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Research on Virtual Touch Panel for Handicapped People

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SUMMARY OF MASTER'S DISSERTATION

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Abstract

Nowadays, the touch panel interface has been used more and more widely. But the handicapped people are facing difficulties when use the normal touch panel interface. In this research, we present a novel input method that allows the user to operate a system with hand gestures instead of only with their fingers. This system allows the user to operate instruments without contact. Instead, it can be operated from a distance. This system is designed to help handicapped people who are finding it difficult to reach the operation button of instruments or are finding it difficult to do actions which can be easily be done by normal people. In this paper, the concept of a virtual touch panel is explained. The composition and structure of this system is introduced. The design of a handicapped people friendly UI is discussed.

Key Word:

Virtual Touch Panel, Non-contact Input Method, Human Interface, Design for Handicapped People, Kinect

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1 INTRODUCTION

1.1 Background

1.1.1 The Fast Developing Technology and Electronic Controlled World

Nowadays, science and technology develop very fast. No matter you want to admit it or not, we actually have stepped in a brand new era of the Information Age, or commonly known as the Digital Age, since the early 1970s on the grounds that the technology of computer microminiaturization began to be broken through.

After that, personal computer and internet sprung up all around the world in the next two decades. From the year 1990 till now, the pervasive adoption of such technology by the public has brought about a great rapid evolution of technology in our daily life. It is a mass of breakthroughs in information processing, storage, and transmission that makes the application of Information Technology possible in virtually all corners of society.

Let's give an example. We used pencil and notepad to jot down something reminder in the past. While now it's the notebook software in computer or cell phone that obliges, being always synced by web cloud. More than that, pictures and audios in the software are enabled and all these stuff saved is searchable.

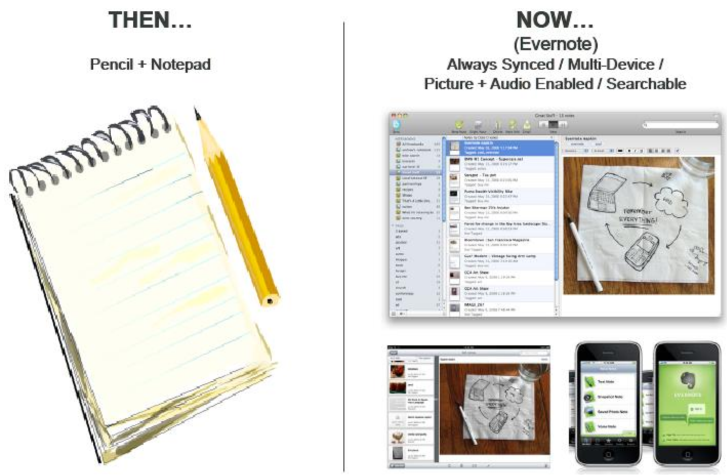

Figure 1: Re-Imagination of Note Taking in Nowadays

However, this instance is just a tip of the iceberg. The electronic technology of the Information Age has an overwhelming and comprehensive impact affecting every human being on Earth in every aspect of his or her life. Look around the world we live in. Newspaper has become electronic news in portal website, twitter and so forth. Newsweek, the second largest and popular weekly magazine in United States, has stopped its printed version and transition to all-digital version from the year 2013 [1]. Ecommerce challenges traditional stores. Paper diary book has been threatened by personal blog with multimedia, location-aware and share function enabled etc. So many manual tools around us are almost replaced completely by electronic products.

At present, Japan is also the electronic controlled society without exception. The growth of internet users in Japan is one proof of it. Two indicators that are often used as statistic factors measure the extent of informatization in a given region by International Telecommunication Union: Internet Penetration Rate and the Number of Internet Users [2].

The internet users here are persons using the Internet from any device including mobile phones. Internet penetration rate refers to the number of active internet users within a specific population. Figure 2 shows number of Internet Users & Penetration Rate in Japan from 2001 to 2011 from the statistic data from household surveys and Internet subscription data by Japanese government [3].

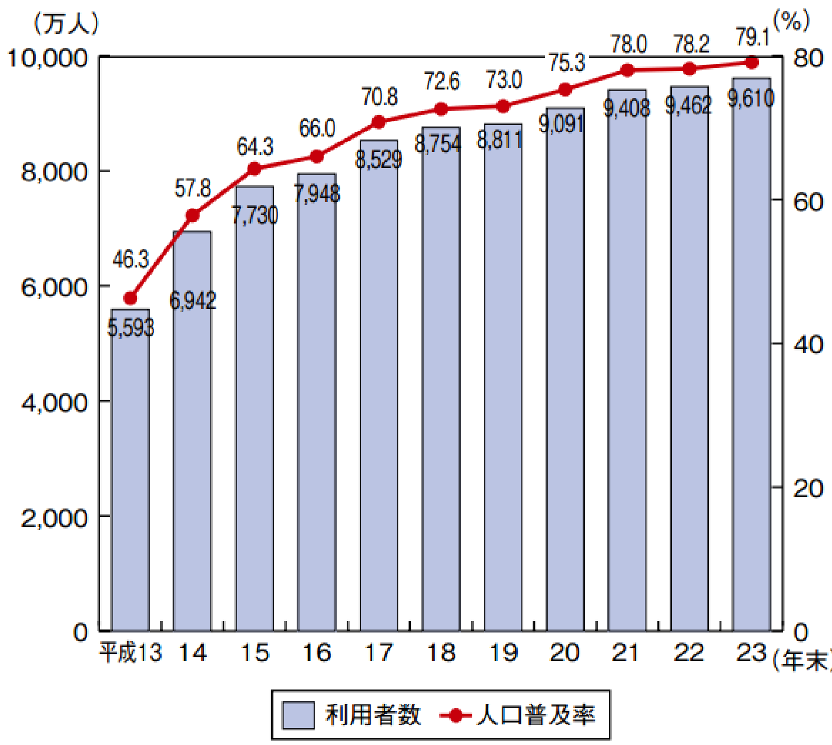

Figure 2: Number of Internet Users and Penetrate Rate in Japan

In Figure 2, the blue bar shows that the number of internet users by year in the period of 2001 to 2011. The internet users increased from 55.93 million in 2001 to 96.10 million in 2011, the percentage of increment is over 70 percent in the decades. The red lines shows the Internet Penetration Rate increases from 46.3 percent in 2001 to 79.1 percent in 2011. Over 30 percent had been increased in the decades. The statistic data tells a story about the astonishing growth of electronic appliance usage in Japan. They have spread over in our life without our attention.

Another data support for the extensive usage of electronic appliance is the growth of electricity demand in Japan.

Speak of electricity, we still remember nearly 2 centuries ago, on an August day in 1831, young Michael Faraday, tinkering in a British laboratory, placed two wires on a ring of soft iron, discovered the secrets of electromagnetism and blazed the way to the miracle – Electric Era [4].

