Developing Sensor Augmented Objects for Self-report of Affect

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Developing Sensor Augmented Objects for Self-report of Affect

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by

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Abstract

In recent years, more and more people have realized that emotion can affect their daily life in a certain extent. However, it is not easy to measure the emotion in a precise way. In this paper, we aim to extend the Sensual Evaluation Instrument to improve the self-report quality of emotion. The purpose of this instrument is to obtain as much information as possible about people's emotion, which contributes to make self-report more precisely. It will be used to detect participants' emotion information while they interacting with computer games. This instrument measures skin conductivity, pressure and movement data with touch sensors, force sensors and accelerometer. The activation area has been implemented in three ways: one is using RFID technology; the other two are using high performance LEDs and light sensors. All of the data which are collected from sensors will be transmitted to an Android phone via Bluetooth so that the designer can gather the information in real time. To make it more intuitive and user friendly, the data will be displayed as a plot on the mobile phone.

To implement this project, the instrument was built with Arduino Pro Mini with sensors embedded, data were collected successfully. An application is developed on Android platform 2.1 to receive and display data. A testing process was used to evaluate the working performance, which followed by some suggestion for the future improvement.

Key words: non-verbal, affect, sensor, RFID, self-report, emotion

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1. Introduction

1.1 Background

Emotion plays an important role in people's daily lives, and people increasingly believe that emotion could affect their behavior [1]. Many researchers have been trying to develop interfaces and systems to measure and evaluate emotions from different aspects [2, 3]. However, emotions are notoriously difficult to measure and they can be shown in both verbal and non-verbal ways, such as speaking rate, stress distribution, facial expression, heartbeat, blood pressure, body gestures, etc. [2]. Some researchers have introduced several methods that can be used to measure users' emotion about what just happened. Self-report is one of the methods in which subjective impressions are collected.

Questionnaire and interview are two classical ways to gather users' real emotion in a method of self-report. Normally, a questionnaire is composed of some highly structured questions that can be answered in an open or closed way. Responders are required to answer these questions one by one, and in this way, their feelings are collected. Interviews usually consist of spoken questions for participants; in the meantime, the questionnaire designer is recording the whole conversation. The advantage of using the question and interview method is that researchers can design the questions according to what kind of information they want. In addition, the data is gathered in a standardized way that is more objective. In some cases, it feels abrupt to ask participants directly how they feel, as feelings are sometimes difficult to express in a verbal way. Exceptional linguistic skills are needed to describe a user's subjective impressions and participants might not be able to write down or speak out their affects. This is true especially for those people, such as children, who are not good at describing feelings. In such a situation, to address this drawback, designers are required to help them finish their self-report to elicit feedback. Unfortunately, the interaction is interrupted somewhat by this situation where participants have to think deeply to verbalize their feelings. However, doing questionnaire and interview only would lose other information, which also contributes to emotion detection, for example, facial expression and body gestures [3].

Another traditional way to do a self-report is to use video to observe an individual's behavior, e.g. voice, facial expressions, and body gestures. However, the analysis of facial expression through recording video is considerably time consuming. The typical ratios of analysis to recorded time can range from 5:1 to 100:1 or even worse [4]. In recent years, some tools based on the use of biosensors have been used to monitor user's physiological features, detecting facial movements or pressure on the mouse [4]. These data are useful cues for measuring affects.

Although many efforts have been made to gain a better self-report or emotion detection in a non-verbal way, standard tools that can be used to measure emotions efficiently and precisely have not been developed. However, with the rapid development of sensor techniques, new material or sensors can be attached to the tools, and more and more physiological features can be collected, which are helpful to detect emotions. For example, measuring how often users click a mouse, how hard they strike keyboards, and what pressure they use when they do it. This information can show us if users are fidgety, angry or not. Other physiological data also need to be measured, such as heart rate, skin conductance, temperature, etc. All the data should be combined together to make a better analysis of the user's affect. To make the interaction more interesting, games are included; sometimes playing games is the whole interaction. The game is designed by Höök, et al. [4] with the purpose of measuring affects. In this way, users are more willing to share their feelings, and it is easier for them to describe their emotions. As a result, it is obvious that through introducing a non-verbal emotion assessment instrument, a better result of self-reporting will be found.

1.2 Sensual Evaluation Instrument and the Previous Work

Sensual Evaluation Instrument (SEI) is a non-verbal emotion assessment instrument developed by Höök et al [4]. It gathers nonverbal information when participants are using SEI to interact with computer games or people. The data collected can be used for further analysis to improve the self-report.

The SEI is composed of eight sculpted objects that are made for self-report, but they do not represent only one emotion respectively, as shown in Figure 1.1. From the back row, they are spiky and pseudopod, the next row are anteater and bubbly, the next row consists of stone, doubleball, and ball, and the front row are barba and papa. It is a good set of tools for expressing basic emotions such as confusion, frustration, fear, happiness, surprise, satisfaction, contentment, stress and flow, but it is not one-to-one mapping [4]. They are made with the same material, just with different shapes and weights.

Figure 1.1 Objects of SEI

The participants are encouraged to freely use the objects to convey their feelings when they are playing games or interacting with others. From the study done by Höök et al. [5], we can see that before starting the self-report, the experimenter explained the orientation of the objects to the participants and encouraged them to use the objects while playing games. Participants usually picked the object up and held onto it for a period of time; they could use multiple objects at one time and move them around as well. During the game, the experimenters left the room to make the participants feel more relaxed. After the game, participants were asked to talk with the experimenters about how the game went. Objects were used to indicate emotion during the talk. A brief interview was then held to ask the participants to give evaluative feedback, for instance, to explain why they chose the object and what their feeling was at that time. Is it hard or easy to use? Do they have any suggestion for the SEI tools? The whole process of playing the games was recorded by cameras. Through the recorded video, experimenters can do an analysis of participants' facial expressions and gestures. In this way, it is helpful for participants to recall what they felt and why they interacted with the object. According to the research, the participants used the objects in different ways. Some people held the object in their hand to show their choice, some put a row of objects in front of them, and some gestured with the object to indicate their feelings.

The research done by Höök et al. [4] has shown that some helpful information would be missing if experimenters were to do an emotion self-report in a verbal way only. Since emotions are usually shown by both body and mind, some physical data could be ignored even though video recording. In order to get evaluative feedback from users, it is practical to use a non-verbal approach to glean users' emotional information and physical features. In the research, many participants refused to verbalize their emotions, but instead used SEI objects. In some cases, it is more practical to express experiences in a non-verbal way than in a verbal way. For instance, when the participant feels angry, he might not say it aloud because he feels that it is rude to do so. However, what he can do is to hold the object much harder to show his displeasure [6] and his heart rate increases higher. During the interaction with computer games and the chat with experimenter's assistance, participants might hold on the object and move it with body language to convey his or her experiences.

In light of the previous research done by Höök et al. [4], in the game Fahrenheit the participant put several objects in a row, and then took some into a special area to show his experiences. This area is called the 'activation area'. The purpose of building an activation area is that the participant can still use the objects while their hands are occupied by game controllers. In this way, they can always tell their feelings by using the instruments. For instance, they can put one or several objects into the area, and different objects and the combinations of objects represent different meanings. What's more, when the participants are playing games or interacting with people, they may express their experiences through gestures instead of words.

1.3 Goal

In this thesis, the objective is based on the previous research to extend the SEI to make it achieve the basic function for self-report; we named it SEI-E (Extension). The SEI-E aims to make the self-report process less dependent on video recording. It can help the participants do a better self-report by adding sensors to the objects to capture physical data. Emotions are usually framed through physical response as well as verbal response [4], and it is impossible to measure how much pressure was put on the object by analyzing the video. In this case, pressure sensors are necessary for measuring the exact value of the pressure on the object. With this value, we can learn whether the participant is calm or excited. If the experimenters want to know how the objects are being used, touch sensors can help. As mentioned above, an activation area is necessary for participants to express experiences when they are playing games with both hands. In this way, they can still interact with objects even though their hands are busy. Some participants like to gesture with the object to convey emotion. Knowing what gesture the participant used is an important cue of detecting emotion. The solution is to add accelerators to the objects to collect the movement data for gesture detection.

To be more specific, the basic functions that the SEI-E should be able to detect are whether it is being held and how tight the users grip it. An activation area is needed for users to convey their emotions. In other words, if a user wants to express emotion, he or she can put an object into the activation area to do it. This behavior may reflect some cues that dictate the user's emotion, so a message should be sent out when an object is put in the area. As long as the objects are inside the area, they should be detected and sent to the mobile phone, so that the experimenters can know which objects are in the area. Furthermore, the user might hold the object in their hand and move it around, like making a particular gesture; this cue contributes to self-report assessment. The SEI-E should be able to capture the raw data of movement. After collection, all the raw data will be transferred to a mobile phone so that the researchers can have the information in real time. With this SEI-E, users can do a self-report by monitoring physiological features, and since the SEI-E is portable and small to be taken of, it is practical for users to move it around or carry it around. Moreover, SEI-E needs to be a real-time tool, which means physiological data is collected and transferred to a terminal simultaneously while the SEI is being used.

2. Requirement Analysis

The SEI-E system overview is shown in Figure 2.1. In order to allow the SEI-E to get physiological information, a touch sensor, force sensor, and accelerator are needed. The purpose of the touch sensor is to detect whether the object is being held. For example, a notification should be sent out when a user picks up a SEI-E object. Since we want to measure how hard the object is being held by users, pressure sensors are necessary. For a normal adult, the range of gripping pressure is from 0 to 170 pounds [7]. In this thesis, the SEI-E is built to detect simple hand or arm gestures, such as making a circle. A 3-D accelerometer is accurate to detect these simple gestures. A Bluetooth module does the task of data transmission. All of the sensors and the Bluetooth module need to be embedded in boards and attached on each object. With the goal of making SEI-E portable, these boards have to be small and they have to be powered by a rechargeable lithium battery. We will build an “activation area”, which is used for participants to show their emotions in a non-verbal way. Simultaneously, on the mobile phone side, an application has to be developed to receive the raw data that is transferred from objects via Bluetooth so that system designers can have the data immediately.

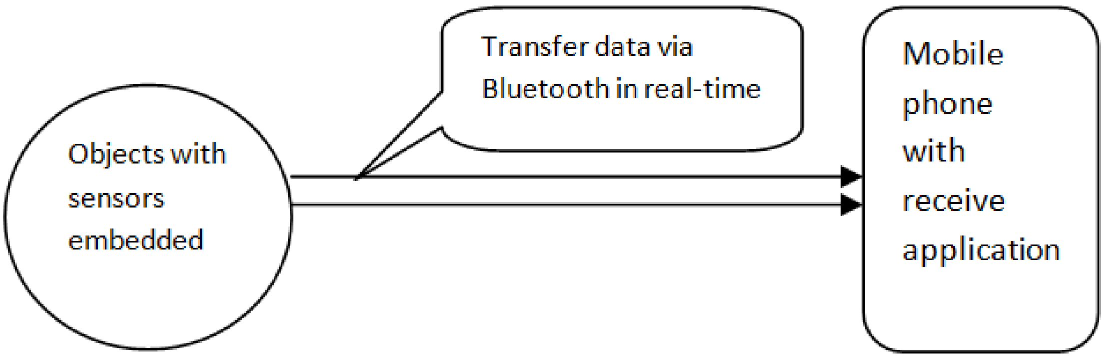

Figure 2.1 SEI-E system overview

In the following sections, the design details and requirements will be analyzed one by one. Section 2.1 will introduce the skin conductivity and pressure detection part of the system. Section 2.2 is the information about how to build the activation area. Section 2.3 will be about the gesture recognition part of the system. Section 2.4 will discuss the platform and the other information to develop the application for mobile phones.

