THE FUSION OF ULTRASONIC AND SPATIALLY AWARE SYSTEM IN MOBILE-INTERACTION DEVICE

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ABSTRACT

Over the past four decades, the prophecy from computer pundits and prognosticators pointed that looming arrival of the paperless office era was coming. However, forty years later, physical paper documents are still playing a significant role due to the ease of use, superior readability, and availability. However, the drawbacks of paper sheets are hard to modify and retrieve, and environmental unfriendly. Camera-based recognition and detection devices have been proposed to augment paper document with digital information to overcome the drawbacks. However, there are still some limitations exist in these systems.

Different from previous approaches, this study presents a novel, spatially aware, mobile system (called Ultrasonic PhoneLens) which adopts 2-Dimensional dynamic image presentation and ultrasonic sound positioning technique. In this study, an asynchronous network is developed to smooth the movement of a mobile device within a large workplace. The results indicate that our application is robust and multifunctional.

ACKNOWLEDGEMENTS

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LIST OF ABBREVIATIONS

2D………………………… 2-Dimensional

3D………………………… 3-Dimensional

RFID……………………… Radio Frequency Identification

SVG………………………. Scalable Vector Graphics

GPS………………………. Global Positioning System

SAS………………………. Spatial Awareness System

ID………………………… Identification

LED………………………. Light Emitting Diode

AR…………………………Augmented Reality

GQM………………………Goal Question Metric

PSSUQ………………...…. Post-Study System Usability Questionnaire

1. INTRODUCTION

Currently, a tremendous transformation is taking place in the workplace. The new concept of "the paperless office" aims to replace all the traditional use of paper with digital representation of information. It is much easier to collect, store, transfer, and combine information in the digital information world. Spatial-aware systems have been invented to support paper-based augmented reality which overlays digital information on traditional paper. However, this is limited by portability and multi-user interactivity.

The need of a portable and multi-user spatially aware application can be applied in many different applications. The objective of this paper is to create a mobile-sized spatial aware system that allows two or more users to work together. The background is briefly described in Section 1.1 and the motivation and problem statement is introduced in Section 1.2. The outline of the thesis is demonstrated in Section 1.3.

1.1. Introduction of Spatial Awareness

Spatial awareness is the ability to make an object aware of itself in a real-world environment. It is a self-recognized knowledge of objects that are relative to oneself, in that given space. The information of spatial awareness refers to the location of an object in a physical or digital world. Therefore, physical and digital information can also be used as resources for spatial awareness. Many spatial awareness systems have been designed and developed in various fields such as web browsing [1], indoor positioning [2], object detection [3] and etc. In 1993, Fitzmaurice's Chameleon [4] proposed a handheld color TV which showed an image from a camera pointed at a graphics workstation. The workstation rendered a 3-dimensional (3D) scene with the view controlled by the position of the TV. The original Wizard-of-Oz implementation of a spatially aware display was introduced by Chameleon [5]. As the computational power of smartphones is increasing, the development of spatial awareness has shifted from traditional computers to mobile devices. It enables new paradigms for developing spatial aware mobile system. These new possibilities require the mobile computing devices to act as a bridge for the gap between the physical and the digital world [6]. Various approaches have been applied to support spatially aware, mobile interactions, such as marker-based methods [7, 8, 9] or content-recognition based solutions [10, 11, 12, 13]. Marker-based approaches convert physical information to digital content, while content-recognition based techniques require high computing power to identify objects in real environments. This work illustrates the benefits of combining the strengths of these two techniques and creates a new, novel, spatially aware, mobile interaction system. This system utilizes the 3D spatial information of a mobile device to augment paper documents with digital information.

1.2. Motivation and Problem Statement

A user can move a spatially aware mobile device over a paper document and the digital information is displayed based on the user's actions. The dynamically visualizing mobile system which provides user-focused information is a typical mobile application that augments paper documents with digital information. However, the mobile device has no ability to directly access a paper document. Spatially aware mobile systems must rely on other hardware to achieve the function of recognizing a user's focus when browsing a paper document. Johnny Chung Lee [14] uses the Wiimote to create Multi-Point Interactive Whiteboards. His invention can replace the information on a paper document with the tablet display but the system reduces the portability because of the large external Wiimote hardware. Marker-based systems [15,16] can work with a large paper sheet without using large hardware. This methodology has a high requirement of computer capability and power. Training sessions are essential and it is hard for an application to provide dynamic and simultaneous results due to the complexity of the calculations. D. R. Reilly [15] developed a marker-based mobile system to combine paper maps with electronic information. This system uses a high performance, compact Radio Frequency Identification reader to recognize the RFID tags on the paper maps. The user can only obtain static electronic information from each tag on a map. In order to address some of the issues mentioned above, the main motivation of this study is to propose a low-cost, portable and high-performance solution for special aware systems. Two ultrasonic sound sensors assembled on an Arduino board provide reliable distance detection in the paper-based working environment. The mini board which is called Arduino transmits the distance as coordinates to a mobile device through Bluetooth. The Scalable Vector Graphics (SVG) formats digital images and stores them in the mobile device. Based on the coordinates detected by the ultrasonic sound sensor, the image file can “spatially aware” the position of an object in the physical environment and provide high-quality graphical outputs on a mobile device screen. The advantages of our system are listed below:

1) **Low cost**: Ultrasonic sound sensors and Arduino boards are readily available, low cost and widely used by students to learn and design electronic projects. Furthermore, smartphones and paper documents are quite common in our lives.

2) **Multi-user communication**: A mobile device connects with an Arduino board via Bluetooth without requiring a wireless network. It is also easy for a Bluetooth module to set the network for mobile-to-mobile communication. The users can share the information with each other without any spatial limitation.

3) **Portable**: The physical size of an Arduino board with Ultrasonic sound sensors is very compact and space-saving. It can be assembled on the bottom of the mobile device which makes Ultrasonic PhoneLens very portable.

In summary, the core contribution is to design an efficient, high accuracy, spatial-aware algorithm for a real-world environment based on inexpensive ultrasonic sound sensors. In addition, I developed a ghost echo erasing framework that supports multi-user interaction without any interference between the ultrasonic sound sensors. A user can add or edit an annotation to modify the information in a digital workplace and send it to his/her partner without any vision interference. Multiple-user interaction allows users to work on a virtual digital platform that is as convenient as a large paper document.

To evaluate our Ultrasonic Phonelens, I developed a comparative, empirical study that requires the participants to use the Ultrasonic PhoneLens to browse digital information on a paper document and make a comparison of other spatial aware systems. The investigator creates the study task and online questionnaire for the tester to obtain objective and subjective feedback from the end user. The results of the study showed a great improvement and usefulness of our proposed system over the other camera-based spatially aware mobile system.

1.3. Outline of Thesis

The thesis is structured in the following manner. In Chapter 2, a description on spatial awareness, ultrasonic sensing technology, camera-based augmented reality, and marker-based augmented reality is introduced. The system architecture and filtering algorithm is described in Chapter 3. A case study on an architectural scenario and observations is presented in Chapter 4. The result and analyze data is discussed in Chapter 5. Finally, I draw conclusions and future work in Chapter 6.

2. RELATED WORK

In this chapter, related works on spatial awareness, ultrasonic sound, camera-based augmented reality, and marker-based augmented reality, are described separately.

2.1. Ultrasonic Sensing Techniques

An ultrasonic sensor is a transducer that converts ultrasound waves to digital signals. The sensor can generate ultrasonic waves and calculate the velocity with which the sound waves travel through the air.

A sonar sensor is the precursor of an ultrasonic sensor. It is perhaps the earliest hardware for processing spatial awareness. In 1985, HP Moravec [17] developed a sonar-based mapping system for mobile robot navigation. The sonar system measures inputs in the robot's environment. Reliable data can be obtained by the sonar sensor. These data can be projected onto a rasterized two-dimensional horizontal map. Moravec is often used as a front-end for Drishya [18]. K. A Drishya added a map environment system and fixed position detection in flying mobile robots to achieve autonomous navigation in Global Positioning System (GPS)-Denied Environments. The body flying robot consists of a flight system and a spatial awareness system (SAS). The SAS enables the aerial robots to self-control flight in the GPS-Denied Environments, such as caves or deserts. Three hardware systems are used for robotic spatial awareness. The accelerometer provides stability and position, and the angular velocity is provided by the gyroscope. An ultrasonic sensor is utilized for obstacle detection, as well.

Since the contributions of Moravec and Drishya are frequently used in autonomous robots, recent systems have recognized the value of combining ultrasonic sensing techniques with digital representation. Surface Mapping Systems using a 3-dimensional scanner, based on ultrasonic sensors, are used to map the shape of an object's surface [19]. The scanner consists of an ultrasonic sensor, a microcontroller and RFID to fuse the data as coordinates of an object's surface. These points are then converted to a 3D image which is produced by Matlab. Surface Mapping System is effective for describing and processing physical objects. This system inspired Chmelar, to develop autonomous mapping to calculate position and distance [20]. He fuses the data from a laser range finder and an ultrasonic sound sensor to create a vector map of unknown space. This autonomous mapping system is reliable but it is hard for autonomous exploring systems to provide complete map information. Hiroki Watanabe [21] developed an application that supports online spatial recognition to detect indoor location from the participant. The system is a wearable computing device which needs the user to carry a speaker. An ultrasonic Identification (ID) is sent from the speaker which it can set up in an environment and on an individual. The system can recognize the position or the user by comparing obtained IDs. These IDs are assigned to each location or person. However, this system cannot provide users with an overview of the graphical layout.

2.2. Camera-based Augmented Reality Techniques

Augmented reality technique is the integration of digital information with physical and real world environments. The elements in the real world are augmented by computer-generated formats such as sound, video or digital images. Basically, the hardware components for augmented reality usually include processor, display, sensors, and input devices. The role of the sensor in augmented reality technique is to detect and observe physical property from the real world environment.