After that electricity almost developed at the speed of light. There appeared hundreds of thousands of uses of electricity, commercial and scientific, such as light bulb, telegraph, telephone, television, electronic mobile, electric bus, microwave, cell phone, too numerous to enumerate. Electricity penetrates into our life anywhere and everywhere in summary by using for lighting, heating, motive power, telecommucation and the basic of electronic technology. The most miracle gift electricity brings to us is that it’s the No. 1 convenient way to transform energy. At present, electricity seems like blood of human society. Community would become wan without electricity even for a short time.

Figure 3 below unfolds that the output of power in Japan fluctuated during 1900 to 2010, but the main trend increased stably [5].

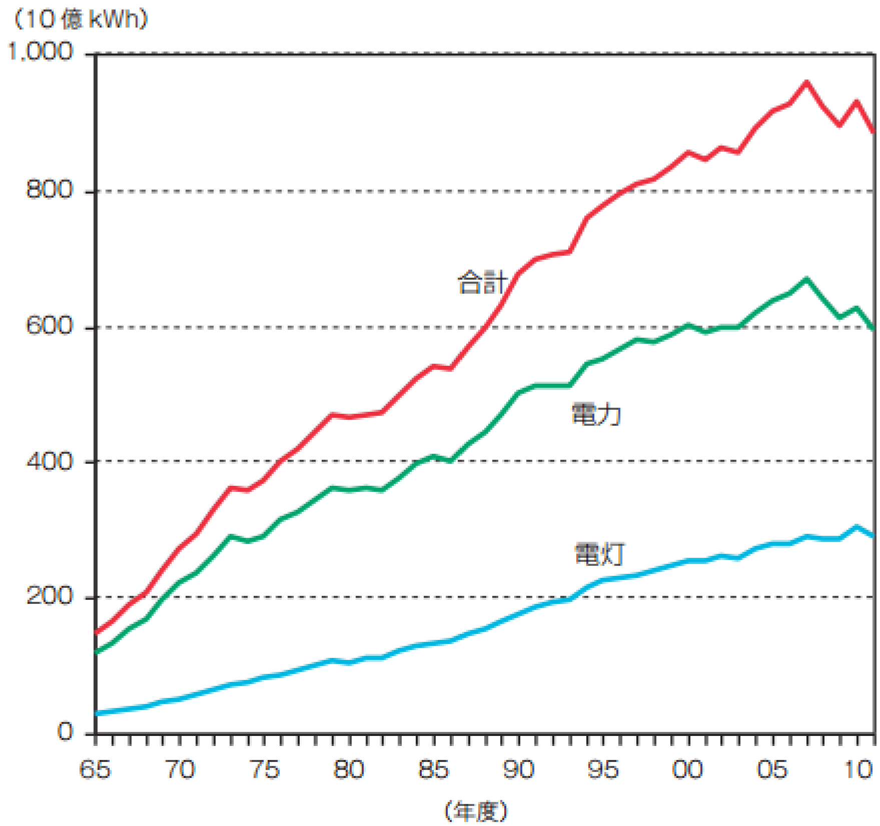

Figure 3: The Electricity Usage in Japan

In Figure 3, the blue line is the electricity usage for lighting use, the green line is the electricity usage for electricity power and the red line is the total usage of electricity in Japan during the year 1965 to the year 2010. The unit in the graph is billion kilo watt hours. The figure shows an unquestionable fact that the usage of the electricity both in lighting and electricity power increase at a stable pace.

1.1.2 The Great Amount of Handicapped People

Handicapped people in Japan have the same rights as people without disabilities. They deserve inherent respect for their human worth and dignity. And in many instances there is a need for updated infrastructures and services for them to embody the attentions, concerns and respects from non-disabled people. Promoting accessibility including built environment, public facilities, social welfare, etc. to handicapped people is an effective way to improve their quality of life, their feeling of happiness and the sense of social belonging.

1.1.2.1 Existing Circumstances of handicapped people

According to the latest census from Japan Cabinet Office (CAO), the number of handicapped people currently in Japan is 7,443,000. Among them, 3,663,000 is the count of people with physical diability. The number of people with cognitive diability is 547,000. And people with mental diability is 3,233,000. Compare to the current Japanese population, among 1000 people, 58 people is disabled. Among them, 29 people are physically disabled, 4 people are cognitivity disabled and 25 people are mentally disabled. [6]

Table 1: The Number of Disabled People in Japan

		総数	在宅者	施設入所者
身体障害児・者	18歳未満	9. 8万人	9. 3万人	0. 5万人
	18歳以上	356. 4万人	348. 3万人	8. 1万人
	合計	366. 3万人(29人)	357. 6万人(28人)	8. 7万人(1人)
知的障害児・者	18歳未満	12. 5万人	11. 7万人	0. 8万人
	18歳以上	41. 0万人	29. 0万人	12. 0万人
	年齢不詳	1. 2万人	1. 2万人	0. 0万人
	合計	54. 7万人(4人)	41. 9万人(3人)	12. 8万人(1人)

		総数	外来患者	入院患者
精神障害者	20歳未満	17. 8万人	17. 4万人	0. 4万人
	20歳以上	305. 4万人	272. 5万人	32. 9万人
	年齢不詳	0. 6万人	0. 5万人	0. 1万人
	合計	323. 3万人(25人)	290. 0万人(23人)	33. 3万人(3人)

The data above is from the the last census which has already published its result. The census takes every 5 years, and the data above is from the census in 2006.

Commonly, physical disability refers to impairment which limits the physical function of fine or gross motor ability. Here in our data, physical disability includes visual impairement, hearing impairment, dysphonia, limb impairment and internal impairment.

According to CAO's explanation, internal impairment, as opposed to other types of impairment displayed above, is about organ impairment or several chronic disorders, such as diabetes, AIDS, etc. Hence, people with limb impairment and internal impairment are the most possible group which requires wheelchairs or medical walkers to help them move.

The census result shows that 8.8 percent of physical disability is visual disability, 10.1 percent is hearing disability, limb disability is 50.6 percent and internal disability is 30.5. So our target group comprises 81.1 percent of physical disability. That's equal to about 24 people of one thousand people.