2.1 Skin Conductivity and Pressure Detection

Research done by Picard et al. [6] has revealed that when people are upset, the pressure that they use to press the mouse is obviously stronger than normal. They made a special mouse that has eight pressure sensors attached, but it looks no different from an ordinary mouse. Users did not know it was a pressure mouse and they were asked to do a multi-page questionnaire that had a data saving problem. Every time the participants tried to save the page, the data was erased, and they had to do it again. After a few times, they got frustrated and pressed the mouse harder and harder. This experiment implied that people might also hold the SEI-E object harder when they encounter frustrating situations. That is the purpose of the pressure measurement.

The touch sensitivity and pressure measurement can be accomplished in three steps. Firstly, the system has to detect whether the object is held by the user or not. There are three major different ways to detect that: by using ordinary cameras, special cameras, or touch sensors. The use of ordinary cameras enables the experimenter to detect daily objects, but it is difficult to get an accurate date [8]. The special cameras, like the infrared camera used in The PlayAnywhere system [9] or the depth camera used in the Microsoft Kinect [10], can be more convenient and efficient. However, all of them need complicated algorithms as support. On the other side, the skin conductivity sensor, which is also known as a touch sensor, has been developed for more than ten years. Its basic principle is as follows: Cover conductive material on one side of the insulator with a small amount of voltage to form an electrostatic field. As we know, fingers are conductors. When the uncovered side of the insulator is touched by fingers, it can add another conductive material and, thus, form a capacitor. Then the circuit can sense the changes of the capacitance. According to the changes, the sensor knows it is being touched [11]. Its sensitivity is suitable for SEI-E and the usability and cheap price makes it the best choice.

Secondly, the system has to measure the pressure when the user holds the SEI-E objects, and to do this, force sensors are required. The best way to get the measurements is to use at least three or four force sensors on the surface of the object to collect data from different angles. To make it more precise, up to eight sensors can be attached. However, different genders or even different users have different strength. Thus, this pressure measurement is just used for the qualitative analysis. It is mainly focused on the fluctuation and tendency of pressure when users hold an

SEI-E object, not of a specific value. As a result, the system does not require high accuracy of detection or an extensive dynamic range.

Finally, the pressure data can also be used to detect if the object is held or not. In order to make the SEI-E robust, both touch sensor and force sensor are used together to detect whether the object is touched or not.

2.2 Activation Area Analysis

As described above, during the game Fahrenheit, participants' hands are always occupied by game controllers. Some participants listed objects in a row and then put selected objects into an 'activation area' to convey his or her emotions. One of the functions of SEI-E is to build such an area, which can send a signal to the experimenter when an object is inside. RFID technology can be used to build an activation area, due to its cheap price and high sensitivity.

It is important to give an introduction of Radio Frequency Identification (RFID) technology. After several decades' development, RFID technology is mature and widespread. Identification exists everywhere in people's daily lives, for example, credit card, office key card, concert tickets, etc. The passive RFID system is comprised of a base station (Reader) and a number of tags. The base station consists of an antenna, transmitter, and a computer for sending commands and processing information. The tag has radio frequency (RF) circuits, logic, memory and antenna. The working principle (shown in Figure 2.2) of the system is like this - the base station sends out a command that has been modulated and amplified through an antenna to the air. The passive tag has no battery; it needs to receive the RF from the reader's antenna to power up its circuit. It then sends the signal, which contains the information stored in its memory, back to the base station. In the end, the base station gets the backscattered signal and passes it to the computer for processing [12].

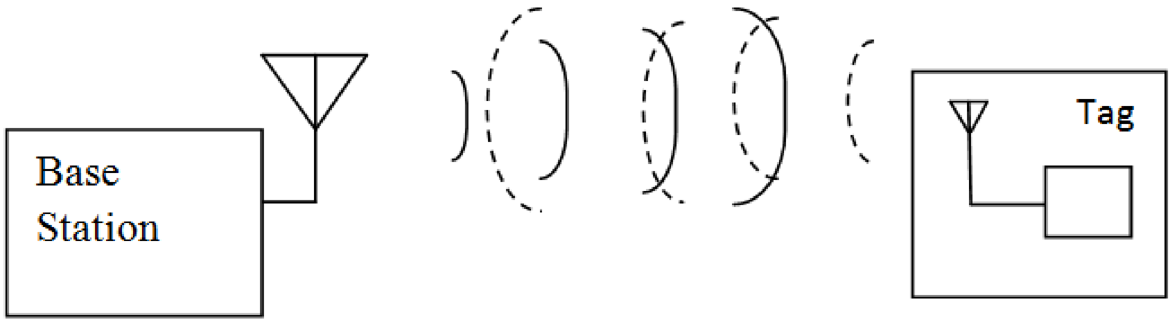

Figure 2.2 Overview of RFID working principle

In this thesis, the requirement of the activation area is to send out a notification when it detects an object inside the area. A passive RFID system is ideal for this requirement. In the case of passive RFID tags, the working frequency varies from about 30 KHz up to 30GHz, which can be divided into low frequency, high frequency, ultra-high frequency, and microwave frequency. Generally speaking, these frequencies affect the cost, size, and performance of the system. A high frequency RFID system has less than a one-meter range, a reasonable data rate, and inexpensive price. It fits the requirement of an activation area.

Tags can be attached to the objects and the reader's antenna area can be viewed as the activation area. The serial number of the tag is unique. In other words, each object has a unique ID. The size of the antenna is determined by designers. According to the research done by Höök et al., the size should be 42cm by 30cm. A low frequency RFID system has a shorter range, a lower data rate, and a larger antenna. An ultra-high frequency and microwave frequency have a long read range (up to 10 meters) and higher data rate, but it is a little more expensive. In this thesis, we chose a 13.56 MHz system because of its reasonable read range, data rate, and price. If the participants put the SEI-E objects into the area, the researcher can detect the existence of the tags and receive a notification of which objects are inside the area.

There is another approach to fulfill the activation area requirement, which is by using light sensors. As we know, a light sensor is very sensitive to lights. The most important thing to remember is that the return value of a light sensor depends on the brightness, which means the return value of strong light is far different from weak light. With this feature, we can build the activation area with something that can give out light. One plan is to put lights into a box and to cover it with a transparent cap. Light sensors are embedded into the SEI-E objects, so that when the objects are put into the area, the light sensor's return value will change according to the luminous intensity of light and this would imply that the object is inside the area. The advantage of using this method is that the box can be divided into several parts and a bulb would be put into each part. The bulbs are powered with different currents, so that the brightness is different from each other. In this case, the system can detect not only that the object is inside the area, but also the exact position of the area the object is located in. It is a good thing to know the exact position of an SEI-E object, because it might reflect different meanings when the object is put in different positions. The reasons why we picked this solution to build an activation area are listed below. With this method of building the activation area, it is much easier and more flexible. The box contains only a few small bulbs and can be moved easily without destroying it. When comparing it to the RFID method, the advantage is that it can detect where the object is located in the box.

Based on the light sensor, another way of building the activation area is to use blinking LED. This method is similar to as the mentioned above. A big box is divided into several small parts, and one LED will be put in the box to light it up. The difference is that these LED are powered up with a blinking circuit. The resistors and capacitors connected with them are different to each other to make them have unique blinking rate. When the objects are put into the area, the light sensor can detect the location by different blinking rate.

There are other ways that an activation area can be built as well. For example, an infrared sensor can be a good idea. It is similar to the light sensor approach mentioned above. To replace the LED and light sensor with infrared LED and infrared sensor respectively can fulfill the activation area. In this thesis, we implemented the activation area in three ways: RFID based, light luminous intensity based and blinking rate based. Since the way of using infrared sensor is similar to light sensor, using one of them is enough to prove that the activation area can be achieved.

2.3 Gesture Recognition

In the middle of doing a self-report, participants are more willing to use gestures to show their feelings rather than saying it. Gestures are a non-verbal way of showing intention. There are two main ways of detecting gestures: vision-based and device-based. A vision-based gesture recognition system using a camera has been done, and it is a pretty good way to recognize gestures [13]. However, this kind of vision-based system is really environment dependent. The quality of the results depends on light condition and angle [13]. If the participant is out of the camera’s scope or the light is too dim, their gestures will not be recognized. The system using an accelerometer is more reliable when compared to a camera [13]. The movement information will be recorded in any condition. We chose the accelerometer for its cheap price, ease of use, and reliability. Movement data is recorded in real time and this data is used to reconstruct the gestures [14]. A 3-D accelerometer is accurate to recognize simple movements, such as forming a circle, as well as detecting whether the object is falling down or moving up. In this paper, only raw data of the three-axes are collected for future work. There is another way of gesture recognition — using a passive RFID system [15]. In future work, we can use this technology to improve the SEI-E tools. In this thesis, only the accelerometer was used to collect movement data.

The accelerometer produces vector data at all times. The continuous data needs to be processed to recognize gestures. The Hidden Markov Model (HMM) is a statistical model that can be used to process the acceleration data in the time domain to achieve pattern recognition, for instance handwriting or gesture recognition [13, 14]. Before sending acceleration data into HMM, we need to build a quantizer to cluster the raw data. A k-mean algorithm will be applied to achieve the goal [17]. The data will be sent to the HMM for recognition after quantization. If we want better quality, filters and classifiers are necessary. Before the quantizer, filters are applied to the acceleration vector data to eliminate noise from the raw data. A classifier is set to optimize the HMM for better recognition [19].

After the recognition, the next step is to evaluate the performance. User-dependent and user-independent are two popular ways to do the evaluation [15]. The former requires users to do some gestures as template samples before using the system, which can be used to augment the training data. For the user-independent case, the system is well developed to recognize all kinds of gestures without template samples. It is more difficult to implement compared to the user-dependent method [15].

2.4 Application on Android Phone

When the SEI-E object is being used by participants, it collects data by sensors all the time, such as skin conductivity, pressure, and movement information. These data need to be sent to the designers for monitoring and further processing. Usually, an application is developed on the desktop for monitoring and processing. However, this traditional desktop network now is far less efficient for today's demands. It can only share information from computer to computer via the internet or by flash disk. On the other side, the smart mobile phone's prevalence in modern life provides a "constantly present, personal service channel" [19]. With the built-in Wi-Fi, Bluetooth module, and various applications, it is always with its user to help them keep in touch with others and manage everyday tasks [20]. This advantage gives a mobile phone "great potential to be the default physical interface for ubiquitous computing applications" [20]. In addition, its ubiquitous computing characters keep totally in line with the future developing tendencies of the computer, which aims to assist users in a way that is "so imbedded, so fitting, so natural," to access network and communication services from anywhere[21].

Since Google launched the Android mobile operating system in 2007, it has gained millions of users all over the world. Reports say that there will be more than 300 million Android users by February of 2012 and over 850,000 Android devices will be activated everyday[22,23]. The Android system is an open source project for anyone who wants to develop applications and it is not difficult to program. Because of its widespread use and the ease in programming, the Android phone was chosen as the handheld terminal to receive and process data from SEI-E objects.