Currently, camera-based augmented reality technique has been widely applied in the field of digital image and traditional paper document interaction. The SESIL [22] is a novel approach to setting up a digital environment to perform the recognition of physical book pages and of specific elements of interest within pages. The pages in books can be captured by a camera. The system can recognize images from the camera and produce an electronic page which can produces an interaction with actual books and pens/pencils. Jee, H [23] designed an electronic learning system which can allow users to read 3D virtual content from traditional textbooks. The main contribution of this paper is the development of a user-friendly tool that creates a 3D modeling environment based on the content of physical book. The virtual environment was created by existing commercial modeling software MayaTM [24]. Ali et al. [25], used a Wii remote and Infrared Light-Emitting Diode (LED) lights to augment a paper-based workplace with digital information. A pair of Infrared LED lights is attached to a mobile device, and the infrared camera in the Wii remote can locate the coordinates of those LEDs through Bluetooth. The mobile device calculates its relative position within a large workspace and displays relevant digital information based on the coordinates from Wii Controller. However, the above proposed device is not portable and is inconvenient since the camera cannot be assembled on a handheld device. That is, it doesn't allow the user to hold the equipment to work wherever and whenever needed. Furthermore, the camera has to be set up in a specific position to catch the whole body of the object. It takes more time and effort for the user to adjust both the camera and the object.

To solve these problems, integrated cameras in handheld devices have been adopted in the field of camera-based augmented reality. Hansen, T [26] used integrated cameras in mobile devices to address how mixed interaction spaces can have different identities, be mapped to applications, and can be visualized. His system can easily determine how devices or objects are manipulated. By applying image analysis algorithms to the camera pictures, the movement or some actions such as rotation and marking, can be determined. The Augmented Reality (AR)

Comic Book [27] aims to enhance readability for children. Children can use their mobile phones to view a 3D image from the comic book. The story book contains small markers which allow the virtual characters to be rendered. But this system is still in the stage of hypothesis. All the markers and 3D image were predefined. The representation of this system is still on a single page of the story book which means the user cannot take the place of the usage of traditional paper media.

2.3. Marker-Based Augmented Reality

Augmented reality is a subject of software development that combines digital data and real environments. It enables real-time interaction between real objects and virtual information. A primary challenge of AR is how to align digital information with the real world. In order to address this problem, a marker-based approach using visual markers can be recognized by computer vision methods.

In 1998, Masutani, Y [28] constructed an augmented, reality-based visualization system to support intravascular neurosurgery and evaluate it in clinical environments. It augments the motion pictures from X-ray fluoroscopy with 3D virtual vascular models. This technique relies on the 3D registration fiducial markers. The data adaptive reprojection technique was introduced to evaluate the reliability of the displayed fluoroscopy. It predicts the number of wrong registrations around the registered objects. The results were compiled using synthetic data consisting of fiducial marker coordinates with 2-Dimensional (2D) or 3D errors. It was perhaps the earliest software that utilized a marker-based approach for augmented reality. As smartphone technology has exploded, marker-based augmented reality has been revolutionized simultaneously. Built-in camera recognition and detection is a recent development which can take advantage of an internal mobile camera to track the markers in a real environment. Klemmer et al. [29] used bar-codes as markers to augment paper transcripts with digital video interviews. The system uses CyberCodes reader [30] to identify real objects by a mobile device. Rohs [16] proposed using 2-dimensional graphical widgets to retrieve the relevant digital information by a camera phone. The widget is a generic, reusable, directly manipulable visual code which is suitable for printing on paper. The four corners of each widget define its own local coordinates. These coordinates provide information which can be used as orientation parameters to reduce the effect of angular deviation. Radio Frequency Identification is another approach to design marker-based mobile devices. D. R. Reilly [15] used RFID tags to create a marker-based mobile system which combines paper maps with digital information. The RFID tags placed in a regular grid set the bottom of the paper map. An RFID reader can be attached to the back of mobile device. It can recognize the RFID tag on the paper map. Infrared light also can be used as a marker to identify the position in a large area. Wen. D [31] studied an indoor tracking system with infrared projected markers for large workplaces. The main part of this system is an infrared projector. The projector generates the infrared markers on the workplace and a user needs to wear a tracking camera which can capture the position and orientation of each infrared marker. The data from the camera is sent to the mobile device through Bluetooth. Based on this information, the mobile device can display digital information from the real environment. The infrared markers do not interfere with the original contents but the system is not portable. The infrared projector has to be installed on the ground or a wall.

All of the above technologies have no capability of displaying dynamic information because of the lack of high performance computing in a mobile device. Smartphone cameras and optical-tracking techniques have been widely used in marker-based augmented reality but none of them are an adequate substitute for users to take digital images compared to traditional paper documents.

2.4. Spatially Aware Computing

Spatially Aware Computing is the ability to observe an object's positional changes in a physical or a digital world. The object of developing spatial aware computing systems is to identify the location of objects in relation to its own body in space. Spatial Aware Virtual Home Region [32] is a good example that uses the Ad Hoc Networks to find the location of each host in the scope of the network. MouseLight [33] integrates spatial aware computing into an interactive paper system. A spatially aware projector is made with a mobile laser projector. It can detect the position of the digital pen and track the handwriting from the end user. Additionally, the location of the projector can also be calculated by the digital pens. Therefore, the users can interact with both the projector and the digital pen simultaneously. However, this application is a bimanual hardware. It is very hard for users to write and operate the system at the same time. For this reason, we are presenting a new spatial aware interactive system which can be operated by a singlehanded device.

2.5. Interactive Paper System

Over the past three decades, the pioneers and prognosticators in computer science have proclaimed the imminent arrival of the revolution of the office environment which is commonly referred to as "the digital office". This objective of this new idea is to transform the traditional working environment into an electronic information-based work office.

Due to many innovative and ground-breaking developments in computer technologies, many interactive paper systems have been developed to combine the benefits of paper and digital products. The Anoto technology [34] is a pen-based interaction system which can track handwriting on physical paper to augment paper documents with digital information. Liao. C [35] also designed a pen-based command system for interactive paper. He proposed pen-top multimodal feedback which combines visual, tactile, and auditory feedback to support paper-computer interactions. The information from digital pens is augmented by LEDs, vibration motors, and speakers. Therefore, the system allows users to reach on physical paper, a level of performance similar to what can be achieved with a similar interface running on a tablet. PenLight [36] is a mobile, spatially-aware, projector-based interaction system which combines a pen input with a projector output. Due to the limitations of pocket projectors, the PenLight adopts the mobile projection technique. The output from the digital pen is transmitted through a standard video projector.

For the paper-based system, Hotpaper [37] aims to augment paper information with multimedia annotations (such as video or audio). The system can analyze the physical information which is a captured document patch image or video frame to identify the corresponding digital information such as electronic document, page number, and location on the page. PaperComposer [38] is an interactive paper interface for music composition. This system supports composers' expressions and explorations in a music book by computer-aided composition tools. In addition, the end user can create musical compositions on paper which can be interpreted by music-programming software. S-Notebook [39] is a mobile application that connects mobile devices with interactive paper for data management. It allows users to add annotations or drawings to anchors in digital images without learning pre-defined pen gestures and commands. Although many interactive paper technology advances have been presented, we are still not much closer to the digital office because physical paper media are still ubiquitous, even though we are now in a great new era of digitization. Additionally, traditional paper documents still have some significant advantages such as ease of use, superior readability and usability. However, the recording of information on paper is static. It is hard for people to search, modify and retrieve information based on the large paper-based work place.

2.6. Discussion

On the other hand, mobile devices can provide great flexibility and portability for users to track and revise digital information. Moreover, the relatively small screen on a mobile device cannot allow users to read the information as well as paper does. To solve this problem, augmenting paper documents with digital information, by a spatially aware, mobile interaction can overcome the shortcomings and combine the strengths of paper documents and mobile devices.

Differing from the above camera-based methods, our system combines the strengths from both ultrasonic sensing techniques and camera-based augmented reality. I use two ultrasonic sound sensors instead of a regular camera, to track the position of a mobile device within a large paper workspace. Our reasoning is based on the following considerations: First, our approach needs spatial awareness in a 3D space rather than a 2D space. Second, in the aforementioned applications, it is hard to augment a paper document with digital information on a handheld device. Third, normal camera-based augmented reality systems may be affected by environmental light. The ultrasonic sound sensor can provide much more reliable physical information than a camera. Finally, users have to keep a certain distance between the device and the paper document when they are using camera-based system. Our approach works irrespective of the distance between the mobile device and the paper document.

Our approach is related to spatially aware, augmented reality and ultrasonic sensing technology to display a positioned screen which is moved around to see different parts of a large virtual workspace. The movement of the mobile screen in a physical environment is mapped to a 3D virtual environment, and corresponding virtual objects are displayed on the touch screen [25]. Our system addresses the shortcomings of camera-based and marker-based systems. A user can use a single hand to move the mobile device to make a precise operation. The real-time data which is gathered by ultrasonic sound sensors can provide a dynamic visualization to the end user.

3. ULTRASONIC PHONELENS

In this chapter, Ultrasonic PhoneLens and the system architecture are briefly described. Additionally, the data preprocessing which is used for smoothing and accuracy is introduced.

3.1. System Overview

3.1.1. Ultrasonic Movement-Based Interaction

The movement-based interface in Ultrasonic PhoneLens allows user to capture digital information from a paper document through hand movements. The biggest challenge in designing this movement-based interface is detecting the real-time interaction between the system and user's activities. Ultrasonic PhoneLens provides a spatially aware display which is based on ultrasonic sensing. Ultrasonic sound is a high-frequency sound wave which can be reflected back when it reaches an object. Thus, the travel time of the ultrasonic pulses can be used to determine the possible distance within certain time period. A user moves a mobile device above a large paper document, and Ultrasonic PhoneLens identifies the distance from the edge of the paper workplace and displays the corresponding digital information in the paper-based area beneath the mobile device. Ultrasonic PhoneLens combines hand movement with the traditional screen touch interaction on a mobile device. The traditional screen touch devices can only allow users to operate the system within the scope of the screen. The movement of the handheld mobile device over a paper document can enhance the system usability without the limitation of small-screen devices. Moreover, ultrasonic Sensing Technique can facilitate navigation in a large information space as well.

3.1.2. Portability

An important goal of our system is portability. Ultrasonic PhoneLens can be widely used in different environments such as indoors and outdoors environments. Therefore, portability plays a significant role regarding the usability and performance of Ultrasonic PhoneLens. Two challenging issues need to be addressed are small-size system hardware and portable power supplement. Therefore, our system consists of three components: mobile device, micro-controller board, and ultrasonic sound sensor. I chose Arduino Uno Board which can accommodate an HC-SR04 Ultrasonic Sensor Distance Measuring Module. They can be integrated together and attached below the mobile device. The total size of the Ultrasonic PhoneLens is 12 cm by 8 cm by 4 cm and the weight is only 315g which is easy for users to move and control. Another benefit of using the Arduino board is that the system can be supported by battery power which is a big factor for portability.