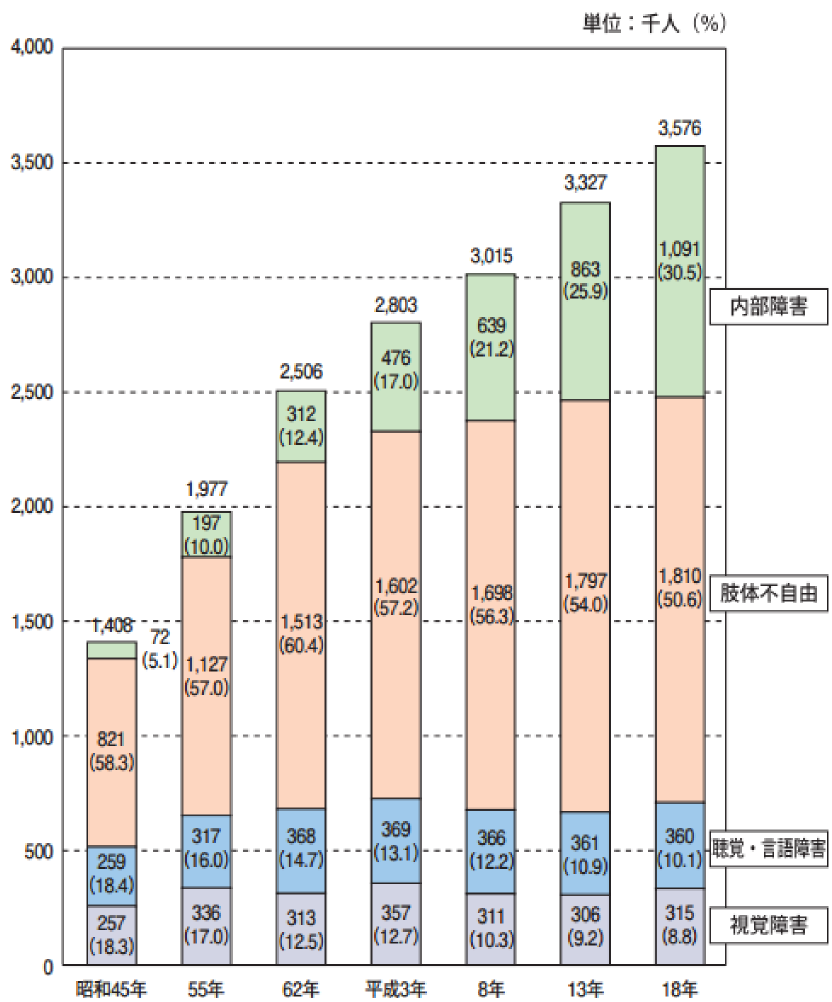

Figure 4: Proportion of People with Physical Disability

1.1.2.2 Growth of handicapped people

We want to know how the number of target group—people with limb and internal disability changes in the future since we have to make decision about how much infrustructures we should design for them. In order to find this answer, we ought to figure out what factors influence the change of the number.

Figure 5 below is about the history numbers of people with disability censused by CAO every five years from 1976 to 2006. It indicates that the number of people with disability above 65 years old during this time increased year after year from 442,000 to 3,576,000. But the part of people with disability under 65 years old did not change very much. Its population basically kept a stable number between 872,000 and 1,237,000. So we conclude that the number of people with disability rose because of growth of people with disability above 65 years old.

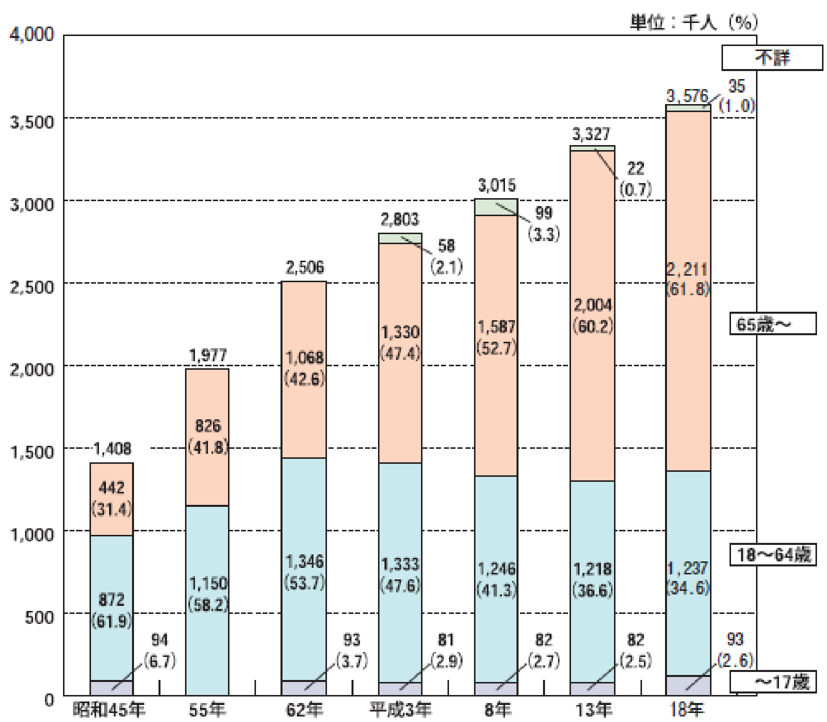

Figure 5: History Numbers of People with Disability

*Note: the number of people under 17 years old was not censused in 1981.

The reason why the number of old people with disability grew over time can be explained in Figure 6.

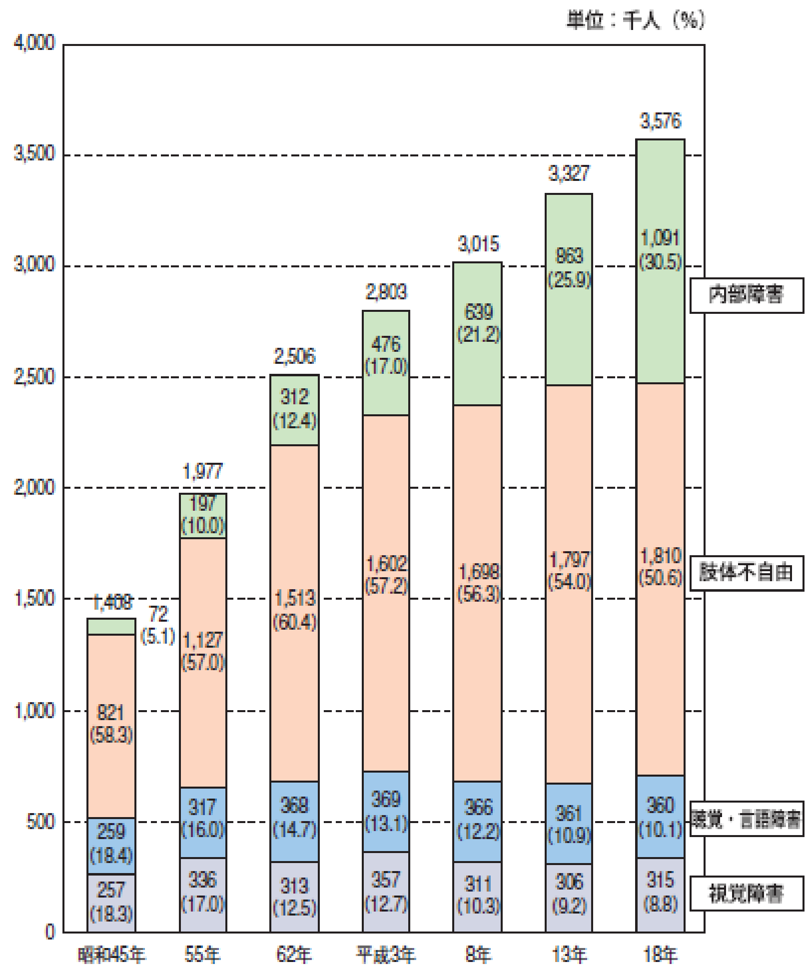

Figure 6: History Data of People with Physical Disability

Figure 6 evinces explicitly that the amounts of people with limb disability, hering disability, dysphonia or visual disability holded stably during 30 years. However, the numbers of people with internal disability grew rapidly from 1, 408, 000 in 1976 to 3, 576, 000 in 2006. It tells the reason for growth of people with disability is the growth of internal disability. Generally, old people is easier to suffer internal illness than young people.