Bluetooth is a wireless protocol for exchanging data over a short range(less than 10 meters) and exists in many products, especially handheld devices. Wi-Fi also can be used to transmit files. It uses the same frequency as Bluetooth, but with a higher transmitting rate and wider range. As a consequence, it consumes much more power than Bluetooth [24]. In this thesis, we chose Bluetooth to transmit data to the handheld terminal, because it has more users and consumes less power.

All the data received by SEI-E tools is transferred to an Android phone using Bluetooth so that the designers can have the real-time information. The mobile application should be able to search and connect to the SEI-E object, and then receive sensor data and display it in graph form. Figure 2.3 shows the use of sensor application. The SEI-E objects are acting as the server; they are always listening while they are on. The Android phone works as a client. It can search the devices and connect to the one that is being used. Data transmitting begins when the connection is established. Since this thesis aims to build the prototype of only one SEI-E object, here we only consider how one object exchanges data with the Android phone at a time.

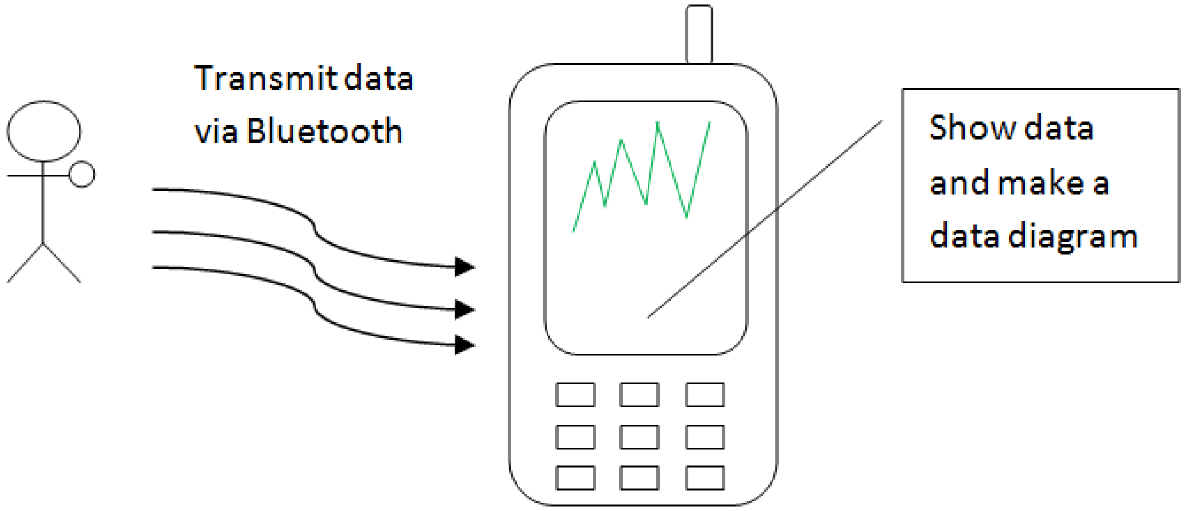

Figure 2.3 Use case of sensor application

Before starting to develop this application, it is necessary to analyze its requirements. From the functional point of view, the application has three functions. The first one is that it has to be able to search devices. Usually several Bluetooth devices will be found, which should be displayed as a list on the Android phone. Select and then connect to the target device via Bluetooth. The Bluetooth module in the SEI-E object is open all the time as long as the object is on. In other words, it is listening to other Bluetooth devices all day long. The application enables the phone's Bluetooth and starts to search. Then it pairs with the target device and establishes the connection (here we assume the target device is found). The second function is that the application receives data from the SEI-E object. Once the connection is established, the object will continuously send data to the Android phone. This data is received and stored in the mobile phone. The third function is to display this data on the terminal in terms of diagram and strings. In order to make the data easy to read, we display them in a diagram, like a cardiogram.

User interface (UI) is the interaction between user and the mobile phone. Our goal is to make the application easy and clear to use to create a friendly UI. Since the function of this application is simple, not too many buttons are needed. A “Search” button is used to start the searching activity and all the surrounding Bluetooth devices are displayed as a list with name and MAC address. In this phase, a “Connect” button is needed to pair up and connect to the target device. Once the connection is complete, the data will be shown on the screen in terms of both diagram and strings. If the application is closed, the connection will be canceled automatically.

3. Implementation

3.1 System Development Tools and Environment

Before describing the implementation process, it is crucial to give a short overview of the development tools and environments. Several sensors need to be embedded in the SEI-E object, and a development board is necessary to power up these sensors. A program developed by us will be uploaded to the board to control the whole process of data collection. In addition, a Bluetooth module is needed to attach to the board to finish the transmission. The development board for this project is called Arduino Pro Mini. Arduino is an open source electronic platform. The Arduino programming language (based on wiring) is used to control the microcontroller, and the Arduino development environment is built on processing [25]. The Arduino Pro Mini can be powered up by a 3.3 Volts lithium battery, instead of a USB, so that it is portable. It has 14 digital I/O pins and 6 analog pins. The Arduino Pro Mini can provide stable voltage output of 3.3 volts, which can be used to power up the sensors and the Bluetooth Module. It has a 16KB flash memory and its clock speed is 8MHz [25]. The size of the Pro Mini PCB is about 0.7 by 1.3 inches, shown in Figure 3.1.

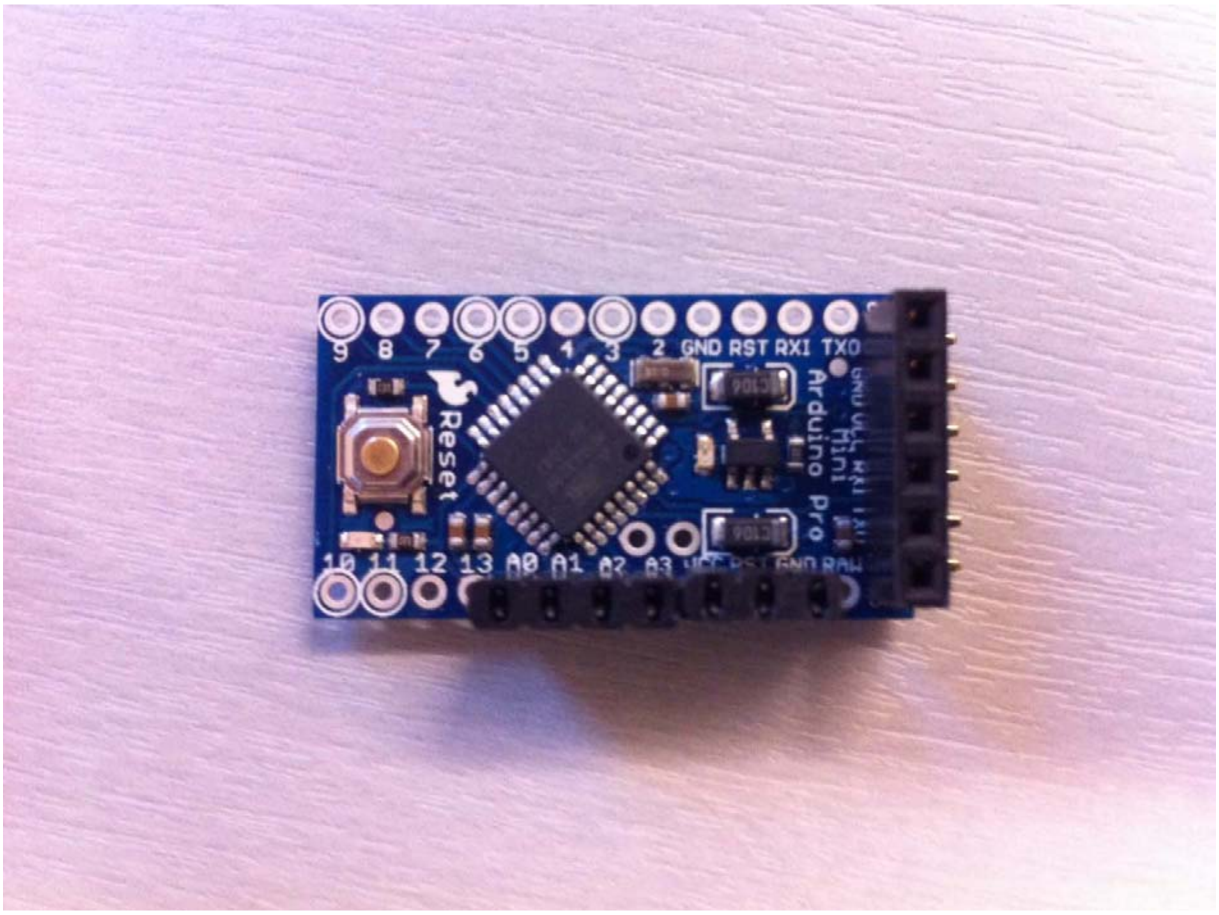

Figure 3.1 Arduino Pro Mini

The official programming IDE is provided on the website www.arduino.cc [25]. It is an open source software based on the software Processing. The program can be written directly on this IDE and uploaded to the developing board by choosing the right board type and COM port. Figure 3.2 shows an example of this IDE.