3.1.3. Low Cost

The intention of this study is to implement a system with low-cost existing technologies which can be widely applied into real-life situations. Our system has two HC-SR04 Ultrasonic Sensor Distance Measuring Modules (each costs less than $10), an Arduino mini-controller board (which is around $30), and a smartphone. Ultrasonic PhoneLens can work on any Android v.2.2 device with at least a 500 MHz processor and 256 Mb memories, which are supplied by almost all smartphones today.

3.1.4. Multi-Users Interaction

The Bluetooth wireless communication in the Ultrasonic PhoneLens allows users to share their digital information with other users. It is different from paper-based information transmission in two key areas: first, digital data transmission minimizes time to receive and send information. Second, it reduces space limitations because of the remote control. It is challenging to remove sound wave interference when two or more users communicate in Ultrasonic PhoneLens. Therefore, I created an asynchronous control framework which supports the multi-users' interactions mitigating environmental disturbances is proposed.

3.2. System Architecture

The Ultrasonic PhoneLens mobile application includes three hardware components: smartphone, ultrasonic sensor, and microcontroller board. Additionally, the Ultrasonic PhoneLens software system has a stand-alone desktop application that allows developers to edit application-dependent data [25]. The Ultrasonic sound sensor emits the sound waves and receives the echoes of those waves when they are reflected by an object. The travel time of the waves can be recorded and transferred to the Arduino microcontroller board to compute the distance between the system and the object. The distance data is sent to the mobile and provides a spatial aware display. The graphical display is based on application-dependent data such as SVG files. The software system combines the spatial aware display with the graphical display to provide a dynamic visualization for end users.

3.2.1. Hardware Design

The HC-SR04 Ultrasonic Sensor Distance Measuring Module and the Arduino Uno Board are used to track the system's location. The HC-SR04 ultrasonic sensor has a transmitter and receiver [40]. It can emit an ultrasonic pulse every 600 µs and then detect the reflection wave. Fig 1, shows the working theory of the HC-SR04 ultrasonic sensor.

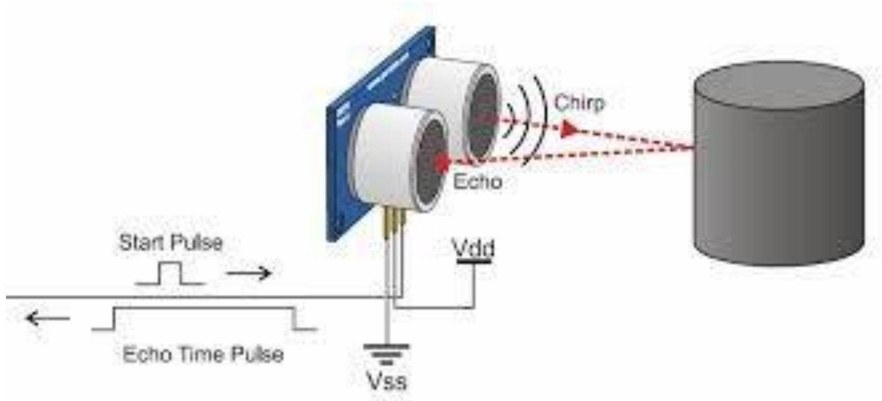


Fig. 1. Working theory of HC-SR04 Ultrasonic Sensor. [41]

The HC-SR04 ultrasonic sensor has 4 pins: vcc, ground, echo, and trigger pins. Vcc and ground are used as power support. The echo and trigger pins need to connect with the microcontroller I/O pins [42] so the sensor can be compatible with the instructions from the microcontroller.

The microcontroller is a small central processor which has the capacity to control the activity of an embedded system. Arduino Uno Board is one of microcontrollers which consists of microcontroller-based circuit boards and the software for programming them [43]. The Arduino Uno Board (Fig 2.) is an open source hardware that uses USB connectivity for communication with the Arduino software. The female header is used for connecting electronic components or wires [44].

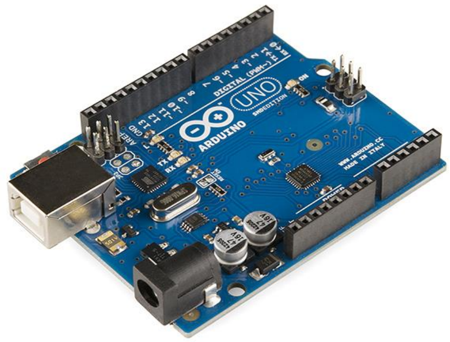


Fig. 2. Arduino Uno Board. [45]

In our system, as shown in Fig 3, we integrated battery, ultrasonic sensor and an Arduino board are integrated into a box and the box is attached it to the back of a smartphone.

Fig. 3. Ultrasonic PhoneLens.

A paper document is attached to a wall. A user takes the mobile phone and brings it into contact with the paper. The phone connects the Arduino via the Bluetooth module. Then, the ultrasonic sound sensor which was assembled on the Arduino Board sends the distance data to the mobile device. With the help of the distance data, the smartphone can locate information for the digital document.

3.2.2. Software Design

The software application is developed on the Android 2.2 mobile device and has four layers (see Fig 4.). The spatial data layer receives the raw distance data from the Arduino board. The graphical layer is mainly focused on parsing the SVG files and retrieving digital information from the mobile database. The presentation layer calculates the distance data and gets the location of the mobile within a paper-based workplace. Then, it generates a visual display of the corresponding digital information. The function layer provides system functions for users to manipulate digital information over the paper document. The communication layer creates an asynchronous communication with another mobile system. The detail process will be introduced in section 3.5.

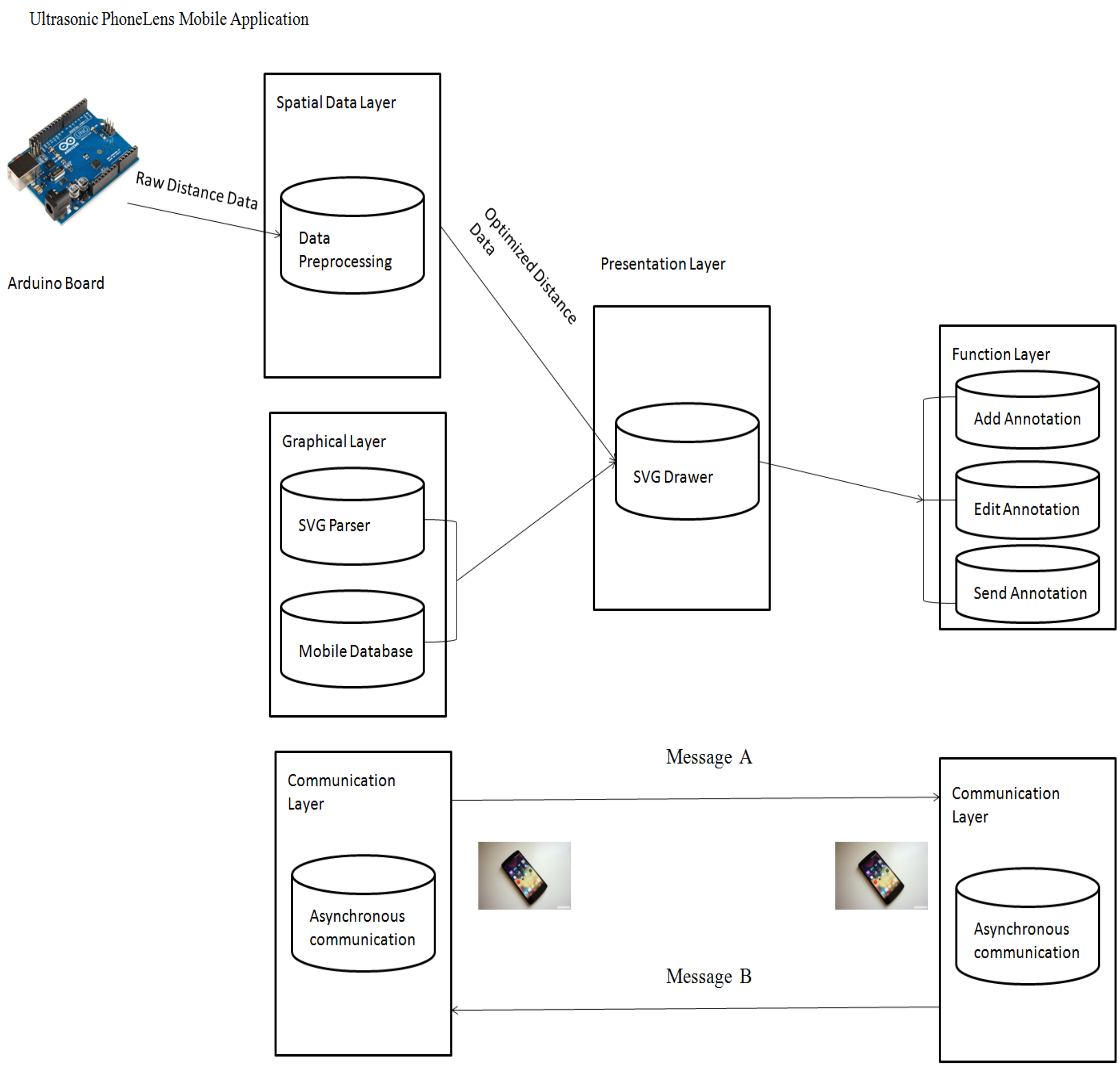


Fig. 4. Ultrasonic Phonelens system architecture.

3.3. Data Preprocessing

An ultrasonic sound wave is not a stable signal because the wave is strongly affected by temperature, magnetic forces and air density. In addition, other factors such as user's hand shaking and rotation can cause unstable position information and reduce functionality for the user. To enhance smoothness and accuracy, I propose to preprocess the raw data in the presentation layer is proposed. The data preprocessing which is used for the position of a mobile device within a workspace, can be divided into the following steps:

1. Previous data comparison;
2. Average distance calculation;
3. Noise elimination.

3.3.1. Previous Data Comparison

The interval of each pulse from the ultrasonic sensor is 600 µs. The differences between high frequency distance data can cause the image to jump. In order to address this issue, I make comparisons between the previous distance data and the current distance data. If the current data is not significantly different from the previous data, the system uses the previous data instead. I set the threshold to determine whether the current data should be replaced or not. The threshold is based on the standard deviation from each predefined point. The predefined point is marked on the paper and the spacing distance between each point is 10cm. For example, I set the lower left corner of the paper as the origin and divided the paper into a rectangular coordinate system. If a point was marked at the 10cm/10cm coordinate, the next point should be added to the 20 cm/20 cm coordinate. To get the standard deviation of each point, I recorded the raw distance data from the ultrasonic sound sensor with a duration of 5 minutes. Then, the standard deviation of the data which is saved before is calculated. The standard deviation can be the margin of error for each point. Also, it can be used as a sample to determine the error of each domain. That is the tolerable error which can be ignored by distance detection. Table 1 shows the average and standard deviation of raw data for each marked point. Also, the average and standard deviations of the data, after the process of previous data comparison, is listed below.