Consequently, syntherizing Figure 5 and Figure 6, we mke a conclusion that target people consist of people with limb disability and people with internal disability. Both of them mostly need wheel chair or medical walker to help them move. While the number of people with limb disability is basically constant, the number of people with internal disability is variable. The reason of this change is the growth of number of old people who suffer internal diseases. The radical reason is the growth of old people due to aging problem in Japan. Therefore, old people is the potential people who is high risk to expand the population of handicapped people.

1.1.2.3 Prediction about the number of handicapped people

Japan is haunted by the problem of aged society for a long time. The statistic data that Japanese Ministry of Internal Affairs and Communications publishedindicated that Japan had the highest percentage of people over the age of 65 in the world in 2007.

According to the newly updated statistic data from the Japan Statistic Bureau, 24.0% of population is 65 years or older. The number amounts to that 30.58 million people in Japan are 65 years old or older at August 2012 [7].

Figure 7 shows historical statistic data and the future forecast about demographic old people in Japan. The historical data is get by Japan Statistic Bureau. The census data of population is taken every five years from 1960 to 2010. The future forecast is the forecast according the historical data till the year 2060 [8].

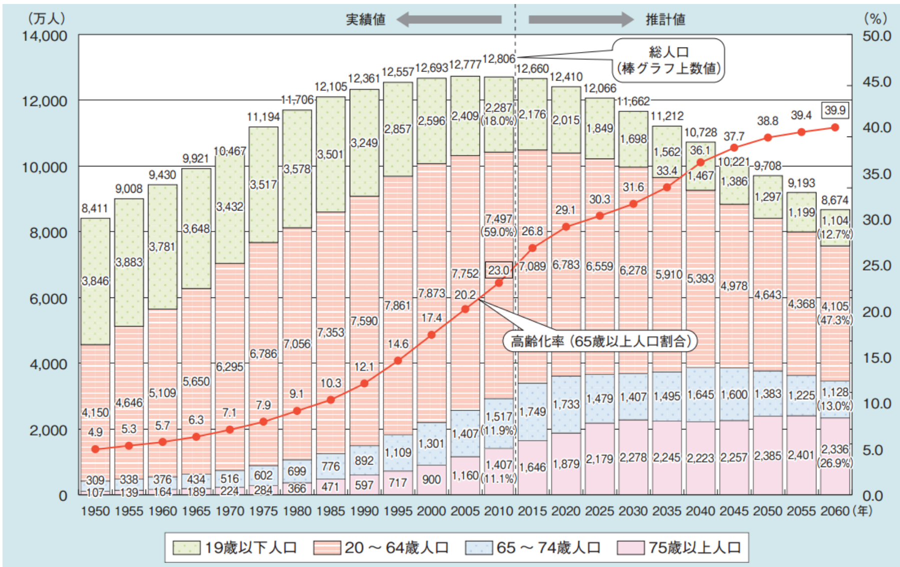

Figure 7: The Historical Data and Future Forecast of Aged People

In Figure 7, the green bar indicates the population of people include and under 19 years old, the red bar indicates the population of people between 20 and 64 years old, the blue bar indicates the population of people between 65 and 74 years old and the pink bar indicates the population of people include and over 75 years old. The number on the top to whole bars is the total population in Japan. The red line indicates the percentage of population of people over 65 years old on the total population.

Figure 7 reveals clearly that the number of 65 years old or older people in Japan increased stably in the history. Due to the change of population has hysteretic quality, the population of old people will keep its growth in a very long future time. The University of Denver once modeled the growth of old people in Japan given the specific birth rate and death rate, presumably the population policy would not change greatly in the future. From the figure, we can know that percentage of Japanese 65 years old or older would not stop increasing even at the year 2060.

As we previously discussed, the aging people has a direct relationship with the number of handicapped people or people who sitting in the wheelchairs, the data shows the number of handicapped people will keep increasing.

1.2 Requirement Analysis

The fact we showed here in this section shows it is clear that now we are in Information Era and the machines use electricity power is all around our world and daily life. Normally, the electronic controlled machines used a button or panel for the operation. The buttons or panel is normally allocated on the wall or on the surface of the machine. Even if the buttons transform from switch of light to touchpad with computer to touch screen on iPad, they still need to be touched to control.

Figure 8: Examples of Control Panels of Electronic Controlled Machine

For the normal people like us, we can use the panels without inconvenient. But for handicapped people sit in the wheelchair, they may find a problem that they cannot use the panel because they cannot reach it. Normally the manufacturer set a handicapped-people-used panel in a lower place.

Figure 9: A Handicapped Panel in Elevator

But is the panel enough for handicapped to use? Are every handicapped people satisfy with the panel and won't face any problem when operating the machine?

About this question, we interviewed the Ms. Qiu, Director of Accessibility Supervise Department from Shanghai Disabled People Assistive Devices Center, one of the official accessible devices support center of China Disabled Persons' Federation, about the situation of the handicapped people operating the panel devices like elevator. This objective of this department is to supervise the accessibility devices in the public area to make the city more accessible for handicapped people to use. She is working for the department for years and now as a director, she knows very well about the accessible devices and handicapped people's situation.

Table 2: The Interview of Ms. Qiu

Q	Is the handicapped people facing difficulty when operating the machines by buttons or panels like elevator?
A	A lot of place have accessible devices like the lower panel in the elevator. The situation of the handicapped people can't operate the panel has been improved.
Q	For the people who can move his/her arms and hands but face problem of move his/her body, will they be able to reach the button and panels?
A	This is a very severe conditions, the people who can only move his/her arms and hands will face a problem that the button is in front of him/her, but they may not be able to reach it. This is also a problem that we want to solve.
Q	If there is a device that can allow the user to operate the button or panel only need moving his/her hand without needing to touch or reach any button or panel, will this help the handicapped people?
A	Yes, that's true. It will help a lot.

From Table 2, we can know that although the panel is in a lower place, it is also not very easy for the handicapped people to use if the handicapped people can't move his/her body but only can move his/her arm. They cannot reach the button if they moves towards the button and the button is in front of them even if their arms and hands can move freely.

To investigate the situation, we did an experiment. We let a tester sit in a wheelchair and let him try to reach the handicapped panel without moving his body to see if the handicapped people can or cannot reach the buttons.

Figure 10: Handicapped People Facing Difficulties Operating Elevator

From Figure 10, we can see clearly that there is still a distance between the user's hand and the panel. If the handicapped people cannot move forward his body, he will not be able to reach the button and operate it.

From the interview, we know that the requirement of the handicapped people is a device that only need to move his/her hand without needing to touch or reach the button or panel.

1.3 Research Purpose

In this research, we want to help these handicapped people or people sit in the wheelchair to meet their requirement: operate the system without needing reach or touch them.

1.3.1 Target User

There is a lot kinds of people who need to sit in a wheelchair. One of them is totally physically disabled and can't move most part of his/her body. Normally the people can't even operate the wheelchair by himself/herself and often have campanions to help them doing things that he/she want to do.