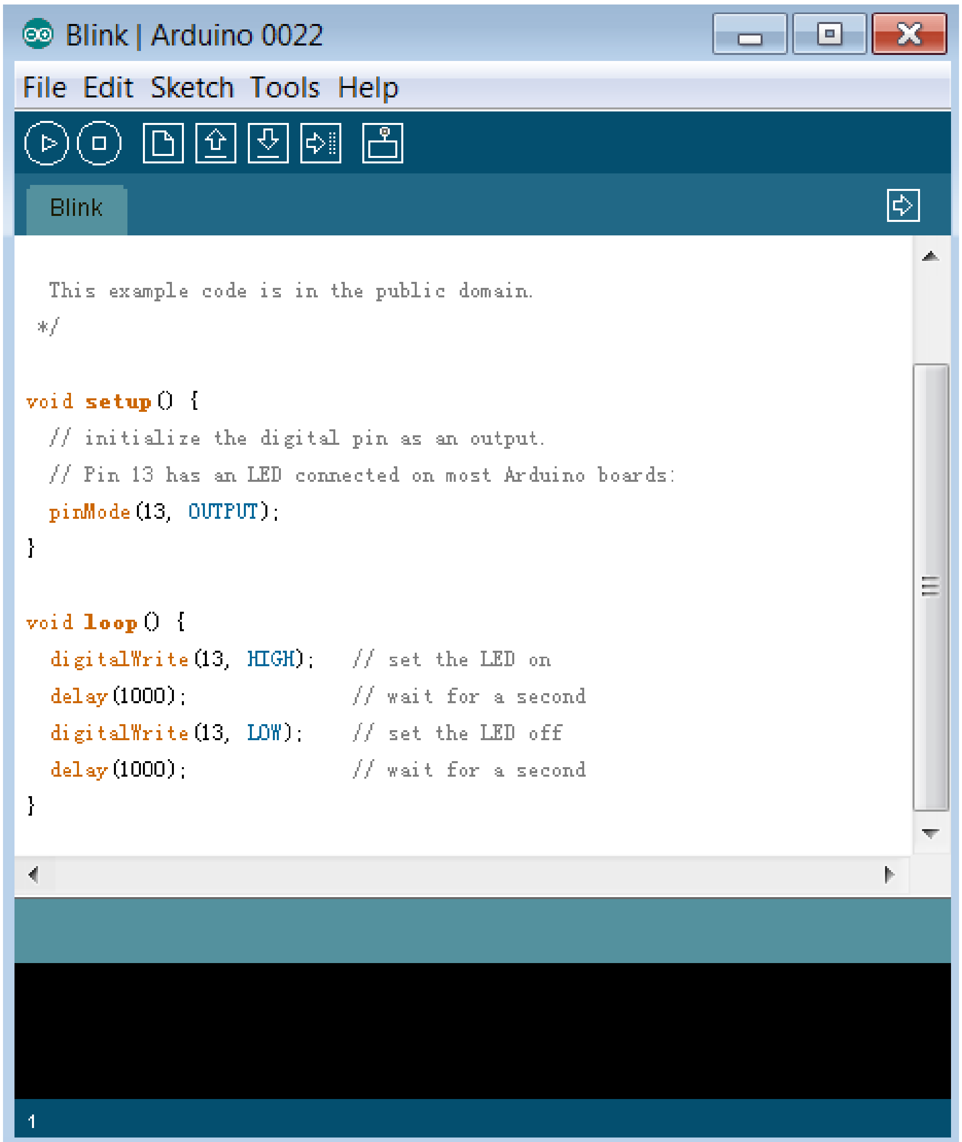

Figure 3.2 Example of Arduino IDE

Since all the collected data will be sent to a mobile phone via Bluetooth technology, the Bluetooth module is necessary in this project. In this thesis, Bluetooth Mate Silver was used to work with Pro Mini to exchange data with the mobile phone. See Figure 3.3. Its size is 1.75 by 0.65 inches, almost the same size of the Pro Mini PCB. This module works perfectly with Arduino Pro Mini. Six pins should be connected to Pro Mini according to the following rule (the former pin is Bluetooth mate silver): RTS-O to GRN, RX-I to TX-O, TX-O to RX-I, VCC to

VCC, CTS-I to GND and GND to BLK. RTS-O and CTS-I are used to control data flow, and they can be disconnected if there is no need to control data flow.

Figure 3.3 Bluetooth Mate Silver

3.2 Implementation of Detecting Skin Conductivity and Pressure

To monitor whether the SEI-E object is touched, a skin conductivity sensor (touch sensor) is a good choice. If several touch sensors are embedded to the surface of the object, the return values will tell whether the object is being touched or not. As described above, the Arduino Pro Mini has six 10-bit analog inputs, which means the return value of the sensor attached to the board is from 0 to 1023. Return value can be used to detect whether the sensor is touched. As shown on Figure 3.4, the sensor we used is touch sensor-1110 produced by Phidgets Inc. The sensor has three wires. The black one is connected to ground, the red one gets power of 3.3Volts from the pin Vcc of the Arduino Pro Mini, which can supply a stable 3.3 volts output. The white one is the data wire. Connect the data wire to the Analog input socket A0. The return value of the touch sensor will be transmitted back to the Arduino Pro Mini through A0. This sensor works because of capacitive changes. Touching the plastic part will change the capacitance of this sensor, which can activate the sensor to make a notification. In the case of somebody is touching the sensor, the return value is 0, otherwise it is 1023. The last thing is to connect the red and black wires of the lithium battery to the pins Vcc and Gnd of Arduino Pro Mini. After finishing the hardware, a program is needed to upload to the board to make all of the components work as expected. The function of this program is to configure the sensors and the Bluetooth module. It first initializes the analog pins and transmission baud rate. Afterwards, it controls the sensors to collect data. This data will be sent to the Android phone via Bluetooth. To identify which small box the object is located in, we need to evaluate the data collected from the light sensor. See Appendix for more details.

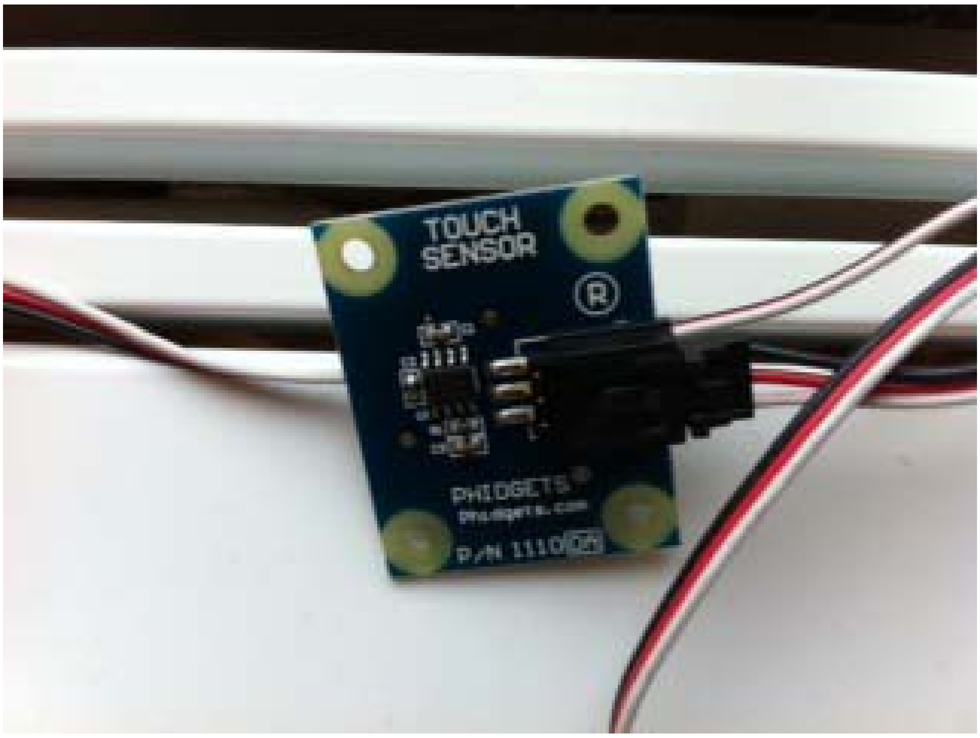

Figure 3.4 Touch sensor

The pressure sensor we used to measure how hard the object is held is also from Phidgets Inc. It is the Force Sensor-1106, as shown in Figure 3.5. Like the touch sensor, the force sensor also has the same three pins - power, ground, and data output. It returns a zero when the blue circular button has not been pressed. The resistor of this sensor will be more than 100kohms if the button is not pressed. It will fall down to 1kohms as the force increases. The output voltage varies from 0 to maximum. This feature will give us the data of how much pressure is applied on the sensor. If several force sensors are embedded on the surface of the SEI-E object, how hard the object has been held can be measured by these sensors. A program was written on the Arduino platform to control the sensors. In the program, the return value of both the touch sensor and force sensor are sent to the mobile phone if the object is held. Designers can easily notice if the object is held or not and receive the accurate pressure that is applied to the force sensor from the return numbers. For example, if the return value of the touch sensor is 0, designers know that the object is being held by seeing the number. A message of “Object 1 is touched” will also be displayed on the mobile phone to inform the designers. The same rule is applied to the force sensor; the return values will be sent to mobile phone and be showed as a plot.

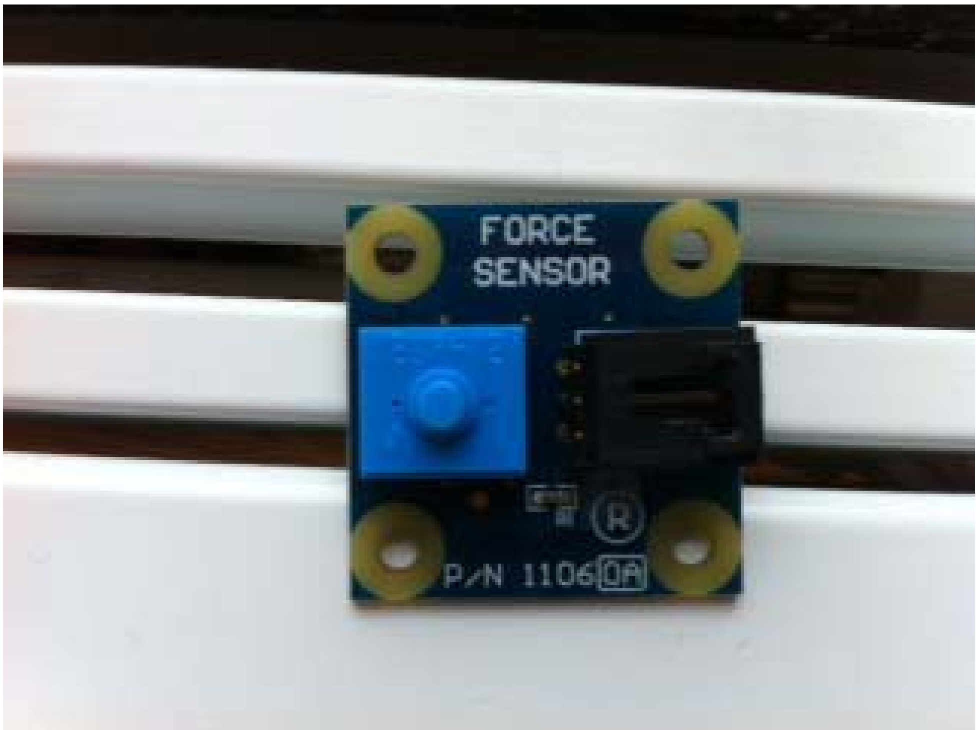

Figure 3.5 Force Sensor

To sum up, the object system is combined of the following components: touch sensor, force sensor, light sensor, accelerometer, and a Bluetooth module. All of them are connected with Arduino Pro Mini development board, as shown in Figure 3.6.

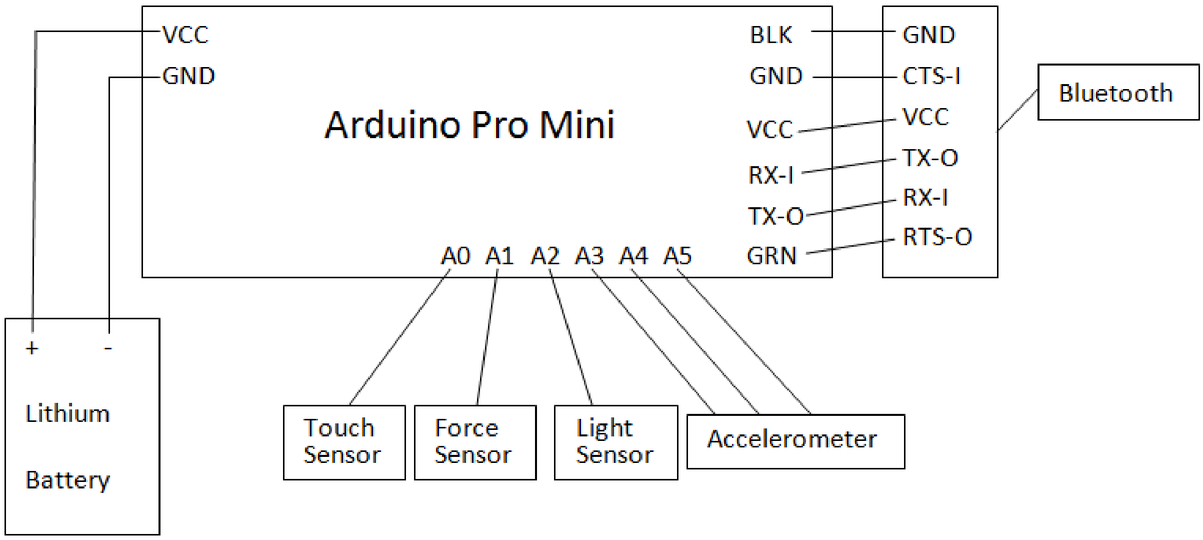

Figure 3.6 The overview of the components of SEI-E Object

3.3 Implementation of Activation Area

3.3.1 Activation Area based on RFID Technology

One way to build the activation area is by using RFID technology. In this thesis, we used the tag-it RFID system designed by Texas Instruments to build the activation area. The RFID system is comprised of the reader, antenna, and transponder (tag). The antenna I made myself (described below) is connected to the RFID reader that communicates with a computer through a serial connection. There is a program "S6350 Reader Utility" [26] provided by Texas Instruments running on the host. It is used to control the reader to send out signals and commands. The reader keeps sending out commands and energy all of the time and is also receiving signals from the tag. A typical tag consists of an antenna and a resonant circuit. It is powered by the radio frequency signal that is sent out by the reader. There is an individual 32-bit long address stored in the tag's memory, which ensures that every tag is unique from each other. Two operations are included during a transaction between reader and tag, which are described as follows: a) the reader sends out a request to the tag; b) the tag sends a response back to the reader. Since the tag is passive, it will not send a response to the reader without receiving a command.