Table 1. Predefined point testing data.

Raw Distance Data									
Point	1	2	3	4	5	6	7	8	9
Actual Distance	10	20	30	40	50	60	70	80	90
Average Distance	10.36	20.78	29.42	39.23	51.26	60.18	71.08	80.25	90.72
Standard Deviation	0.13	0.19	0.18	0.22	0.35	0.26	0.37	0.28	0.47
Data Processed by Previous Data Comparison									
Point	1	2	3	4	5	6	7	8	9
Actual Distance	10	20	30	40	50	60	70	80	90
Average Distance	10.02	20.44	30.33	39.25	50.26	60.02	70.80	80.05	88.71
Standard Deviation	0.09	0.10	0.06	0.12	0.15	0.26	0.33	0.07	0.15

3.3.2. Average Distance Calculation

The ultrasonic sound sensor can emit a sound wave every 600 µs which means the system can receive the distance data every 600 µs. The refresh rate of a digital image is 3000 µs. The sensor receives 5 records of distance each time the image refreshes but only one record of the distance is useful. To increase accuracy, I recorded all 5 instances of distance and removed the maximum and minimum distances. Then, I calculated the average of the remaining 3 distance data points to get the best approximation of the real environment. The average distance calculation can only have applied in the static state. It cannot increase accuracy when the user is moving the application. In order to solve this issue, the integrated accelerometer in smartphones was applied to detect whether or not the device is moving. An accelerometer is a sensor which can detect changes of gravitational force and measure the parameter of the user's motion (such as orientation and translational acceleration) when they are using a mobile device [46]. Therefore, the static state can be judged by our system. If there is no acceleration detected by the accelerometer, Ultrasonic PhoneLens can identify that the user didn't move the device and can launch the average distance calculation. Table 2 shows the improvement of distance data after completing the process of average distance calculation. The average and standard deviation of the distance data is compared with the previous steps.

Table 2. Distance data after average distance calculation.

Data Processed by Previous Data Comparison									
Point	1	2	3	4	5	6	7	8	9
Actual Distance	10	20	30	40	50	60	70	80	90
Average Distance	10.02	20.44	30.33	39.25	50.26	60.02	70.80	80.05	88.71
Standard Deviation	0.09	0.10	0.06	0.12	0.15	0.26	0.33	0.07	0.15
Data Processed by Average Distance Calculation									
Point	1	2	3	4	5	6	7	8	9
Actual Distance	10	20	30	40	50	60	70	80	90
Average Distance	10.04	20.24	30.10	39.70	50.28	60.81	70.31	79.92	91.00
Standard Deviation	0	0.09	0.10	0	0.12	0	0	0.08	0.13

3.3.3. Linear Regression

Linear regression [47] is a statistical methodology that models a straight line to express the relationship between a scalar dependent variable, **y**, and explanatory variables, **x**, in a coordinate system. In this system, I have optimized points that I predefined but there are other points that have not been tested. To find the relationship between each point and predict the error in an untested place, I adopt linear regression to generate a calibration line based on the value of the predefined point I tested before.

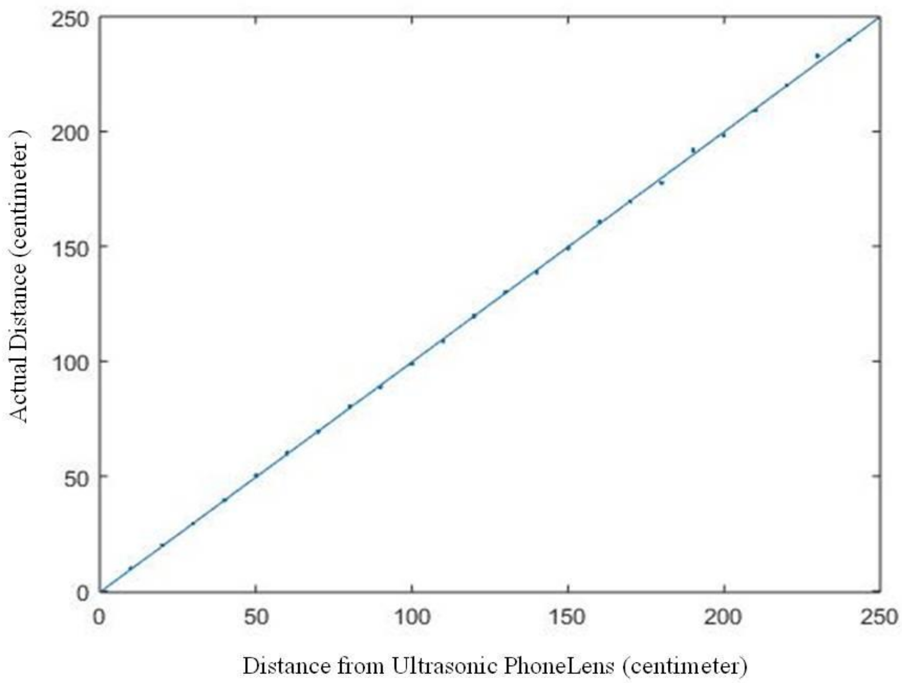


Fig. 5. Ultrasonic PhoneLens linear regression.

As shown in Fig 5, the x-axis (horizontal) is the value which represents the distance detected by Ultrasonic PhoneLens and the y-axis (vertical) is the value which is the actual distance in the real environment. Therefore, I can mark the point on the coordinate system based on the information from the predefined place. The best-fitting straight line can be through each point. This straight line is the regression line which can help us find the difference between the distance determined by the Ultrasonic PhoneLens and the real distance. The slope of the regression line is the compensation for the distance error in the Ultrasonic PhoneLens. For example, once the distance data was produced by the Ultrasonic PhoneLens, the distance needs to be multiplied by the slope of this regression line to reproduce the value closest to the actual distance. In Fig 5, the slope of the regression line is 1.0002 which means that there is not much difference between the distance data from our system and the distance in the real world. From another perspective, it also indicates that the Ultrasonic PhoneLens has the capability of high accuracy detection after the process of previous data comparison and average distance calculation.

3.3.4. Noise Elimination

It is common that the user rotates the mobile device unintentionally when he/she browses a paper document. The deviation angle causes inaccurate position information. Additionally, phone rotation also causes different viewports to the real environment. In order to prevent the wrong viewing caused by user's rotation, I used an integrated sensor called a magnetometer in the mobile device. The magnetometer is a software-based sensor which is used to detect the orientation of the phone in relation to the Earth's magnetic field. As a result, the phone can always know where true north is. The sensor is usually applied into the development of a digital compass [48]. In our project, I calibrated the degree from the magnetometer beforehand to get the degree of deviation angle. The real distance is calculated by the distance data multiplied by the cosine of the degree of deviation angle.

In addition, the digital image can be auto adjusted if the phone is rotated. This is because the system can get the deviation angle and rotate the image in an opposite way.

3.4. Accuracy Evaluation

Accuracy is a significant element for the performance of the Ultrasonic PhoneLens. The points which have been predefined are tested to evaluate accuracy after the data has been preprocessed. The accuracy was calculated by comparing the optimized distance data with the actual distance. I use the absolute error to analyze the accuracy of the two systems. Absolute error is a measure of statistical accuracy to calculate how close forecasts or predictions are to the eventual outcomes [49].

$$\Delta x \equiv |x_0 - x|/x \qquad (1)$$

In this project, I use Equation 1 to get the absolute error rate from different devices where $x_0$is the inferred value from the Ultrasonic PhoneLens and x is the real distance. I calculate the absolute value based on the distance from the predefined point to the real point, then divide by the distance to the real point to convert the result to a percentage.

Table 3. Error rates of distance data.

Point	1	2	3	4	5	6	7	8	9
Actual Distance	10	20	30	40	50	60	70	80	90
Raw Data Error Rate	0.56%	1.68%	1.13%	0.27%	0.57%	1.10%	1.52%	0.89%	1.34%
Processed Data Error Rate	0,01%	2.14%	1.17%	0.02%	0.01%	1.10%	1.41%	0.86%	0.52%

In addition, a paper document with dimensions of 106 cm by 62 cm is applied into the evaluation. A 16 by 27 table is printed on the paper. I can use Ultrasonic PhoneLens to observe the difference between each cell in the mobile screen with the cell printed on the paper (Fig 6.).

Fig. 6. Demonstration of accuracy evaluation.

3.5. Ghost Echo Filtering Mechanism

The ultrasonic sensor cannot completely detect the distance. Many factors can reduce the performance of reading digital paper. The sound waves which reflected from different surface properties of the objects or from different shape of the objects make the different traveling time. Then, the waves return to the sensor is called ghost echo (Fig 7.).

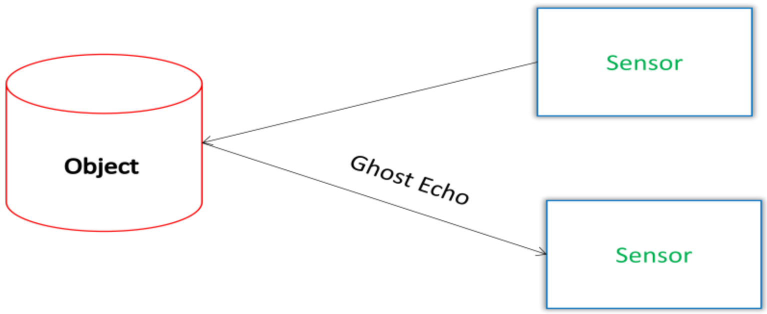


Fig. 7. Illustration of ghost echo.

In the multi-user mode, ghost echo usually appears when users control the Ultrasonic PhoneLens. This is because sound waves can collide with each other and the sensor sometimes receives the pulses from other sensors.