The target people who we need to help is: people need to use a wheelchair to move in the ground and have the ability to use his/her arm freely. These people have the ability to operate buttons by themselves if the button is not out of reach.t

As we discussed previously, the disability investigated is catagerized into three types, physical disability, cognitive disability and mental disability by CAO. However, not all these people are the target people on our research. The mental and cognitive disabled people normally will find it difficult to know what he/she should do to operate the system or what he/she shouldn't do. And normally those people have campanions who help them moving and living. Those people can help them with the operating the normal system normally. The target user of the system is the people who needs wheelchaires to move around but with no problem of move his/her arms and knowing that he/she should moving his/her arms. Normally, the target user is physical disabled people and the aged people who need wheelchair to move.

1.3.2 Target Function of the System

The main target function of the system is to let the user can operate the buttons without needing them to touch the buttons. The system shall let the user operate the buttons when the user is still have a distance with the system, normally 1 or 2 meters. In this distance, the user can see the system and put out his hand, moving his hand in the air and operating the buttons.

Another function is allow the user to operate the buttons with his/her whole hand instead of his/her finger. The finger move is a much complex move than moving the whole hand. When move the whole hand, only the joint of elbow, shoulder and wrist need to move, but when moving the specific finger, the joint of elbow, shoulder and wrist still need to move, the joint in the hand and the finger also need to move. Some handicapped people may not be able to complete such a complex movement.

1.3.3 Scope of the System

Theoretically, the system can be used in any system that need the user to operate the button. For example, elevators, security doors that need password, call panel in the hall of the apartment etc. The system can work as an extra application, works simultaneously with the existing physical buttons.

2 RELATED WORKS

Firstly, let's pick up some related work on the virtual touch panel interface and see what is the benefit and the disadvantages for the virtual touch panel for handicapped people to use.

2.1 Non-Contact Touch Display

Xiang *et al.* from University of Electronic Science and Technology of China designed a non-contact touch display [9].

The basic concept of the system is using a laser pointer to point the button on the display, with using a camera to get the video and image of the display and detecting the position of the laser pointer to determine the touch operation.

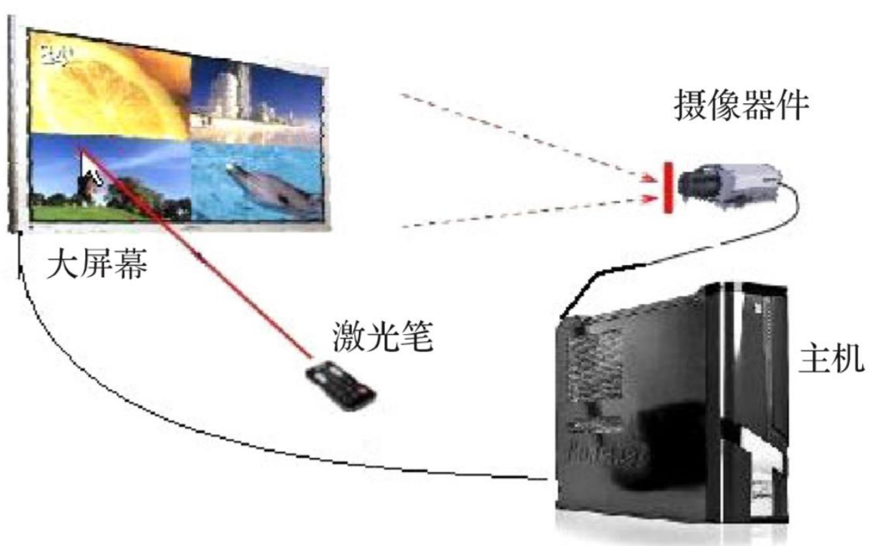

Figure 11: Non-contact Touch Screen

The technology of the system is good and the accuracy of the touch position is very high. The problem is the system cannot be implemented in a public place like elevator and security door.

2.2 Virtual Touch Panel Display

Chan *et al.* from National Taiwan University developed a virtual touch panel display in 2008 [10].

Figure 12 shows a prototype of the virtual touch panel display.

Figure 12: Virtual Touch Panel Display

The virtual touch panel display is a tabletop display with 2 virtual touch panel on the top of the display. The user can share the content on the tabletop display with the user can't see each other's virtual panel. The virtual panel is reflected by several mirrors from the projector under the table.

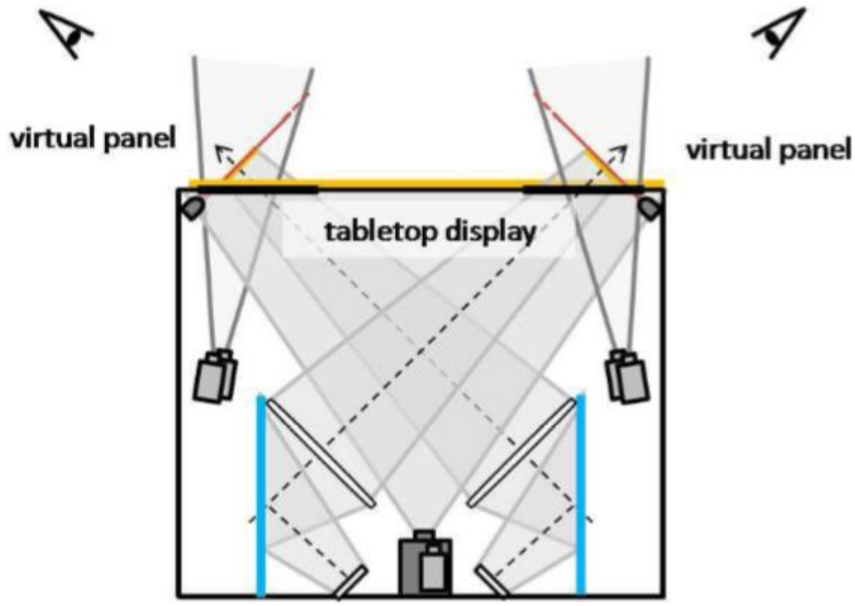

Figure 13: The Composition of the Virtual Touch Panel Display

2 infrared line illuminator is used to detect the position of the user's finger.

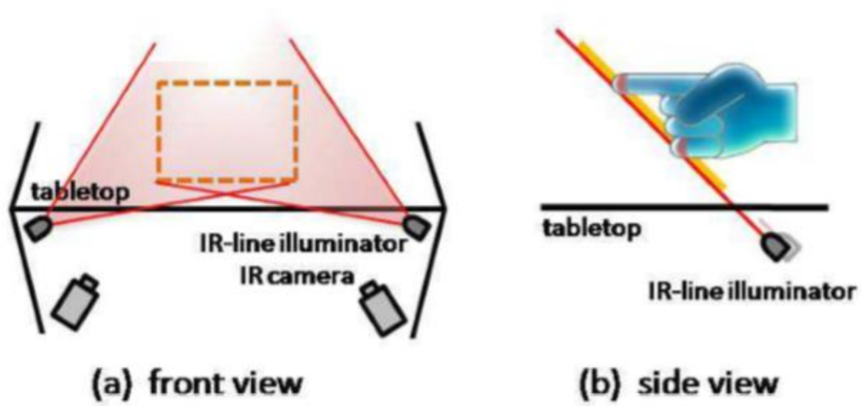

Figure 14: Infrared Line Illuminator in Virtual Touch Panel Display

The advantages of the system is the accuracy of the position of the hand is very high and the display is very near to the user. However, this system is very difficult to be integrated as an input method for the handicapped people to operate. The virtual panel is not too far from the display which doesn't change the situation of the handicapped people can't reach the button. The infrared illuminator and projectors with mirrors is difficult to be integrated in a public area like elevators.