The size of the activation area should be neither too big nor too small. We asked Jarmo [4] who designed SEI for opinions and reached an agreement that the size of 42cm by 30cm is appropriate. The first thing that needs to be done is to make an antenna that is a 42cm by 30cm rectangle. The material used to make the antenna is copper wire that can be bent to make a rectangle shape. After designing the shape and size of the antenna, bend over the copper wire to the desired size rectangle. Another important thing is to leave a 1cm gap where the ends of the copper wire connect together. To maintain good performance, the antenna was taped to a piece of cardboard to make it fixed. That way the user can move it without changing the shape of the antenna.

The working theory of this loop antenna is that when the inductive impedance equals to the capacitive impedance, the circuit will be at a resonant state. To make this antenna work at resonant state, we need to calculate the inductance L and then use equation (2) [27], to calculate capacitance C. The next step is to calculate the inductance of the wire loop using the equation (1) [27].

$$L_{\mu H} = \text{Side} * 0.008 \left[\text{LN} \left(\frac{\text{Side} * 1.414}{2 * \text{Diameter}} \right) + 0.379 \right] \qquad (1)$$

Where

Side = Centre to centre length of the antenna side (cm).

Diameter = Tube diameter (cm). We used solid copper wire, so here we use the copper wire diameter, instead of tube diameter.

Because the antenna is not square, we use $\sqrt{ab} \approx 35.4965$ as side instead. The diameter is 1.2mm. According to equation (1), we get the result of the inductance as about 1.6249μH. After calculation, we used the LCR meter to measure the inductance of the copper wire loop; the outcome is 1.68μH, closer to the result we get by equation (1). A capacitor is necessary to make a parallel resonant circuit for the antenna. We used equation (2) [27] to compute the value of the capacitor we need at the frequency of 13.56MHz.

$$C_{RES} = \frac{1}{\omega^2 L} \qquad (2)$$

Where $\omega = 2\pi f$

Based on the outcome we got from equation (1), L=1.68μH, f=13.56MHz, we can get the value of the capacitor $C_{RES} = \frac{1}{(2*\pi*13560000)^2*0.00000168} = 8.2 * 10^{-11}(82pF)$.

After making the antenna at resonant state, the performance of the antenna should be considered. To ensure the performance of the antenna, we need to consider its quality factor and whether it is good or not. The quality factor of the resonator is the ratio of the resistance and the impedance, see equation (3) [27].

$$Q = \frac{R}{2\pi fL} \quad (3)$$

The Q factor reflects the quality of a resonant system in terms of energy dissipation. Generally speaking, the output power is high when the Q value is high. But if the Q value is too low, the circuit would not be resonant at all. The Q factor should not be too high nor too low - 10 to 50 is the normal range [27]. To lower the Q factor, a 'Swamping Resistor' will be used. Here we built the antenna with a load of 50 ohms impedance and at 13.56MHz, the value of Q should be 20 or less to have a good performance. Equation (4) [27] is used to calculate the value of the swamping resistor of parallel resonant circuit.

$$R = \frac{Q_{prsent}*Q_{required}*2\pi fL}{Q_{present}-Q_{required}} \qquad (4)$$

Here we have f=13.56MHz, L=1.68μH, and the value of required Q equals to 20. According to equation (4), the present value of Q is necessary to compute the value of resistor we need to build a resonant circuit. A program called ADP (Antenna Design Program) from Texas Instruments [28] is used to compute the self-inductance, the Q value, and the value of resonant capacitor in theory. After entering the data needed (we assumed that the outer diameter of tube is 2mm, and the inner diameter of tube is 1mm), for instance, the length and width of the antenna, the diameter, the frequency, we get the theoretical outcome of self-inductance. See Figure 3.7.

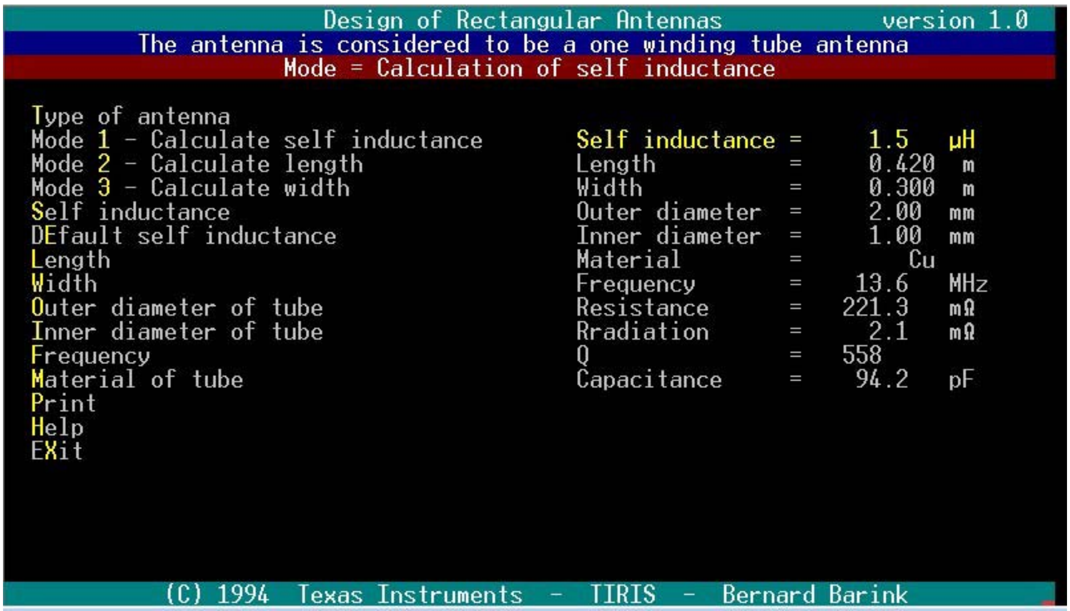

Figure 3.7 The theoretical outcome of antenna's parameters

From Figure 3.7 we can see that the self-inductance is 1.5µH, just a little difference from the value we got using equation (1), and the capacitance is 94.2 pF, which is also close to the 84.78 that was calculated by equation (2). The present value of Q is 558, which can be used in equation (4) to compute the parallel resonant resistor. The value of the swamping resistor is about 2969 ohms. Since the desired swamping resistor and capacitor has been calculated, the next step we will do is assemble the antenna. To get perfect performance, the antenna needs to be tuned by adjusting the value of the capacitor, so we chose two variable capacitors rather than a fixed value capacitor. One of them is for coarse adjust, the value range is from10 to 120pF, and the other one is for fine adjustment, ranging from 5 to 15pF. Using these two variable capacitors to adjust the total value of capacitance makes the antenna achieve better performance. Solder the capacitors and swamping resistor as shown in Figure 3.8.

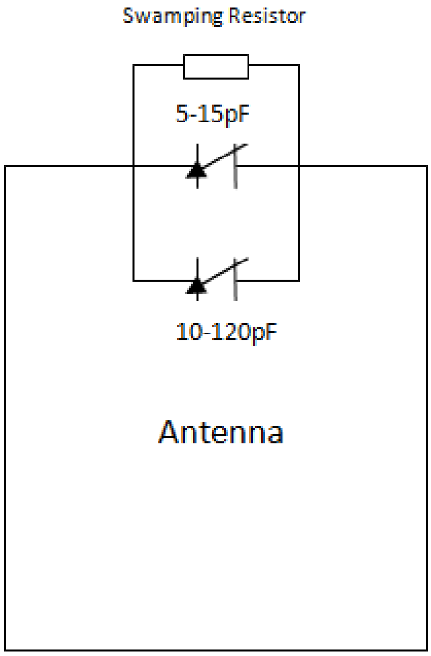

Figure 3.8 The resonant circuit on the antenna

After assembling, attach a RG-58 coax cable to the antenna using a T match; connect the other end of the cable to the antenna analyzer. To adjust the impedance as close to 50+j0 as possible, use a screwdriver to change the value of the coarse adjust capacitor and then use the fine adjustment capacitor to make Xs close to zero. The ideal situation is Xs equals to zero, but it will still have very good performance if the Xs is less than 5. Then adjust the matching point of T match to make the Rs shown on the analyzer to become 50 ohms. Check and see if the Xs are small enough or not. Otherwise, adjust the fine variable capacitor to make it close to zero. The best outcome we had is shown in Figure 3.9. The resonant circuit of the antenna is shown in Figure 3.8.

Figure 3.9 The outcome of the antenna analyzer

Connect the antenna to the reader, and connect the reader to a computer through a serial port. Start the program “S6350 Reader Utility”, and set up the parameters for communication, including the COM port, baud rate, data bits, stop bits and parity, as shown in Figure 3.10. In the program S6350, set up the command to “Read TRP Details” and press the button “Start Continuous Mode”.

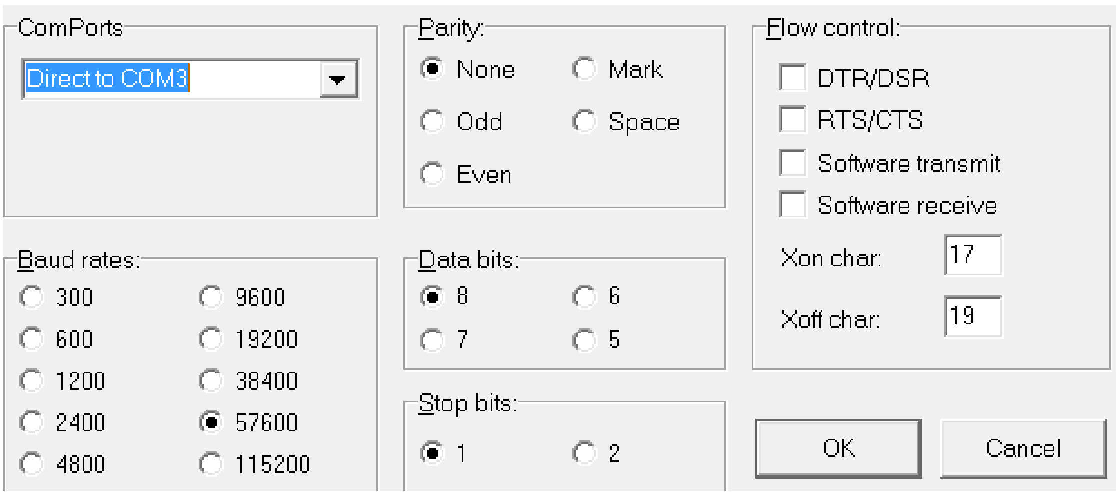

Figure 3.10 Set up of S6350 RFID Reader

When no tag is inside the RF signal range, "No Transponder Found" will appear on the computer's monitor. If only a single tag is put into the antenna, the screen will show the information of the tag. See Figure 3.11.