In order to remove the influence of ghost echo, I designed an asynchronous network which controls one machine not to start its job until it receives a message from the other machine. The message indicates that the other machine has finished the distance data collection. This asynchronous network mitigates the interference of ghost echo in multi-user communication. As Fig. 8 shows, the Arduino board is controlled by the message sent from the mobile device. Once the message has been received, the Arduino board signals the sensor to emit a beam of ultrasonic sound wave. Then, it generates one instance of distance and sends it back to the mobile application. Therefore, the mobile device can control the sensor directly through the Arduino board. In the Ultrasonic PhoneLens application system, in order to achieve asynchronous communication, two mobile devices need to be connected together via Bluetooth. When one mobile sends a message to the Arduino board, the message is sent to another mobile simultaneously. If one mobile receives the message from another, it can send a new message to the Arduino board for distance detection. The messages from each mobile device are totally different which eliminates confusion for asynchronous transmission.

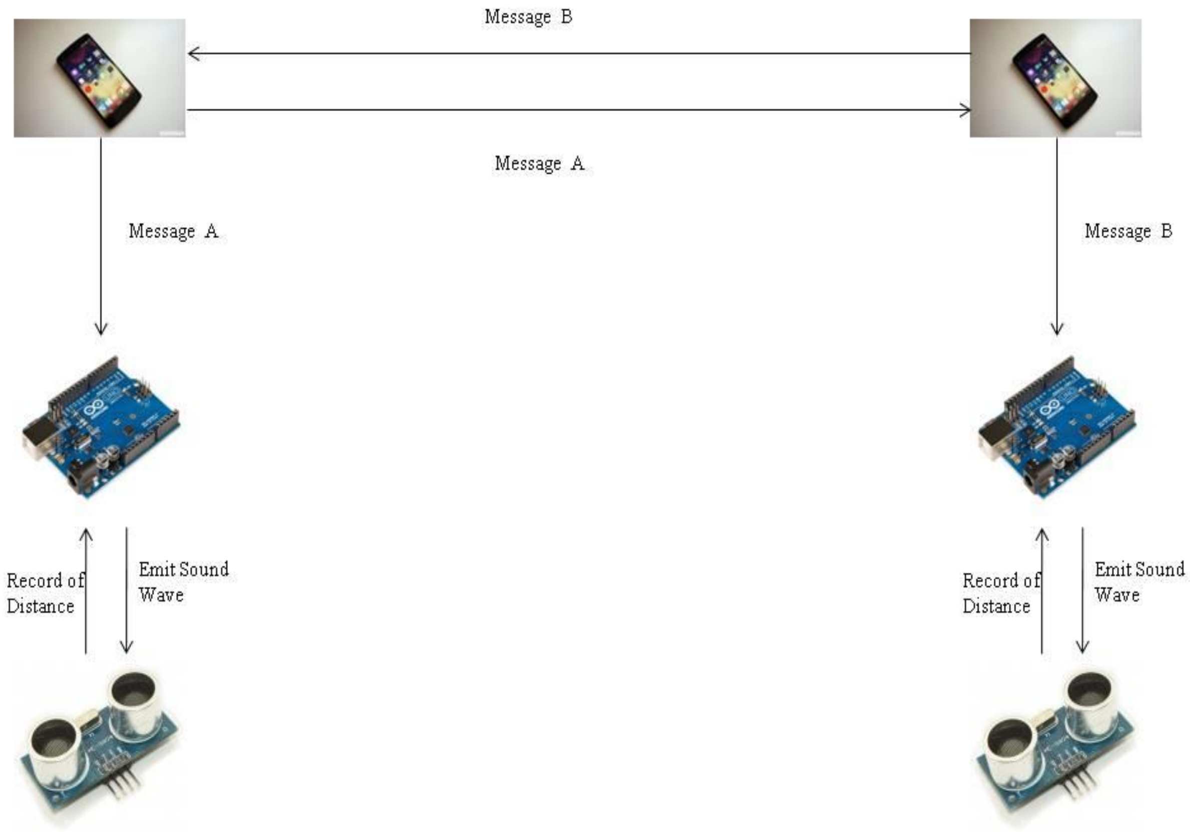


Fig. 8. Asynchronous system architecture.

4. METHOD FOR EMPIRICAL INVESTIGATION

In this chapter, a case study from an existing work and the method for research investigation are introduced.

4.1. Study Overview

A goal of our empirical investigation is to evaluate users' feedback and the performance of Ultrasonic PhoneLens for browsing digital information in a paper document. Penbook [50], is a usability study conducted with 10 non-professional participants (5 females and 5 males). To start with, an investigator introduces all the interactive features of the Penbook system. This provides an opportunity for participants to make themselves familiar with the application. Then, the investigator requires the user to finish tasks such as using the system to search for item. After a practical exercise, the investigator interviews the participants on their usage experiences and records feedback from them. A testing report was generated which was based on the users' feedback. Similarly, a training section and an evaluation of multiple tasks performed by participants also are incorporated in our user study. Different from Penbook system study, we not only collected subjective feedback from the users but also made a comparison of Ultrasonic PhoneLens and PhoneLens systems to gather objective data based on the users' experiences. PhoneLens [25] is a paper-based browsing system which uses a Wii Remote and infrared LED lights to augment paper-based workplaces with digital information. Analogously, our system is also an augmented reality system that uses an ultrasonic sensing technique to provide digital information for paper documents. The motivation for designing this user case study is to test which is a better paper-based browsing system, PhoneLens or Ultrasonic PhoneLens. Finally, after concluding the testing process, I intend to improve the usability and accessibility of each system while still keeping their unique advantages.

A posttest and repeated measures experiment is applied in this study [51]. The repeated measures experiment can be applied to the same subject with different research requirements. All subjects were introduced to take the first task, and then they were asked to complete the second task. This experiment allows all subjects to perform the tasks in a sequence. For example, the participants can be divided into two groups. Each group needs to perform the same two tasks but in reverse order. This is called 'counterbalancing of the treatments'. The advantage of a repeated measures experiment is the reducing of the learning effect. The tasks for testing PhoneLens and Ultrasonic PhoneLens may not be quite different because of similarity but a user may find it much easier to finish the second task than the first one. It is because of the learning process when they are working on the first task. With two branches of counterbalancing, the researcher can get four group's feedback from only two group of participants. Additionally, the overall evaluation is not, or is minimally affected. In our empirical study, the subjects were introduced to the wall frame architecture plan. After that, the subjects were divided into two groups. The order of training and testing on each system for each group was reversed. So, in the training section, subjects were trained on how to use the PhoneLens and Ultrasonic PhoneLens systems. Next, the investigator asked users to finish tasks to examine the efficiency of each system. The performance of each system was then evaluated by the investigator. He recorded the times of each task that the participants performed in order to evaluate the systems' efficiency. At the end, the two groups of participants were gathered together to finish a task which only applied to the Ultrasonic PhoneLens. Their usability experience was measured by their post-study questionnaire.

4.2. Research Hypotheses

The Goal Question Metric (GQM) approach [52] is based on the hypotheses that organize and measure the software in a purposeful way. The goals need to be defined for the study, then the data are intended to trace those goals, and eventually provide a framework that introduces the relationship between the data and the stated goals. It is a simple and elegant approach which can be applied to evaluate any possible defects in our project. To define the goal for our study, I obtained the following goals and related hypotheses as shown below:

Goal 1: Analyze PhoneLens and Ultrasonic PhoneLens for the purpose of evaluating the efficiency on multivalent documents.

Hypothesis 1: Participants using Ultrasonic PhoneLens need significantly less time than participants using PhoneLens.

Goal 2: Analyze the function of multi-users' communication for the purpose of improving the usability of Ultrasonic PhoneLens.

Hypothesis 2: Users operating the Ultrasonic PhoneLens can communicate effectively and share annotations on digital paper with other end users.

4.3. Participating Subjects

28 undergraduate/graduate students who were studying at the North Dakota State University were invited to participate in this study. They had a variety of majors and did not have specific backgrounds with respect to this study area. The training section is designed to help them to operate both systems to browse information in a multivalent document.

4.4. Artifact and Document

The documents used in this study were from an architectural plan for an interior wall structure that has four different components: a) wall plan, b) lighting plan, c) electric power plan, and (d) audio plan. The wall plan was a scaled diagram which shows the internal layout of the wall as well as the relationships between the components of this structure. The electric power plan shows the locations of circuit breakers, electrical sockets and the wiring between them; the audio plan shows the locations of the doorbell as well as its wiring; and the lighting plan shows the locations of lights, switches and the wiring between them. Each layer was displayed on a separate and independent digital paper document. Participants needed to use the Ultrasonic PhoneLens and the PhoneLens, to achieve the tasks that required them to browse the digital information in different layers.

In addition, Ultrasonic PhoneLens was evaluated for multi-users communication of this study was evaluated. This was motivated by the fact that the PhoneLens system has no capability of sharing digital information with other users. To test this new feature, the hotspot plan was providing for users to add or edit annotations on digital documents and to allow a user to send their annotations to another end user.

4.5. Study Tasks

As the hypothesis mentioned above, the two major strengths of the Ultrasonic PhoneLens relative to the PhoneLens, are efficiency and multi-user communication. Therefore, I needed to design navigation tasks and multi-user communication tasks in the User Case Study.

4.5.1. Navigation

A wall frame architectural digital plan can be searched for specific information at different layers (e.g., searching for the position of a circuit breaker in the electrical plan or a door bell in the audio plan). For each test, the subject was asked to use the Ultrasonic PhoneLens and the PhoneLens, to find the position of a certain object on the paper-based wall frame architecture plan. A piece of white paper covers the paper-based wall plan, thus eliminating the possibility that the participant would just locate the object with their eyes. Participants needed to find the target object and the time they spent to do so, was recorded.

a. Browse the audio plan, and find the position of the junction box on the plan.

b. Browse the electric power plan, and find the position of a circuit breaker on the plan.

Due to the randomness and uncertainty about the searching location, the time to find the object is influenced by the searching technique rather than the performance of each system. In order to unify the search routine and reduce the search time because of users' behaviors, two special search patterns are designed and recommended during the training section.

In our experiment, there are two targets which have been set up in the navigation task. Each of them is designed such that the different search patterns introduced in the training would be easy to master and effective. Therefore, the two positions of the objects on the wall paper plan were set on the top-right corner and the bottom-left corner. The search pattern recommended was a snake formation search which can systematically cover all of the area of the paper document quickly, while not missing any area. In order to find the position of the junction box on the white paper, participants browse the audio plan using the search pattern shown in Fig 9. The initial location of the mobile device is at the bottom-left corner and the position of junction box is on the top-right corner. The participants start from the initial location with the mobile device, which is the bottom-left corner, and search for the junction box by following the pattern indicated by the arrows, until it finds the junction box. Similarly, Fig 10 is the search pattern for participants to find the position of a circuit breaker on the electrical plan. However, the initial location of the mobile device is set to top-right corner and junction box is at bottom-left corner. The participants start from the top-right corner and search, using the method illustrated, until they find the circuit breaker.

