyesight”.

The feedback about the faster detection demand, we assume that it is because of the little delay before generating the transmitting signal, caused by the PIR sensors. While detecting human movement and then triggering the generation of the tone, there does exist approximately 400 ms of the delay in the process.

Chapter 5. Discussion and Future Work

So far, we have proposed a new method for exhibition guide systems, using near-ultrasonic signals. Here we discuss some issues and future directions of the system.

Because the system is using near-ultrasonic tones as the communication signal, the current system has some limitations. The primary barrier that the system confronts is its sensitivity to the energy of incoming signals. During our research, we found that the microphone's ability to pick up higher frequencies drastically decreased as the distance between the device and the sound source increased, beginning with the highest of the higher frequencies. Also, although the extreme directionality of the near-ultrasound helped the accuracy in the above experiments as proven in our "artwork position experiment", it could also be a weakness of the system. For instance, objects that block the path of the mobile device and the sound transmitter for more than a few seconds can also block the incoming sound signal to the mobile device. However, the current system functions well with objects blocking the path of the signal for a brief moment (i.e. person walking in between the artwork and the device).

We assume that the fundamental solution to this problem is changing the transmitter location. During our research, the transmitters were installed at a height of 100cm from the ground, about the waist height of an adult. We have tested placing transmitters on the floor, and on the wall facing 45 degrees downward as well. The installation on the wall performed the best and showed the most robust results even if multiple users are on the same spot. However, it is much more difficult to install the system due to the wires and cables. The solution is left to as future work, and we expect better results with this in scenarios of crowded places.

On another note, although sound with frequencies above 18,000 Hz is known to be inaudible for most adults, they can be audible and annoying to children and animals [38], and may even cause hearing damage [43]. Even during the case study, the youngest participant aged at 24, claimed that he could definitely hear something coming out from the tweeter unit. Because of this issue, controlling the sound level and finding the optimal decibels of signal tone, as well as shifting the current utilized frequency range (18,100 to 20,000 Hz) to higher range will be crucial for use in the real-world.

Additionally, the current system is able to handle up to only 255 (2^8 -1) identifiers since the system uses 8-bit binary transmission. But to be utilized in real museum situations this number is would not be enough to handle every artwork ID. By expanding channels, more than 8-bit binary transmission will be available (i.e. 80 channels makes 16-bit binary transmission possible; handling up to 65,535 (2^16 -1) IDs).

The Manual/Automatic applications used in the case study, both applications are designed to play the narration manually upon users' touch of a button. But some participants wished that the narration would play automatically as the system detects the artwork, while others responded that they prefer the current way, since the automatic playing narration would cause distraction and be annoying to them. Opinions diverged on this issue. Also, we found out that there are artwork knowledge level gaps among the visitors. So we assume that by adding menus reflecting various types of users' preferences such as automatic narration on/off, different description text or narration regarding the knowledge level, would lead to a better system, improving the user experience.

Chapter 6. Conclusion

In this thesis, we proposed an exhibition guide system using inaudible near-ultrasonic sound waves, which enables to provide implicit, seamless interactions in museums or galleries and could also replace traditional methods.

We have developed and tested our prototype, which is a new approach to exhibition guide systems. We have proposed an improved system by implementing a new signal design compared to the previous related work, as well as conducting complete experiments and a case study. The experiments conducted in various configurations showed the robustness of the system against other interfering signals and noises. A case study also showed that the participants favored the proposed system to existing systems and that it was not only easier to use but also helped stay focused in viewing the exhibition. Future work will be dedicated to improve the proposed system by considering and resolving some existing issues that we have mentioned previously.

As the purpose of museum guide systems is to help visitors enjoy exhibitions with useful information and history about the artworks, we believe that the method in this study could result in significant benefits. And also, we expect to stimulate further research in the field of the museum informatics.

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초 록

정보사회의 발달과 유비쿼터스 컴퓨팅이 강조되는 이 시대에서는 유비쿼터스 센서 네트워크(Ubiqutous Sensor Network)이 인간의 주변을 이루고 있다. 식별(Identification) 시스템 혹은 추적(Tracking)으로 불리는 시스템은, RFID나 적외선(Infrared) 등의 기술을 활용하며 다양한 분야에서 활용되고 있다.

이러한 시스템을 필요로 하는 분야는 너무나 다양하며, 미술관 내지는 박물관의 전시(Exhibition) 가이드 시스템 분야도 예외가 될 수 없다.

전시 가이드 시스템은 오래된 역사를 가지고 있으며, 전통적으로는 도슨트(Docent) 내지는 큐레이터(Curator) 라는 명칭의 인력이 방문객들에게 정보 전달을 하는 것이 일반적이다. 하지만 기술의 발전에 따라 인력을 대체하는 기계가 등장하게 되었다. 현재는 모바일 기기의 발전으로 인하여 모바일 앱(App), 각종 센서를 이용하는 시스템 등으로 플랫폼 이동이 벌어지고 있으며, 다양한 형태로 변화, 발전하고 있다.

본 연구에서는 추가적인 센서의 활용이 아닌, 모든 모바일

디바이스가 가지고 있는 기본적인 장치인 마이크와 스피커 만을 사용하여 비가청 초음파 근접대역(Near-ultrasound region)의 음파를 활용하는 전시 가이드 용 식별 시스템을 제안한다. 이러한 방식의 활용으로, 자연스러운 상호작용(Imlpicit interaction)을 가진, 기존 시스템 대비 높은 편의성을 가지고, 추가적인 장치의 구축이 필요하지 않아 높은 호환성 및 낮은 구축 비용이 드는 장점을 가진 시스템의 구현을 연구 목표로 한다.

본 연구에서는 기존에 진행된 연구에서 해결하지 못한, 음파(Sound wave)의 특성으로 생기는 간섭을 극복할 수 있는 음파 신호의 방식을 제안하며, 핵심 시스템을 제안한다. 이후 성능 실험과 사용성 평가를 진행하며, 결과를 통해 연구를 검증한다.

주요어: 비가청 주파수, 전시 가이드, 식별 시스템
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