3 CONCEPT

The goal of virtual touch panel interface is to provide an input method which can allow the user to operate a system by using their whole hands instead of moving their fingers, which are very complicated actions that many handicapped people even a small part of non-disabled people cannot handle very well. Also, we want to give users a way to doing operations from a distance, which can allow the user to do the action in a more comfortable way, with no functional absence compared with a normal touch panel.

3.1 Composition

In order to build such a system, we need 3 fundamental parts to help us:

- Display panel
- Kinect sensor
- PC

The display panel in this system shows the virtual panel with the visual button and shows the current hand position of the user. It will help the user with visualized information to lead the user finish the operation just like the display in many other systems do.

The Kinect sensor is a COTS machine produced by Microsoft Corporation. Having a Kinect sensor in our system can help us in detecting the user's hands and getting the real-time data of hand position. Using this data, we can do the hand tracking and detecting the operation by users [11]. (See detail in Section 3.2)

The PC is a necessary part. The PC is used for running the program and processing the data for the reaction of the operation. And also the PC is being used in debugging to improve the system.

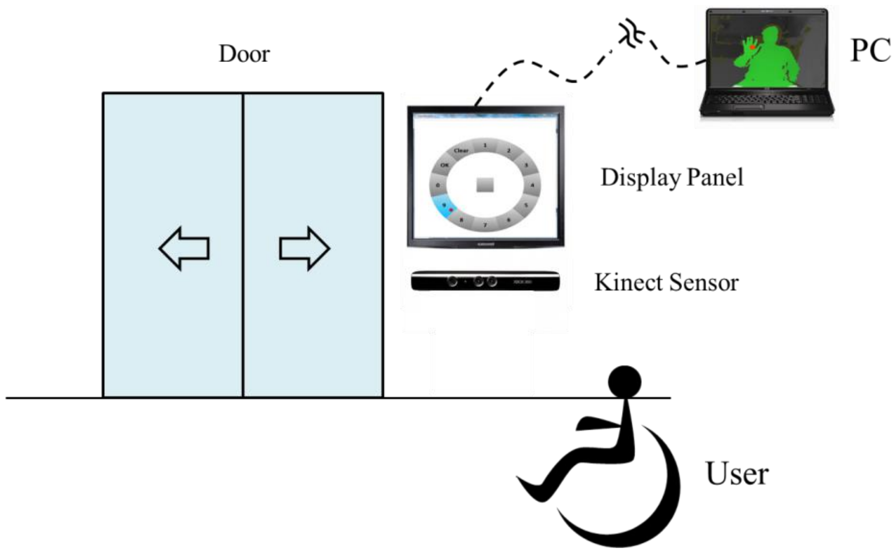

Figure 15: Composition of the Virtual Touch Panel

The display panel and the Kinect sensor is direct in front of the user, while the PC is in front of the operator or monitor of the system if needed. If the system is fully developed and the debugging is unnecessary, we can simplify the system to only PC and Kinect sensor, with PC is using for both processing data and showing the panel.

3.2 Key Technology - Kinect Sensor

A Kinect sensor (also called a Kinect) is a motion sensing input device developed by Microsoft. It enables the users to control and interact with the system without need to touch buttons or keys [11].

Figure 16: A Kinect Sensor

The Kinect sensor is a horizontal bar connected to a small base with a motorized pivot and is designed to be positioned lengthwise above or below the video display. Inside the sensor case, a Kinect sensor contains:

- An RGB camera that stores three channel data in a 1280x960 resolution. This makes capturing a color image possible.
- An infrared (IR) emitter and an IR depth sensor. The emitter emits infrared light beams and the depth sensor reads the IR beams reflected back to the sensor. The reflected beams are converted into depth information measuring the distance between an object and the sensor. This makes capturing a depth image possible.
- A multi-array microphone, which contains four microphones for capturing sound. Because there are four microphones, it is possible to record audio as well as find the location of the sound source and the direction of the audio wave.
- A 3-axis accelerometer configured for a 2G range, where G is the acceleration due to gravity. It is possible to use the accelerometer to determine the current orientation of the Kinect.

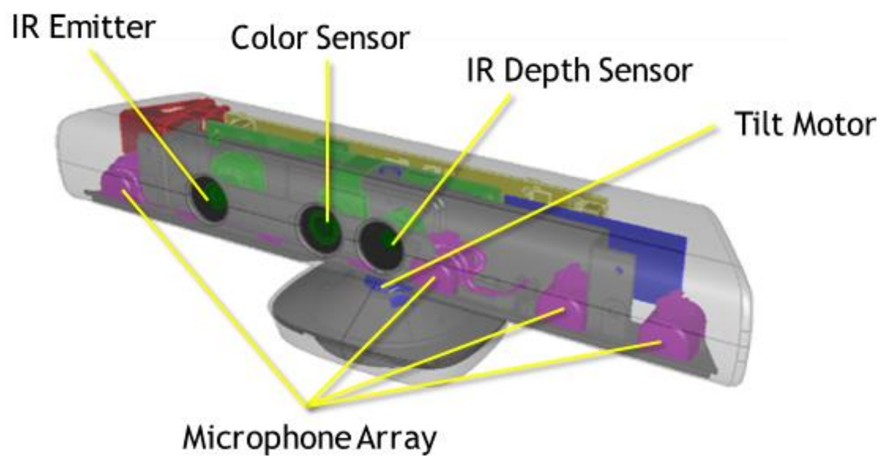

Figure 17: The Construction of Kinect Sensor

The detail specification of the Kinect is list in Table 3:

Table 3: Kinect Sensor Components and Specifications

Kinect	**Array Specifications**
Viewing angle	43 ° vertical by 57 ° horizontal field of view
Vertical tilt range	±27 °
Frame rate (depth and color stream)	30 frames per second (FPS)
Audio format	16-kHz, 24-bit mono pulse code modulation (PCM)
Audio input characteristics	A four-microphone array with 24-bit analog-to-digital converter (ADC) and Kinect-resident signal processing including acoustic echo cancellation and noise suppression

Accelerometer characteristics	A 2G/4G/8G accelerometer configured for the 2G range, with a 1 °accuracy upper limit.

The interaction space is the area in front of the Kinect sensor where the infrared and color sensors have an unblocked view of everything in front of the sensor. If the lighting is not too bright and not too dim, and the objects being tracked are not too reflective, you should get good results tracking human skeletons. While a sensor is often placed in front of and at the level of a user's head, it can be placed in a wide variety of positions.