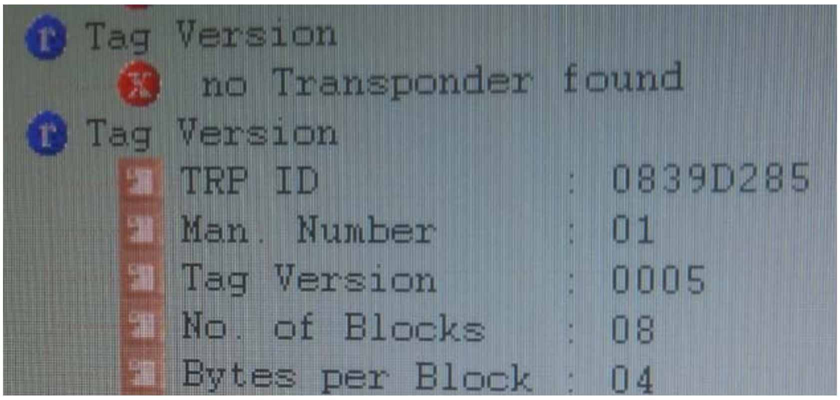

Figure 3.11 Information of the tag found

3.3.2 Activation Area Based on Light Intensity

As described in section 2.2, another way to build an activation area is by using light sensors. The activation area can be built with a cardboard box that has a crystal cap. In order to know the exact position of the object, this box is divided into 16 parts with the same size area. A LED is put into every part of the box to provide lights for detecting SEI-E objects. The power of these LEDs is the same, but the luminous intensity can be customized by controlling the current. Every time the object is present in the box, the light sensor detects the light giving out from the box and returns a value according to the strength of the light. This return value can be viewed as the ID of the LED. This offers a lot of help in identifying the position in the area. This box is lightweight enough to be moved around and all the LEDs just need to be connected to a power supply with a resistor, as seen in Figure 3.12. As described, every LED is connected to a resistor to control the current. One reason for this is that it is necessary to protect the LED from damage, because the maximum current for the LED is usually very weak - in our case, it is 20mA. LEDs could be destroyed due to operation mistakes if it is connected to the power supply directly. The other reason is to control the LED's brightness by controlling the current. Since the LED's luminous intensity is decided by the current, higher current (not exceeding the maximum) means a brighter

LED. Different resistors are connected to these LEDs to make different luminous intensities. In this way, the return value of light sensor is different, although the LEDs are the same. In this thesis, we used resistors from 450 ohms to 1500ohms to acquire different brightness levels. This project is a prototype before building the real product. We used a stable power supply, instead of a lithium battery to offer stable voltage. If the participants or designers want to move the activation area, they just move it with the voltage source together. The box is made as shown in Figure 3.12. A lithium battery should be used to make this activation area more portable in future work.

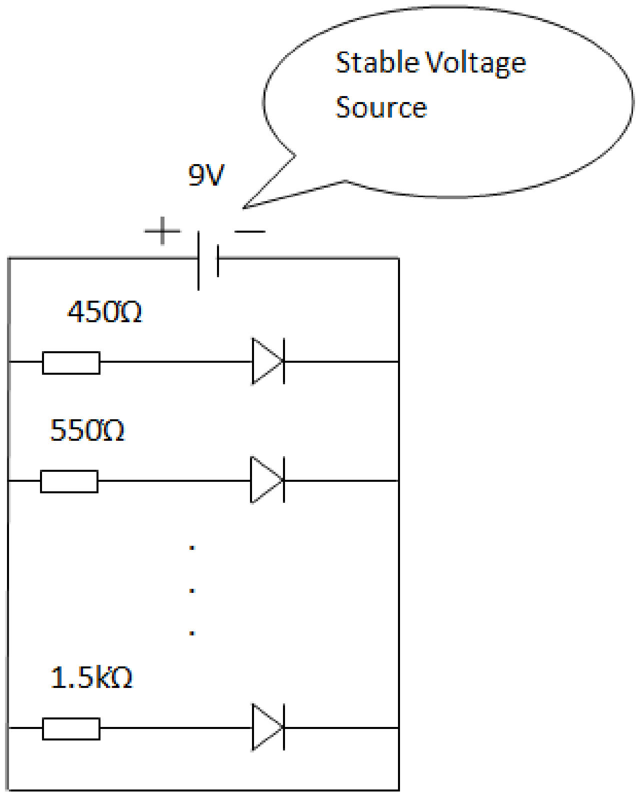

Figure 3.12 Circuit for controlling LED's luminous intensity

Figure 3.13 Activation box with high performance LEDs

A light sensor is made by using two resistors. One is a variable resistor that is sensitive with lights; the other one is a standard resistor. The working principle of this light sensor is shown in Figure 3.14.

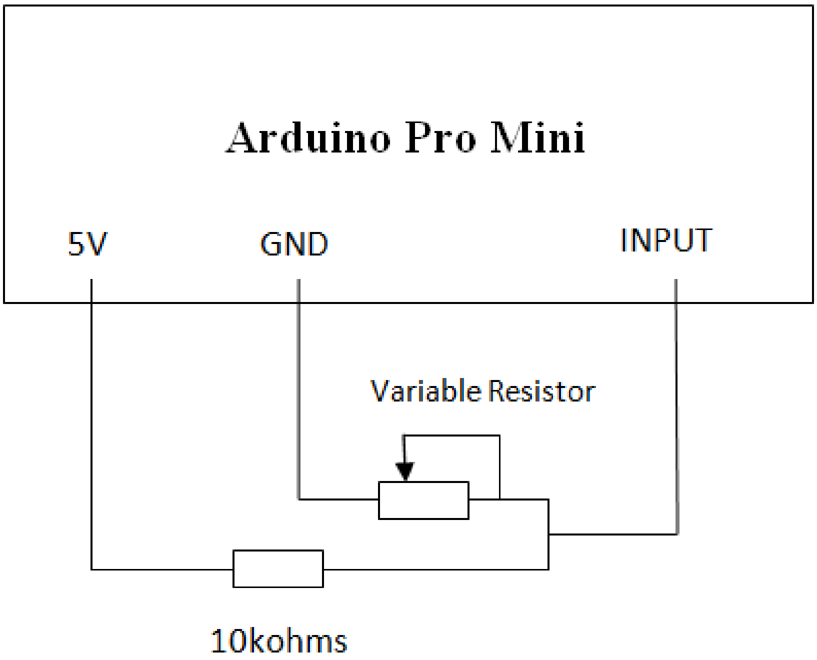

Figure 3.14 Light sensor circuit

It is obvious from the circuit that the voltage of the variable resistor is measured by connecting it to the analog input of the Arduino board. The value of the variable resistor becomes smaller when it meets stronger light and vice versa. The voltage between "INPUT" and "GND" will change according to the light. Arduino Pro Mini can detect the changes of voltage in real time and get a value, which shows the corresponding voltage. The return value is always within a small range when the light sensor is put inside the shining box. The analog input in Pro Mini is 10 bit, from 0 to 1023. Several thresholds are set up to divide this range into a few small ranges to give a unique identity to every LED.

In this project, a big box is divided into 16 small boxes as the activation area. Since the analog input of Pro Mini is only ten bit, these 1024 values need to be divided into 16 ranges to identify LEDs, with 64 values per range. It is too difficult to control the LEDs with 16 ranges of luminous intensity, because the range is too narrow. In this case, we used only 9 boxes of them after our discussion with Jarmo [4]. Every LED should have its own range, which is about 100 wide. For instance, the return value of box 1 is between 50 and 150, for box 2 is from 150 to 250, and so on. Obviously when the object is put in box 1, the board can send out a notice in light of its return value. But the standard LED gives out lights directionally, as shown in Figure 3.15.

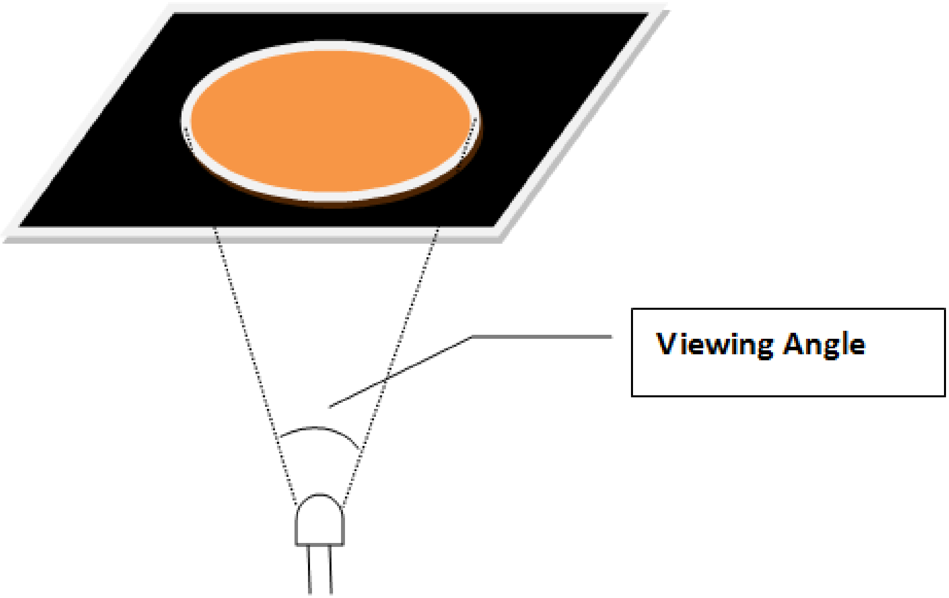

Figure 3.15 View Angle of standard LEDs

The viewing angle of a standard LED is usually less than 50 degrees. In this situation, the object might not be detected or misidentified if it is put in the black area, because the light is too weak. The luminous intensity of a standard LED is pretty low, about 10 mcd (cd: candela). There is no big difference, even though one LED is given the maximum current and the other one is just half of the maximum. It is more difficult to make obvious differences among 9 LEDs. The high performance LED has a wider shining angle, even up to 180 degrees. The luminous intensity can be much higher than a standard LED, up to hundreds of candela. The luminous intensity of the LEDs used in this thesis is 1160 mcd and the viewing angle is 70 degrees. These high performance LEDs can light up the whole box. After setting up the circuit, the code is also needed to upload to the Arduino Pro Mini to control the procedure. Some pseudo code is shown in the Appendix.

The alternative way is using bulbs instead of LED. In normal cases, bulbs give out light uniformly in every direction, which can light up the entire small box. Bulbs with different powers are put in the box separately in much the same way as putting LEDs. The biggest disadvantage of this idea is that the bulbs are too power consuming. The power of the bulbs used in this project is from 5 to 50 watts, which is much higher than LED. A lot of heat is produced and wasted by these powerful bulbs.