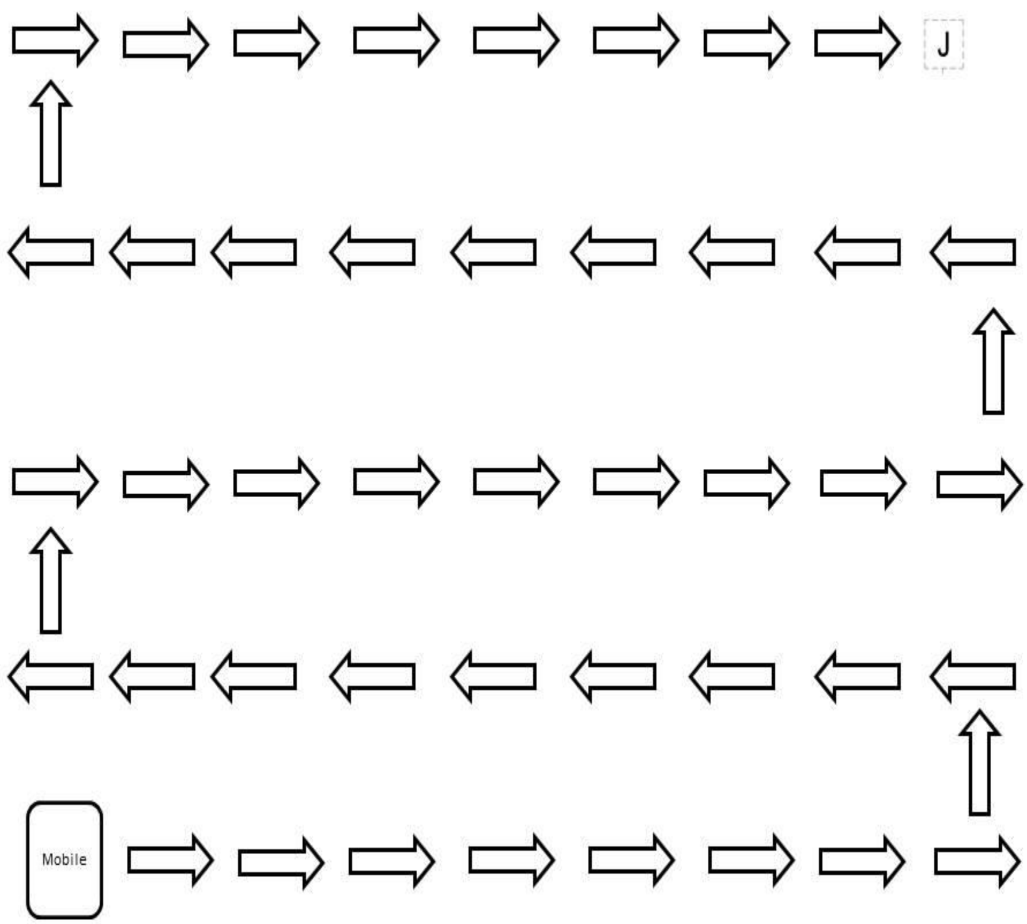


Fig. 9. Snake formation search on audio plan.

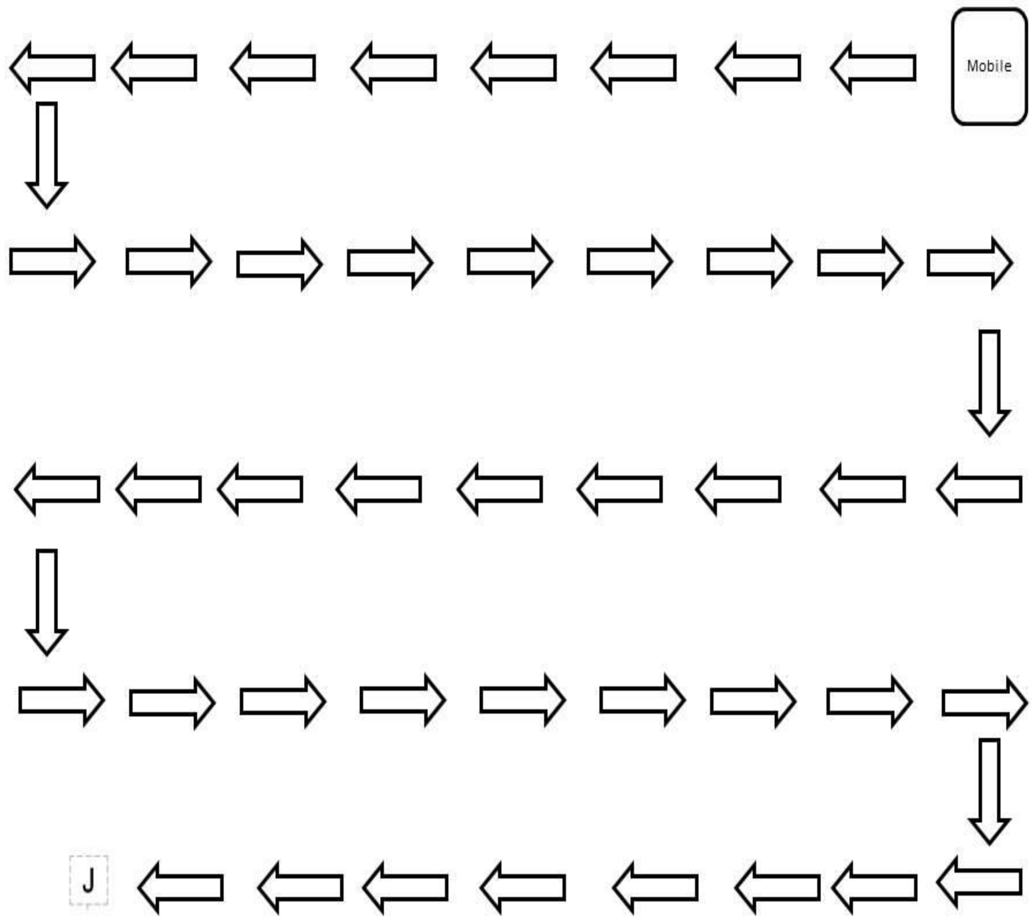


Fig. 10. Snake formation search on electric power plan.

4.5.2. Multi-users Communication

Different from the navigation tasks, the multi-users communication tasks required the investigator to add the annotation as shared information. The participant was asked to search for the annotation where the investigator had placed it. After the participant found the annotation, he/she needs to tell the investigator and then describe the annotation. The specific task utilized is a user case scenario in which the investigator and the participant are playing the roles of architects. They are working in separate rooms on the same wall frame architecture plan. The structure of each room is the same. The investigator adds the annotation as shared information in room A. The participant was asked to search for the annotation while in room B.

The multi-users communication tasks were designed to simulate the working conditions of engineers who may need to share digital information remotely. It not only enhances multi-user interaction on digital documents but also breaks through typical space constraints.

4.6. Study Procedure

The procedure of this user study consists of nine steps for each subject. An overview of the experimental step is shown in Fig 11.

4.6.1. Pre-Study Survey

The first step of our user study is to elicit some background information about their reading ability, knowledge of construction and their experience with browsing on mobile devices. I gathered this information during the pre-study phase because the performance from some of the subjects in this experiment may be affected by their individual backgrounds. After finishing the pre-study survey, the 28 participants were separated into 2 groups. Each group had 14 individuals.

4.6.2. Training Section

The training section is divided into two parts: training on the PhoneLens and training on the Ultrasonic PhoneLens. The subjects are trained on how to operate the two systems by the same researcher before they started the tasks. The length of the training section is about 10 to 15 minutes. During this time, the researcher teaches each subject how to use each system to find information on a testing paper plan. After each subject finished the training section, they start to use the machine which they have been trained on to finish the navigation tasks. For example, if the subject finished the training on the PhoneLens system, then he/she needed to use that system to browse the wall frame architecture plan. Then, after they finished the navigation task and evaluation, they began to learn how to use the Ultrasonic PhoneLens system and repeated the task.

4.6.3. Browsing Wall Frame Architectural Plan

In this step, each subject is required to use PhoneLens or Ultrasonic PhoneLens to finish the navigation task after they completed one of training sections. The order of each task in this process was altered which means that the subjects were looking for different targets when they used different systems. It is because of the repeated measure experiment method that the subjects used a variety of sequences. For example, if a subject in group A, used PhoneLens to find the position of a junction box on the audio plan, then he/she needed to use Ultrasonic PhoneLens to find the position of a circuit breaker on the electrical plan. Conversely, if a subject in group B used PhoneLens to find the position of a circuit breaker on the electrical plan, then he/she needed to use Ultrasonic PhoneLens to find the position of a junction box on the audio plan.

Therefore, each subject can complete two different tasks without influence from the previous task. This design allowed the researchers to reduce the number of participants and minimize potential learning effects. The researchers compared the subjects' performance while using two systems on two different navigational tasks.

The researcher who trained the subjects recorded the training time for each subject. The same researcher also asked the subjects to finish the questionnaire to gather the subjective feedback. The questionnaire utilizes a 5-piont scale. After the users finished browsing the wall frame architecture plan, they were asked to evaluate the overall experience of the application.

4.6.4. Multi-Users Communication

After the participants finished browsing the wall frame architectural plan with the two systems, the two groups merged together to perform the multi-user communication task. In this step, each subject needed to cooperate with the investigator to get the information which had been sent by the investigator. For example, if the investigator added and shared an annotation which added an electrical plug, then the subject needs to find the point where the plug was added and read the annotation description regarding specifically what the type of plug needed to be added. Finally, the researcher records whether the subject can find the right information from the annotation.

4.6.5. Post-Study Questionnaire

In the final step, the participants need to complete a questionnaire to provide their subjective feedback about the experience of multi-users communication. I adopted a Post-Study System Usability Questionnaire (PSSUQ) which is a research measurement tool for scenario-based evaluations at IBM [53]. In 2005, Ann Fruhling and Sang Lee used Cronbach's coefficient alphas to assess the reliability of PSSUQ [54]. The coefficient alphas are close to .96 and exceeded the generally accepted minimum value of .70. This evidence suggests that PSSUQ is a reliable and consistent questionnaire.