The interaction space is defined by the field of view of the Kinect cameras. The sensor supports tilt function by using the built-in tilt motor. The tilt motor supports an additional +27 and -27 degrees, which greatly increases the possible interaction space in front of the sensor.

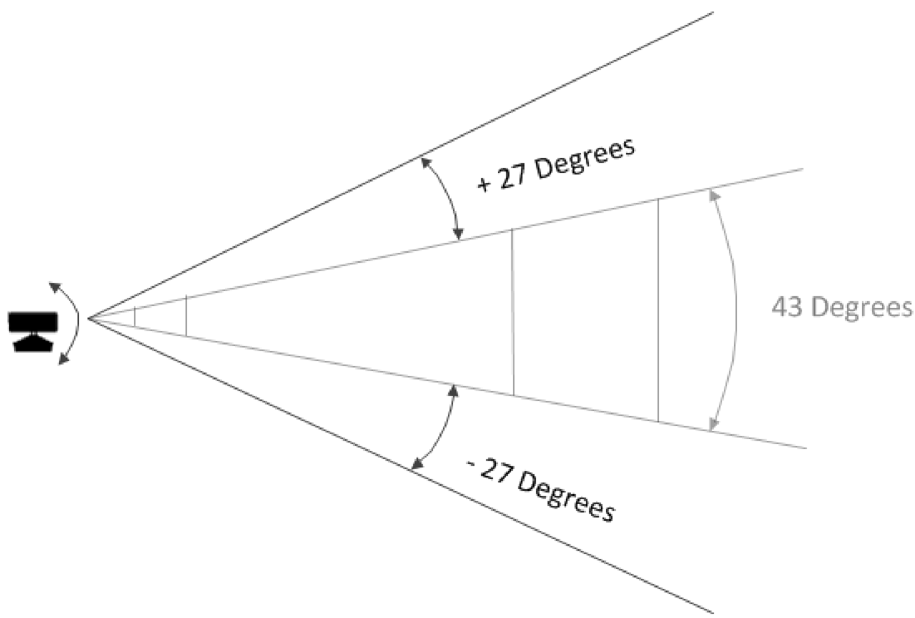

Figure 18: The Interaction Range of Kinect Sensor

3.3 Data Flow

In this system, we use the Kinect sensor's IR depth sensor to get the real-time depth map of the real world. Depth map is an image that contains information relating to the distance of the surface of objects from the viewpoint. The depth map is sending to PC for processing.

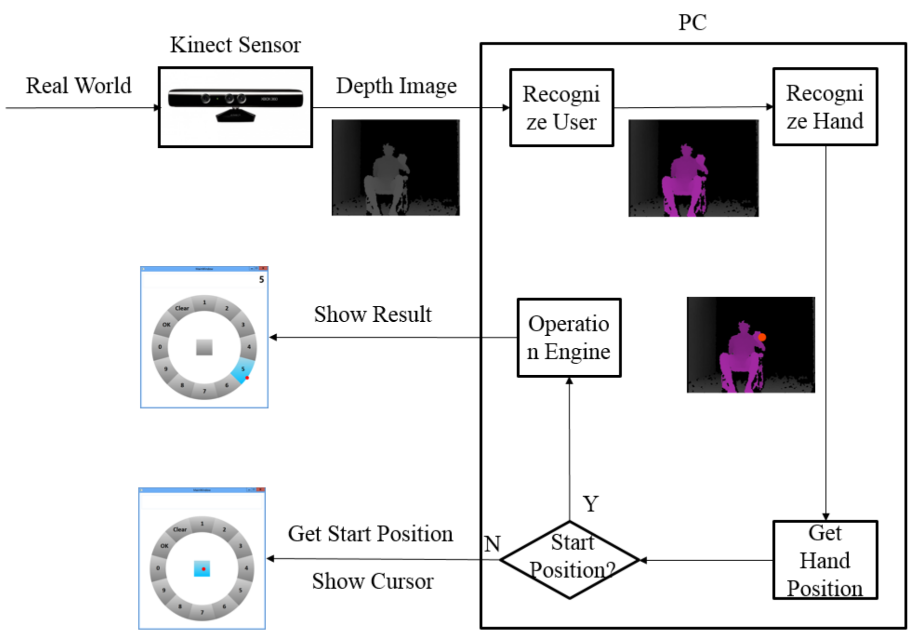

Figure 19: The Data Flow of the System

In the PC, we use the program written with Microsoft Kinect SDK for Windows to processing the depth map sent by the Kinect sensor. From the depth map, we can get the general outline of the object in the sensing range of the camera. We judge the outline of objects one by one to recognize the user among all the objects.

After we recognized the user, we attach the skeleton model of the user to recognize the hands of the user. The system will first recognize the start position when the user stop his/her hand for 1 second and record the start position and shows a cursor in the center of the display. After that the system will recognize the operation by the operation engine in the system to recognize the operation by the user's hand movement.

Beside the cursor, the current selected button will highlight in the display and a textbox on the display will show the result of the user's operation to give user the feedback.

4 GUI DESIGN

The most important part of a human interface is the GUI (Graphic User Interface). This part is directly seen by users, and the good or bad aspects of the GUI have a direct impact on the usability of the system.

4.1 The Differences and Attention Points of Design

The virtual touch panel interface is a novel interface that different to the physical interface and current human-machine interface. So before discuss about the detail design, we shall first discuss about the differences and points we need to pay attention in the interfaces design of virtual touch interface.

4.1.1 Distance cannot be Directly Known

In a physical user interface. The operation is directly. User use his/her hand directly touch the panels and the buttons. The position of the buttons is at the same place where the user see where they are. The user can know exactly how much they need to move to reach the target button. So normally the user won't find any problem to reach and operate the physical panels or buttons.

But in a virtual touch panel interface, the user cannot direct operate the button by his/her hand. The user need to operate the system by operate the cursor by moving his hand. Because the cursor only a relatively relationship with user's hand, user can know exactly which direction the cursor is going to move before the user move his/her hand, but will not know exactly how much the cursor is going to move.

User don't exactly know how much he/she need to move his/her hand in order to get to the target button because the user doesn't know the speed of the cursor until the user pays his/her learning time to get used to this system.

4.1.2 Relation between Cursor Movement and Button Activation

Normally in a user interface, the cursor movement and button activation operation is controlled by different module. Like when the user is operating a computer with a mouse, left button is used to activate the button while move the cursor use the optical sensor or trackball. But in a virtual touch panel interface, both the cursor movement and button activation requires the user to move his/her hand.

If we consider the X axis as left to right, Y axis as down to up, Z axis as behind to forward. The value of X and Y will be used to decide the cursor's position and Z value will be used to decide if the user is doing the button activation operation. When the user want to move a cursor, the ideal situation of the operation is to change the X and Y value and not change the Z value. And ideal situation of operation is to change the Z value while not changing the X and Y value.