3.3.3 Activation Area Based on Light Blinking Rate

Another way of using light sensors to build the activation area is to put blinking LEDs inside the box. The idea is that when the object is put inside the box, a notification is sent out because the light sensor can detect the blinking pattern. The LED can be set to blink periodically, for example, to be turned on for 1 second and turned off for 0.5 second. The Pro Mini starts accounting the time of the blinking period when the return value of light sensor shows the LED is on. If the time matches the LED's blinking period, a notification will be sent out to the mobile phone. The circuit of making blinking LEDs is shown in Figure 3.16.

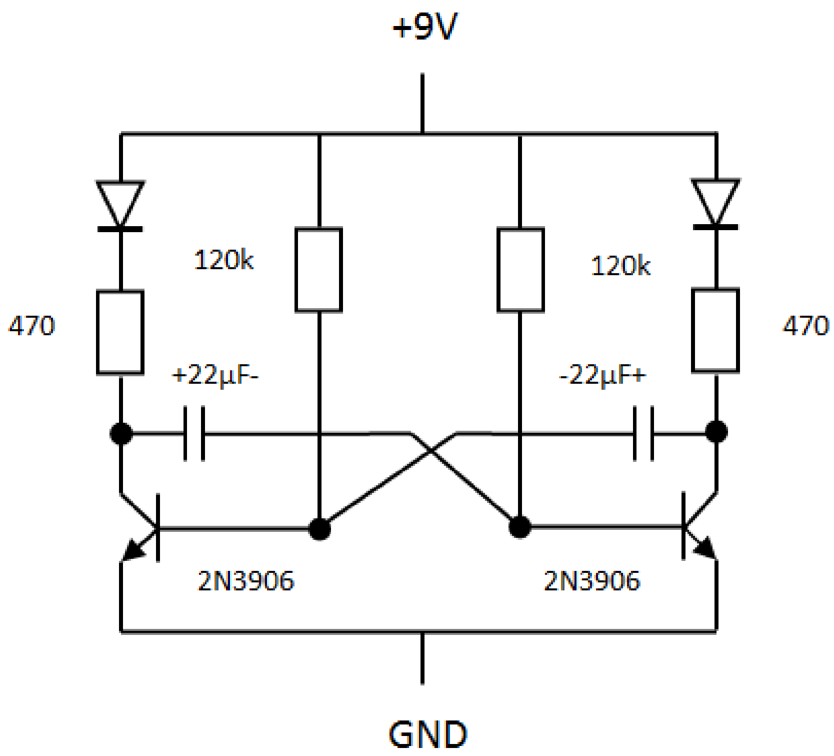

Figure 3.16 Blinking LED circuit

The flashing rate of the LED is controlled by the resistors, capacitors, and power supply. In this research, the 120kohms resistor is used to control the blinking rate. This blinking circuit is simple and costs very little power, because only two transistors, two capacitors and four resistors are involved.

3.4 Gesture Recognition

In order to monitor the participant's behavior, a three dimensional accelerometer, MMA7361, was used in this system. It collects the instantaneous accelerations of x, y and z axes with a measuring range up to 6G, which can be used to recognize the activity. The accelerometer has three analog outputs that are connected to the Pro Mini's analog input pins directly, so that it can monitor the movement of the object. The data generated by the accelerometer was transmitted to an Android phone over Bluetooth, and they are stored in the phone for processing.

Only simple gestures can be recognized with one three-dimensional accelerometer, such as hands movement [18]. Two or more three-dimensional accelerometers can be used to improve the precision to recognize more complex gestures. In this thesis, we only gathered the raw data of the movement. Data processing for gesture recognition will be carried out in the future.

3.5 Sensor Mobile Application

The functions of the application include searching and connecting target Bluetooth devices as a client, then receiving the raw data from SEI-E tools. After the data has been received, the data on the mobile phone will be displayed in terms of text and diagram. The Android phone used in this project is SonyEricsson X10mini and the IDE is Eclipse. The Android programming language is based on JAVA. In the interface design, we focused on easy to use and clean principles. Only two buttons are involved. Button “Search” is for searching Bluetooth devices; button “Paired” is for listing the devices that have been paired with this mobile phone.

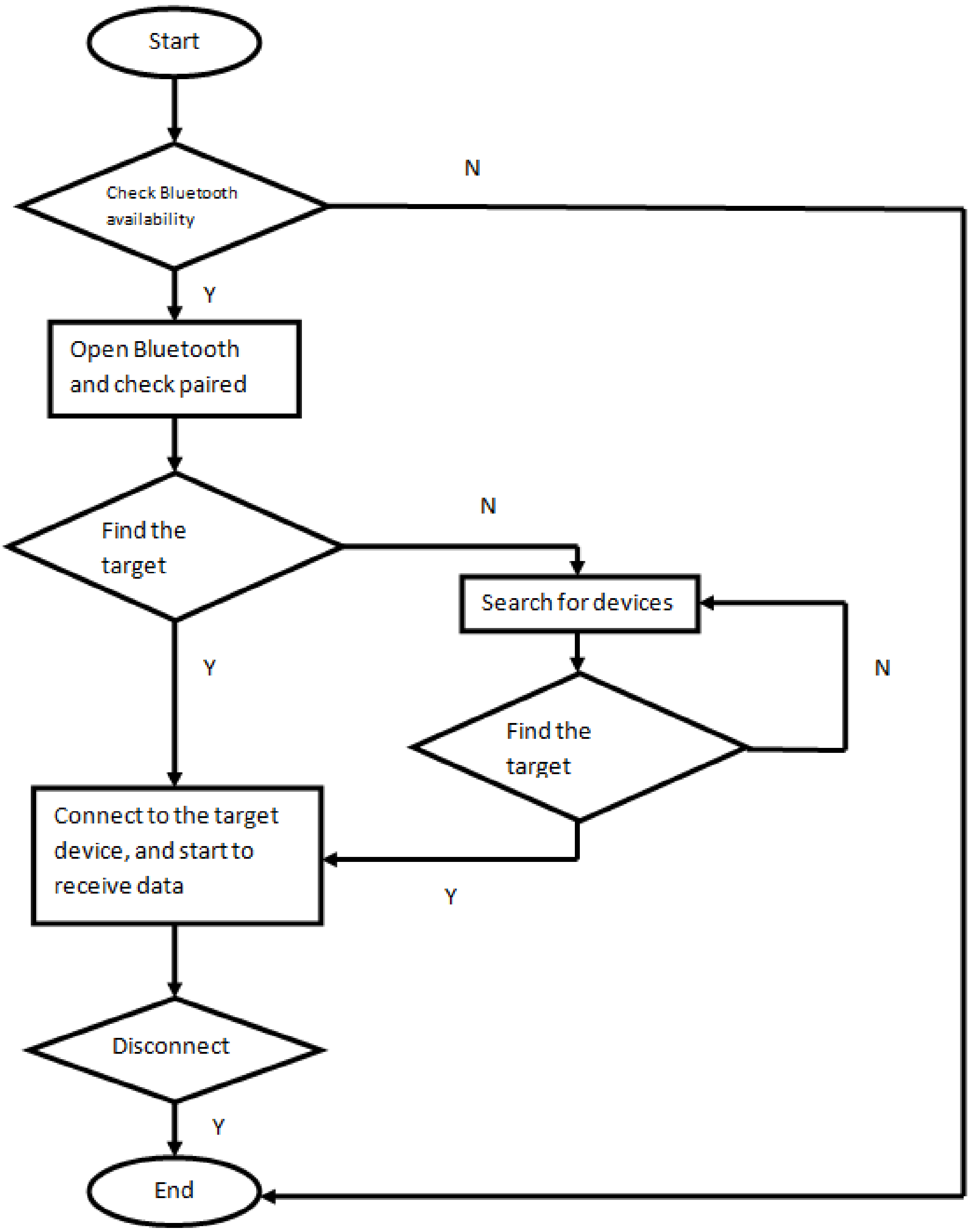

Figure 3.17 Flow chart of application

Figure 3.17 illustrates the whole process of the application. First, the application checks whether the mobile phone has Bluetooth or not. The application will end if the mobile phone does not support Bluetooth. A window will pop up for the user to open Bluetooth if it is off. Once the

Bluetooth is open, check the paired devices list to see whether the target device is on it. If it is, that means the mobile phone has the target device's MAC address. Just connect to the SEI-E object directly. If not, push the "Search" button to search for the target device. A list of found devices will be displayed. Select the target device and then build a connection. The function for connecting to a Bluetooth device is encapsulated. It starts up a Radio Frequency Communication (RFCOMM) channel service to exchange data with SEI-E object. After the connection is established, the mobile phone starts to receive data from the SEI-E object. In order to show the pressure data in more detail, a diagram is made according to the data value. A dot will be drawn on the Android phone's screen according to the return value. Harder pressure means a higher return value and a higher position on the screen; lighter pressure means lower position, vice versa. All the dots compose many continuous straight lines, much like a cardiogram, as shown in Figure 3.18. Pseudo codes of this application are shown in Appendix.

Figure 3.18 Diagram of the pressure data

4. SEI-E Testing and Results

This chapter will provide the SEI-E testing process and the results. We tried 20 times to use the SEI-E object to evaluate the operation effects of the system. According to the previous research, the interaction was done indoors, so we tested the SEI-E within this environment. Here we indicate that the lights in the office were on when we did the testing. Since the hardware for the objects are the same, the only difference is the shape of the object. We tested only one SEI-E object to collect data. Basically, there are four parts we tested in this process. The first part tested the touch and force detection. The second part tested the working effects of the three built methods of activation area. The third part tested the data collection of gesture movement. The final part tested the mobile application and the data transmission via Bluetooth. Each of these parts will be followed by its evaluation result, cooperation between different methods, and the suggestions for the future to improve work.

4.1 Testing Process of Touch and Force Detection

The testing process of this part is the touch sensor and force sensor, respectively, and the feedback data on the mobile phone application. During all of the 20 tests, the touch sensor successfully detected when the object was being held and changed the return value from 0 to 1023, and sent this feedback notification to the mobile phone instantly as Figure 4.1 shows. The success ratio is 100%. From this result, we can conclude that the touch sensor is sensitive to detect the object and that it will not be interrupted by outside environment. In order to make it easy to be understood as the pressure sensor, an inverter should be used to change the return value. In this case, 1023 means the objects are being touched while 0 means that they are not.

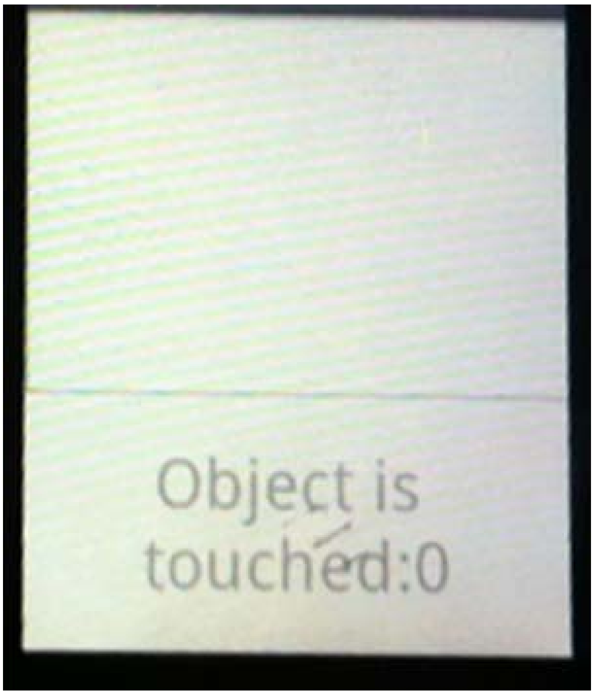

Figure 4.1 Notification of the object is held

On the other side, the force sensor also successfully detected the pressure from testers all 20 times. Every time the sensor detected the change of the pressure, a return value will be sent to the mobile phone as a notification immediately, as shown in Figure 4.2. Also, the success ratio is 100% no matter whether the lights in the room were on or off. However, the detect range of this type of sensor is too narrow when compared to a human beings power of grip. According to the relative research [7], an adult male's grip power can be up to 170 pounds in the normal case, and that does not count when he is being exasperated.