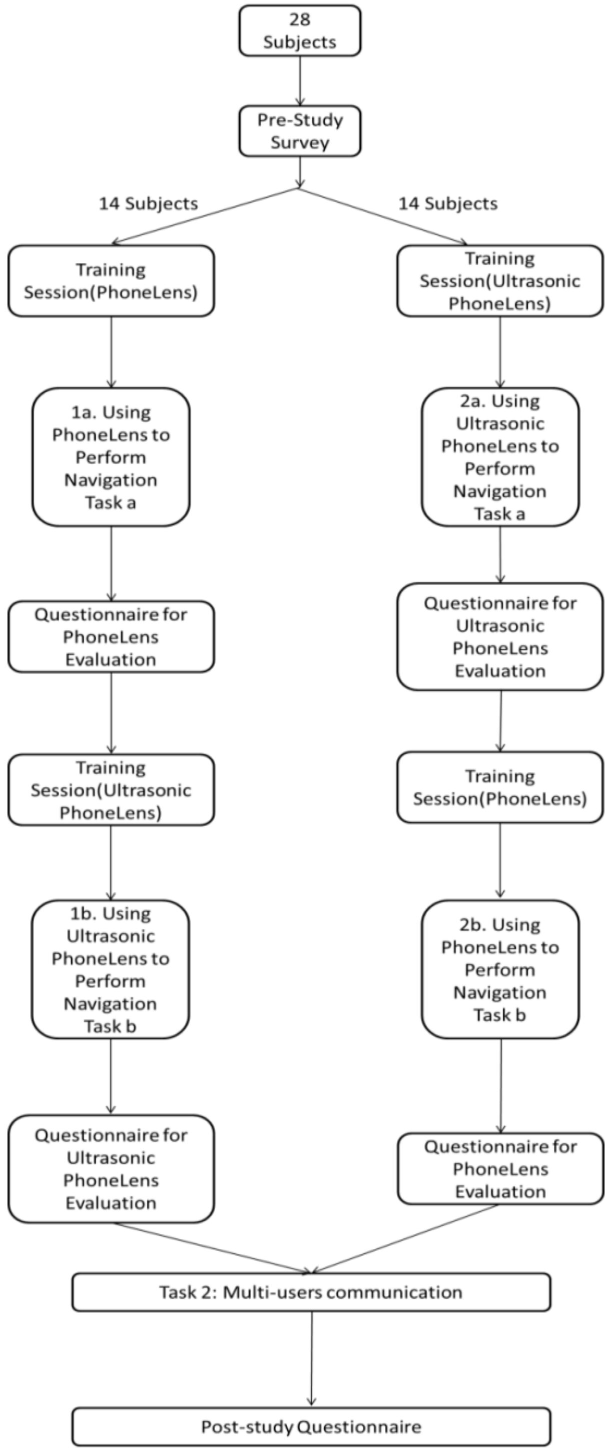


Fig. 11. The procedure of user study design.

4.7. Data Collection

In this subsection, the qualitative and quantitative data which was collected during the study are described.

The quantitative data included the time the subjects took to complete each task. The timing information was recorded from the start time to the end time for each task.

For qualitative data, I designed two questionnaires to gather the subjective, self-reported data at the end of the study. The first questionnaire is the feedback about their use of each system. I adopted a 5-point Likert scale (“1 is very low” to “5 is very high”). The subject can rate their overall experience based on their comfort level, interface satisfaction, software usability, and learning process. The second one is the evaluation about the performance of multi-user communication. I used a 7-point Likert scale (“Strongly Agree” to “Strongly Disagree”). The Strongly Disagree has a rating value of 1 and the Strongly Agree has a rating value of 7. I averaged the scores of each item to obtain an overall satisfaction score on this function.

5. RESULT AND ANALYSIS

In this chapter, the results of the user case study is discussed. The results can be divided into three categories: comparison of browsing efficiency, comparison of browsing accuracy and user's feedback on multi-user interactions. The former two categories are based on the two research goals which were introduced on Chapter 4.

5.1. Comparison of the Browsing Efficiency

I analyzed the time which subjects spent in navigation tasks to evaluate the comparative browsing efficiency of PhoneLens and Ultrasonic PhoneLens. Therefore, I calculated the average time taken by subjects in the two subtasks (i.e., tasks a and b) as shown in Fig 12.

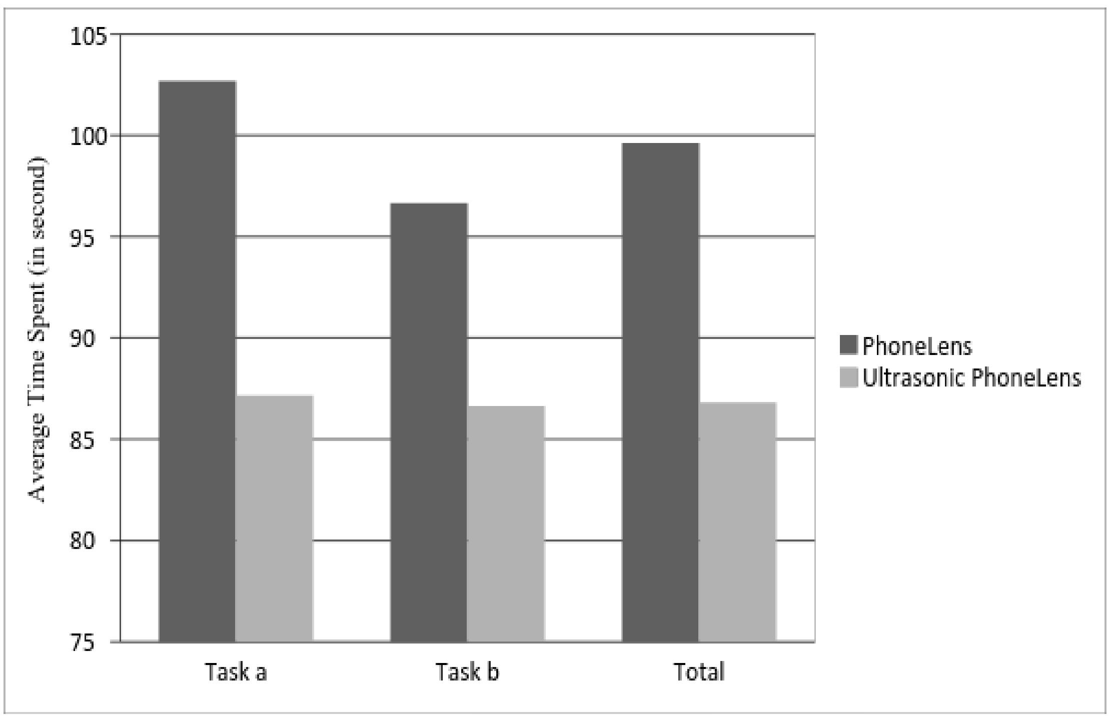


Fig. 12. Comparison of the average time spent on Tasks a and b.

During the navigation task, the performance of Ultrasonic PhoneLens was shown to be more efficient than PhoneLens. In task a, the average time of using Ultrasonic PhoneLens is around 15 seconds faster than that of using the PhoneLens system. In task b, the gap is narrowed to 10 seconds because of learning effect (the PhoneLens system was used after the user finished the Ultrasonic PhoneLens task). Therefore, the total average time for using PhoneLens and Ultrasonic PhoneLens in navigation tasks was 99.65 sec and 86.81 sec., respectively. A paired sample t-test was imported to examine the significance of the average time for each system. Paired sample t-test is a statistical technique that calculate the average of difference between the two samples. If the result is less than 0.05, it means that the two paired observation is significantly different. The p-value in our study is 0.003 ($p =< 0.005$) which means that Ultrasonic PhoneLens is significantly more efficient than PhoneLens.

Table 4. Paired samples T-test.

		Paired Differences					t	df	P-value
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	PhoneLens - UltrasonicPhoneLens	12.84	21.46086	3.91820	4.82638	20.85362	3.277	29	.003

The reason that Ultrasonic PhoneLens exhibits better performance is that the Ultrasonic PhoneLens is more flexible for users to control the system. Ultrasonic PhoneLens allows users to face the front of the paper to browse the information whereas a PhoneLens user has to hold the mobile phone at the left side of paper.

It is because the Wiimote has been set at the right side of the workspace in order that it can covers the entire paper document. To avoid blocking the Wiimote camera, users have to stand at the left side of the workplace and this can increase the time consuming when user is browsing the right area.

The Ultrasonic PhoneLens utilizes ultrasonic sensor to detect position. The sensors are assembled on the bottom of the mobile so users do not need to consider where the specific place is for working. It can provide a non- constrained environment for users without any limitation of blind area.

5.2. Comparison of Subjective Feedback about PhoneLens and Ultrasonic PhoneLens

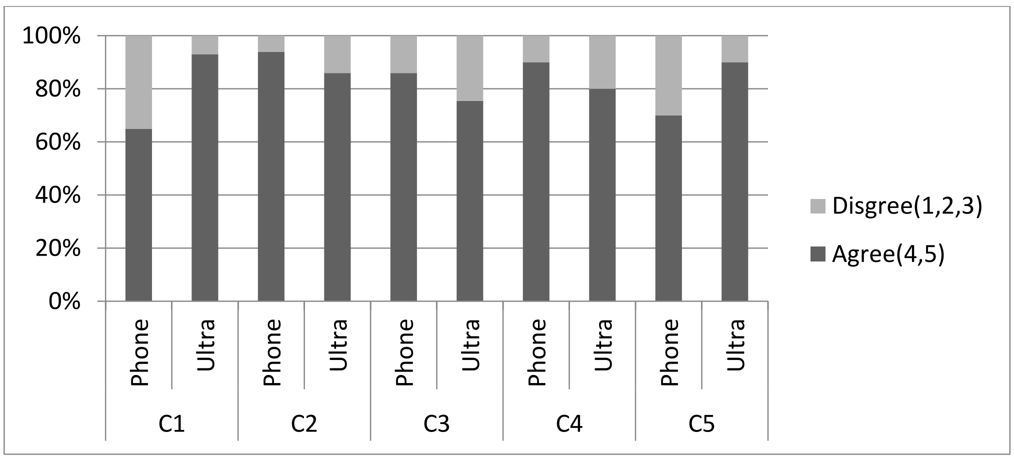
The rating results of five characteristics (C1 through C5, in Fig.15) are calculated in the overall experience of using PhoneLens and Ultrasonic PhoneLens systems. The 7-point scale of the questionnaire is divided into two categories, “Disagree” and “Agree”. A rating value which is lower than 3 belong to the “Disagree” category. Ratings of 4 or 5 are included in the “Agree” category. I calculated the percentage of “Disagree” and “Agree” in each characteristic to analyze which system is more useful and user-friendly.

Before I made comparisons of the systems, I adopted a non-parametric, one-sample Wilcoxon Signed-Rank test which is widely used in comparing two related samples. It calculates the difference between each sample and analyzes the mean of rating values for each difference to compare the samples. In characteristic C1, the positive mean rank of Ultrasonic PhoneLens (Subjects think Ultrasonic PhoneLens performs better than PhoneLens) is 9.90 and the negative mean rank (Subjects think PhoneLens performs better than Ultrasonic PhoneLens) is 7.50. The p-value of this characteristics is 0.004. Therefore, I can draw a conclusion that the subjects feel significantly more comfortable when they are using Ultrasonic PhoneLens system, relative to PhoneLens. In characteristic C2, the positive mean rank for Ultrasonic PhoneLens is 9.50 and the negative one is 8.73. It seems that the accuracy of the Ultrasonic PhoneLens is slightly less than that of the PhoneLens system because the p-value of this characteristics is 0.315. Therefore, the difference, in this characteristic, between the two systems can be ignored. The results of C3 and

C4 are also similar to C2. Positive rank and Negative rank for C3 are 9.00 and 9.82. The p-value is 0.275. The positive rank and negative rank for C4 are 10.71 and 8.73 and its p-value is 0.623. Consequently, I can conclude that the readability of the PhoneLens is marginally better than the Ultrasonic PhoneLens. In C5, the positive rank of the Ultrasonic PhoneLens (7.64) is marginally higher than the negative rank (7.64). The p-value in C5 is 0.029. It shows that the Ultrasonic PhoneLens is more functional for new users and the learning process of using Ultrasonic PhoneLens is superior to that of PhoneLens. Overall, a percentage agreement and disagreement for the Ultrasonic PhoneLens compared to PhoneLens is shown in Fig 13. This indicates that the participants are prone to use the Ultrasonic PhoneLens when they are browsing the architectural plan. One reason is that subjects frequently block the Wii-mote camera when they are using PhoneLens to browse, especially when they are browsing the right side of the document where the Wii-mote is set up. This often results in unexpected system interrupts and negatively impacts the user experience. Some people try to stand to the side of the workplace to avoid this problem but this is a very uncomfortable way for the user to use the system. However, although the Ultrasonic PhoneLens allows the user to stand comfortably in front of the workplace the hand which holds the Ultrasonic PhoneLens can interfere with the ultrasonic sound if a certain part of hand blocks the sensor. It may result in a loss of accuracy and reduce the readability when the user is browsing the plan. This is probably the reason that the evaluation of the Ultrasonic PhoneLens is lower than that of the PhoneLens in characteristics C2, C3 and C4. The feedback from the subjects’ comments gave us valuable suggestions to improve the Ultrasonic PhoneLens design in the future.

Table 5. Wilcoxon signed-rank test report.

	C1	C2	C3	C4	C5
Mean Rank (PhoneLens)	9.90	9.50	9.82	10.71	7.64
Mean Rank (Ultra-PhoneLens)	7.50	8.73	9.00	8.73	7.32
P-value	0.004	0.315	0.275	0.623	0.029
Significance	Yes	No	No	No	Yes



Characteristics:

C1: Comfort level within browsing the plan

C2: Precise detection of real position

C3: Smooth movement on image visualization

C4: Stabilized presentation of digital information

C5: Ease of learning how to use system

Fig. 13. Subjective feedback on PhoneLens and Ultrasonic PhoneLens.

5.3. Evaluation on the Performance of Multi-Users Communication

The performance of multi-user communication by PSSUQ is analyzed. This questionnaire consists of three sub-scales: system quality (items 1-6), information quality (items

7-12), and interface quality (items 13-16). The three sub-scales to obtain the overall satisfaction score as the evaluation of this function are averaged. Averaging the answered items is a good way to calculate the scale score and enhances the flexibility of use of the questionnaire [50]. This is why the questionnaire is still useful if subjects reject an item which they think it is not appropriate in a specific context. For example, the subjects can skip the question, "Did the system give an error message that clearly told me how to fix a problem", if they did not make any mistakes and an error message was not displayed. Therefore, averaging items to obtain scale scores have no effect on the importance of the statistical properties of the scores. Additionally, it is a standardized method for analyzing scale scores and making reports easier to interpret and compare [52]. As shown in Fig 15., the average scale score of system quality is 6.77, information quality is 6.15, interface quality is 6.58 and overall satisfaction score is 6.5 out of 7. It shows that the performance of multi-users communication is appreciated by the participants, generally.

	The Post-Study Usability Questionnaire	Strongly agree 1	2	3	4	5	6	Strongly disagree 7	NA
1	Overall, I am satisfied with how easy it is to use this system.	O	O	O	O	O	O	O	O
2	It was simple to use this system.	O	O	O	O	O	O	O	O
3	I was able to complete the tasks and scenarios quickly using this system.	O	O	O	O	O	O	O	O
4	I felt comfortable using this system.	O	O	O	O	O	O	O	O
5	It was easy to learn to use this system.	O	O	O	O	O	O	O	O
6	I believe I could become productive quickly using this system.	O	O	O	O	O	O	O	O
7	The system gave error messages that clearly told me how to fix problems.	O	O	O	O	O	O	O	O
8	Whenever I made a mistake using the system, I could recover easily and quickly.	O	O	O	O	O	O	O	O
9	The information (such as online help, on-screen messages and other documentation) provided with this system was clear.	O	O	O	O	O	O	O	O
10	It was easy to find the information I needed.	O	O	O	O	O	O	O	O
11	The information was effective in helping me complete the tasks and scenarios.	O	O	O	O	O	O	O	O
12	The organization of information on the system screens was clear.	O	O	O	O	O	O	O	O
13	The interface* of this system was pleasant.	O	O	O	O	O	O	O	O
14	I liked using the interface of this system.	O	O	O	O	O	O	O	O
15	This system has all the functions and capabilities I expect it to have.	O	O	O	O	O	O	O	O
16	Overall, I am satisfied with this system.	O	O	O	O	O	O	O	O

Fig. 14. Post-study system usability questionnaires.

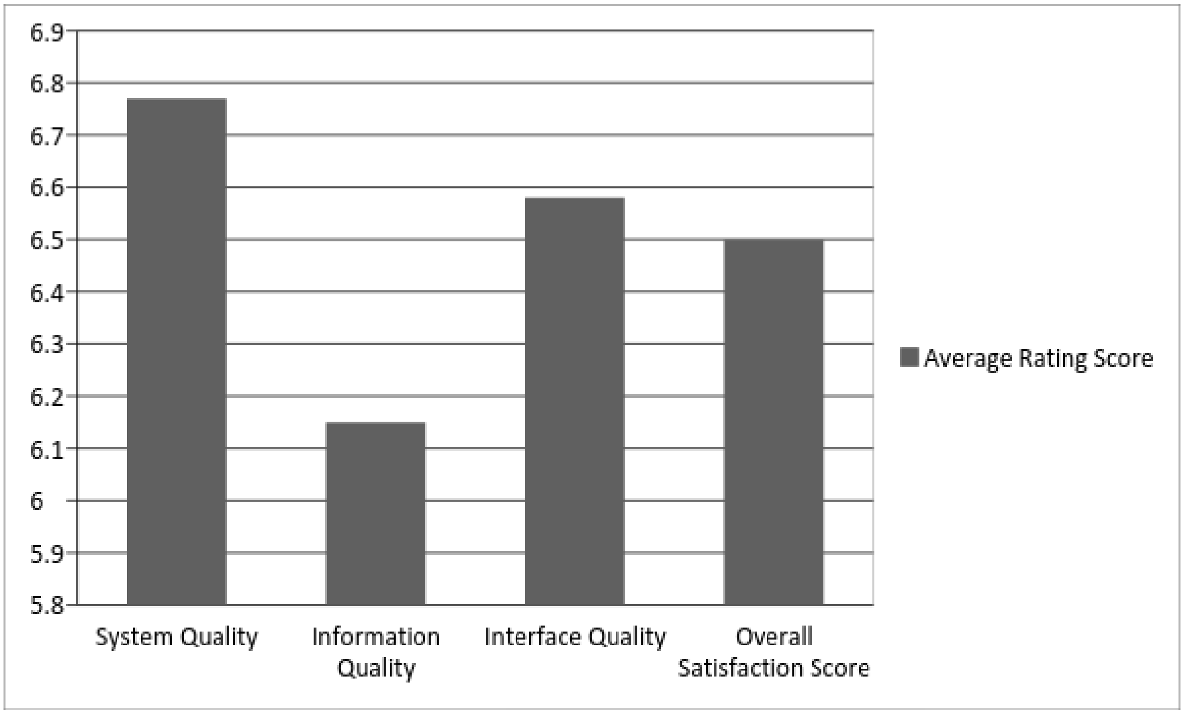


Fig. 15. Evaluation on the performance of multi-users communication by PSSUQ.

6. CONCLUSION

In this study, a novel, spatially aware, mobile system, called Ultrasonic PhoneLens, is introduced. The Ultrasonic PhoneLens which is worked on the mobile device provides a great flexibility and convenience to retrieve and modify the digital information. A user can use this system to dynamically visualize the digital information within a paper-based workspace. A smartphone installed our application can connect with a mini board called Arduino board via Bluetooth module. Arduino is a single-board microcontroller, intended to make the application of interactive objects or environments more accessible. An ultrasonic sound sensor assembled on the Arduino board provides reliable distance detection in the paper-based working environment.

This system takes advantage of dynamic image visualization to augment paper documents with digital information. The main benefits of the system are ease-of-use and multi-user communication. The system applies an asynchronous network to avoid the effect of ghost echo. Data preprocessing enhances the accuracy and performance when users control system. The system doesn't require any extra expensive hardware and doesn't require the user to stand in a specific location.

A user study was designed to evaluate the usability and the user experience of this system. I compared Ultrasonic PhoneLens with the latest similar system and obtained positive feedback. However, the preliminary user study is not classified the result from the group of participants. In future, I will categorize the pre-study information for subject and make the analysis more scientifically. Another part should be improved is that this system is limited by the scope of the paper document. I will incorporate the Ultrasonic PhoneLens into interaction with real objects, such as browsing a wall to replace the function of a stud finder. It will provide a visualization model for users to explore some unreachable places.

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