There are two suggestions for the future work. First, a new type of force sensor with an extensive range is obviously needed. The maximum is better - reaching 80KG to satisfy the demands. Second, in order to install the object, a thin and flexible sensor with good performance, instead of these PCB board sensors, would be a better choice in the future.

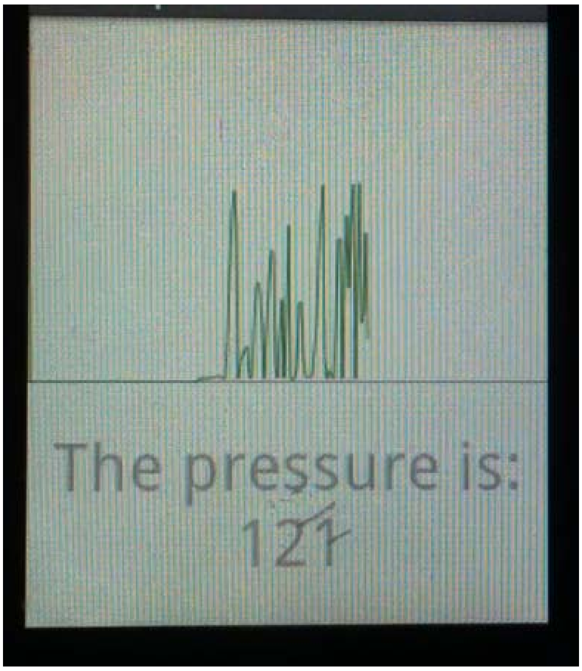

Figure 4.2 Notification of Pressure on the object

4.2 Testing Process of Activation Area

The testing process of this part was divided into three sections to test the three methods of building the activation area. During the 20 tests of the RFID method, the object with an attached tag was only identified 15 times and the success ratio was 75%. The 5 times misidentified tests happened was because the reader could not find the tag. Two of the five misidentifications happened in a bright environment. The other three happened in a dark environment. This testing data indicates that these misidentified times have nearly the same probability in bright circumstance and dark circumstance. Therefore, for this section we can learn that environment condition has little effect on this RFID method. This misidentification occurred during the test because of the poor performance of the antenna. The antenna we made was too simple, the signal was too weak at some places inside the antenna, and the reader could not identify the tags.

The activation area based on light intensity misidentified the object 3 of 20 times and the success ratio was 85%. While analyzing these three missing times, we found that because the small box is much bigger than the LED, the light cannot uniformly fulfill the entire box. Thus, the lights were different when the light sensor was put in different position of the same box. This caused the return value to vary, which led to the misidentification mistakes.

The activation area based on the light blinking rate method has a 100% success ratio. From this result, we can conclude that this blinking method will not be affect by the change of light, because the working principle is the blinking rate, not the light itself.

Comparing these three methods, it is easy to see that the light blinking method is the best way for now. It has a high accuracy and is environment independent. See Figure 4.3. However, this testing process is not strict enough. Since the light sensor is involved, the light circumstances around it should be divided into more levels in the future test. More testing should be done to make the data more convincing.

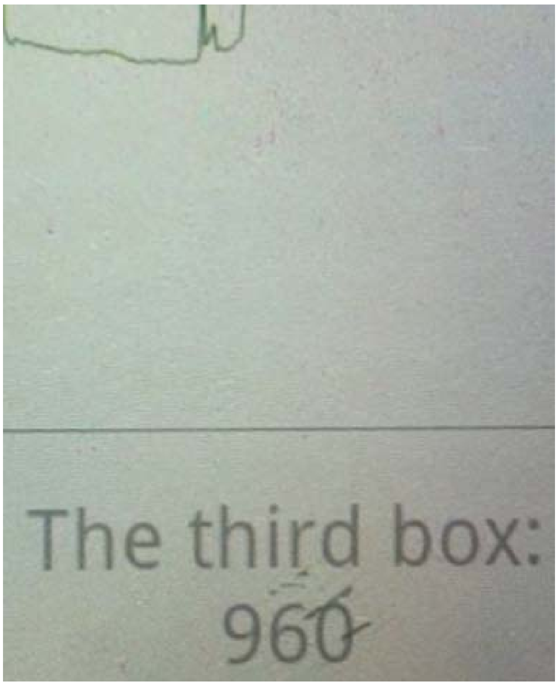

Figure 4.3 Notification of activation area

4.3 Testing Process of Data Collection of Gesture Movement

For the accelerometer, we tested whether the system can identify the movement data. The tester freely moved the object. As shown in Figure 4.4, the movement data was successfully collected, although there was a little delay to see the data from the Android phone. As we mentioned in the section 2.3, this data collected by accelerometer was used to help designers analyze participants' body movement, even in a dark environment. From the test, we can easily see that the success ratio was 100% and it was not affected by light changes. So we can conclude that this method can be used as the assistant in future work.

Figure 4.4 Acceleration data

4.4 Testing Process of Application on Mobile Phone

As the implementation described, we connected all the sensors and the Bluetooth module to the Arduino Pro Mini as Figure 3.6 shows. In this testing process, we tried 20 times to use the SEI-E object to evaluate the system. The Android phone successfully connected to the object for 19 times via Bluetooth. It only failed once because the Bluetooth module had not finished initialization and this can be avoided in the future, because the LED on the Bluetooth module blinks fast if the module is initializing. The test should be started after the tester notices the signal. The UI of this application was simple. The collected data was shown on the screen separately during the testing process. The tests and diagrams were clear. In future work, all of this data should be shown on one screen, so the designers can get the information from every sensor. More evaluation on the UI design side should be done.

5. Conclusion and Future work

5.1 Conclusion

In this thesis, the prototype of the sensual evaluation instrument was implemented with several sensors and RFID technology. Firstly, the background of SEI-E tools is introduced to give a clear overview of this project. Secondly, according to the previous work done by Höök et al. [4], the knowledge and technology, such as more detailed introduction of the instrument and RFID technology, which will be used, are discussed. An analysis of how to achieve the goal is presented. For example, using touch sensor and force sensor to detect whether or not the object is being held and how much pressure on it. Three solutions are raised to build the activation area. One solution is to use RFID technology to build an antenna as the activation area. The other two solutions involved light sensor. One is using luminous intensity difference of high performance LED to identify different locations in the activation area. So the light sensor can distinguish the intensity and thus identify the object. The other solution is using blinking LED. The blinking rates of different areas could be seen as the area codes. When the light sensor detects the blinking rate, it can tell which area the object is locating at that time. In the implementation section, the process of how to build this instrument, which fulfills the basic functions, is presented. The mobile application for receiving data via Bluetooth was implemented based on Android platform 2.1. The working process of this application was discussed. Pseudo codes of the mobile application and Arduino Pro Mini are given in the Appendix.

I learned many things from doing this thesis. First of all, the most important thing I learned is to be patient and calm to deal with trouble, rather than being nervous and frustrated. It will help me a lot in my future career. Secondly, the skills of how to manage a project and how to communicate with colleagues is a precious thing I got from thesis. Finally, I mastered how to use the hardware of Arduino, RFID, and sensors, and I learned how to develop an Android application for the mobile phone. The things I learned from my thesis will be valuable memories and help me in my future work.

5.2 Future Work

This thesis only implemented the basic functions of the sensual evaluation instrument. And from the testing results, there still have many problems need to be improved in the future. Also, more tests under different circumstance condition are needed. These tests could help designers find bugs of the system and make it stable in the long term. Some additional functions can be added in the future, for instance, monitor a user's pulse or blood pressures which contribute to measuring people's affect. Only raw data of movement were collected in this project and gesture recognition could be done by using these data.

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Appendix

---------------------------------Pseudo Code of Program for Arduino Pro Mini------------------------------------

```
  Setup input ports and bound rate;
  Get TouchSensorValue, PressureSensorValue, LightSensorValue, Xvalue, Yvalue, Zvalue;
//Monitor the object is being touched
IF TouchSensorValue <= 0    THEN
    Send a message ("The object is touched") and data to the mobile phone
//Monitor the pressure on the object
IF PressureSensorValue > 5    THEN
    Send a message ("The pressure is ") and data to the mobile phone

  // Monitor the object is inside the activation area or not
IF    threshold1 < LightSensorValue <=threshold2      THEN
     Send a message ("In the first box") and data to mobile phone

IF    threshold2 < LightSensorValue <=threshold3      THEN
     Send a message ("In the second box") and data to mobile phone

IF    threshold3 < LightSensorValue <=threshold4      THEN
     Send a message ("In the third box") and data to mobile phone

IF    threshold4 < LightSensorValue <=threshold5      THEN
     Send a message ("In the fourth box") and data to mobile phone

IF    threshold5 < LightSensorValue <=threshold6      THEN
     Send a message ("In the fifth box") and data to mobile phone

IF    threshold6 < LightSensorValue <=threshold7      THEN
     Send a message ("In the sixth box") and data to mobile phone

IF    threshold7 < LightSensorValue <=threshold8      THEN
     Send a message ("In the seventh box") and data to mobile phone
```

IF threshold8 < LightSensorValue <=threshold9 **THEN**

Send a message ("In the eighth box") and data to mobile phone

IF threshold9 < LightSensorValue <=threshold10 **THEN**

Send a message ("In the ninth box") and data to mobile phone

//Send out the raw data of the accelerometer to the mobile phone

Send a message("The acceleration of X is") and data to mobile phone

Send a message("The acceleration of Y is") and data to mobile phone

Send a message("The acceleration of Z is") and data to mobile phone

--------------------------------Pseudo code of application for the Android Phone---------------------------------

// Check whether the mobile phone supports Bluetooth

Get BluetoothState;
IF Bluetooth is not supported **THEN**
Close the application

//Enable Bluetooth module

IF Bluetooth is not open **THEN**

//Check the paired device, if it is empty discovery new devices.

For BluetoothDevice on PairedDevices
Add the name and address to an array adapter to show in a ListView

//Search for new devices
IF the phone is discovering **THEN**
Cancel Discovery;

Start Discovery Activity;
Creat a BroadcastReceiver;
Add name and address to a ListView when a device is found;

//Connect to the device

Creat a Tread to do the connection;

Creat a BluetoothSocket;

Connect to a target device using the BluetoothSocket with a UUID;

IF Exception **THEN**

Close the BluetoothSocket;

//Manage the connected thread, read data from device

Creat a Thread to manage connection;

```
REPEAT
        Read inputStream;
        Draw the plot according to the data obtained;
UNTIL the application is closed
```

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