But such operation is impossible to be done as when the user move his/her hand, the direction is always not absolute parallel to the axis and normally even not in a line. And because when the user operates the system, the user's hand is moving in the 3D space without anything to be used as reference object for the axis. The user's feeling of the axis may have a degree to the real axis of the system. The hand movement done by the user may deviate from the direction the user want to move. Also the Kinect sensor is a machine which have machine error that the hand position recognized by the sensor is not absolutely accurate. This will lead the hand movement detecting by the system is not a perfect line parallel to the XY plane when moving the cursor or along the Z axis when activating the button. Normally the movement detect by the system is a curve line along the user feeling axis.

This may lead the system misjudge the current cursor movement operation or part of the operation as a button activation operation and vice versa. In order to make the system recognize the correct operation, we need to pay attention and make special design in every part of the system.

4.2 Traditional Matrix Design

Traditionally, we align the buttons in rows and columns. A sample of the matrix design of number input system is shown in Figure 20.

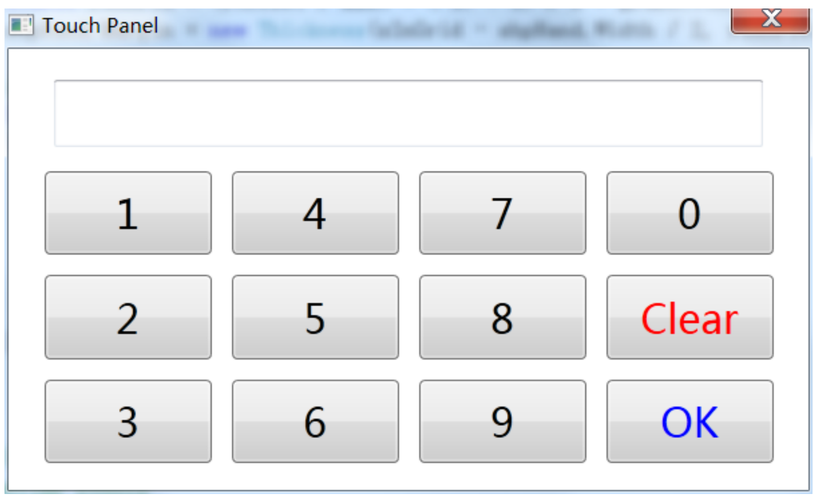

Figure 20: A Matrix Design of Button

The matrix design is a very common human-machine interface. It is being widely used both in the graphic user interface in the display and operation buttons or panels in the real world. It works very well when the panel is a real panel in a flat plane and the user operates it in 2D interface. But according to the previous section, we can find that the matrix design are not very good in the virtual touch panel interface. Here are several disadvantages.

4.2.1 Disadvantages

4.2.1.1 Disadvantage 1: The distance between buttons is not easy to know.

In the matrix design, the buttons is a limit-sized shape, either the user move the cursor too less or too more won't let the cursor stops on the target button. As we previous discussed, the user operating a virtual touch panel interface cannot easily know about the distance, because the user doesn't know the speed of the cursor until the user pays his/her learning time to get used to this system.

The same problem happens when the user uses the mouse to operate the cursor in the computer's display. It takes time to get used to it. The time seems very little because normally we operate the computer in hours and normally we have experiences. But for a novel system like the virtual touch panel and the normal operation time is in seconds. The learning time costs too much.

4.2.1.2 Disadvantage 2: May pass through other buttons when moving from current position to target button.

In matrix design, if the user want to move the cursor from a button to another button, he may pass through another button. Like in Figure 11, if the user wants to move from button 4 to button 0, he/she must pass through button 7 or other buttons if he/she use another route.

As we previous discussed, in this system, both the cursor movement and button activation requires the user to move his/her hand. When the user want to move a cursor, the ideal situation of the operation is to change the X and Y value and not change the Z value. But such operation is impossible to be done as when the user move his/her hand, the direction is always not absolute parallel to the axis. The hand movement done by the user often is a curve and had a big change of Z value. Also the Kinect sensor is a machine which have machine error that the hand position recognized by the sensor is not absolutely accurate. This may lead the system misjudge the current cursor movement operation as a button activation operation. If there are buttons between the current position and the target button, the action that the user takes to move the cursor may end up with the wrong activating operation and activate the wrong button.

4.2.1.3 Disadvantage 3: The button is surround by lots of other buttons.

In matrix design, each of the buttons is surround by other buttons. If we called the other buttons surrounding the current button as “neighborhood button”, the number of the neighborhood buttons is at least 3 when the current button is in the corner and at most 8 when the current button is not on any side of the panel.

As we discussed previously, in this system, both the cursor movement and button activation requires the user to move his/her hand. When the user want to activate such a button, the ideal situation of the operation is to change the Z value and not change the X and Y value. But when the user move his/her hand forward, the direction is always not absolute forward. There are some changes of the X and Y even the user doesn’t want to. This will cause a problem that when the user want to activate such a button, his/her hand moving cause the cursor make movements too. This may leads this action end up with activate the neighborhood button instead of the target button.

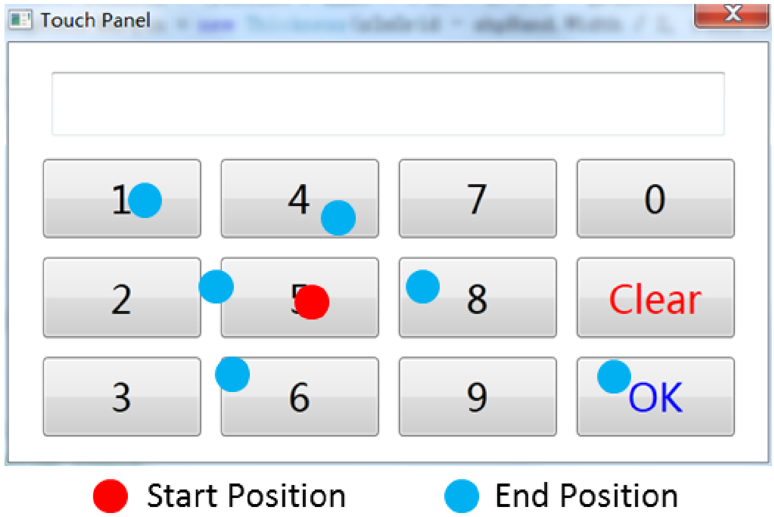

Figure 21: Example of Differ between Start and End

This possibility of wrong operation increases as the number of neighborhood button number increases. As the matrix design have a lot of neighborhood button of the target button, it doesn't performance very well in this situation.

4.2.1.4 Disadvantage 4: The distance between each button is not equal. Maximum distance may be too much for user to reach.

In matrix design the distances between the buttons is different. Like in Figure 20, the distance the user need to move from button 4 to button 7 is not equal to the situation he/she need to move from button 4 to button 9.

In this system, the user move his hand in front of the camera, but not all the place of the sensing range of the camera can be reached by the user. Only a limited range can be reached by the user.

Figure 22 shows the user in the sensing range of the camera. The whole image is the infrared image get by the Kinect sensor, where the pink is the user detected and recognized by the system. The red dot indicates the current position of the user's left hand. The big red circle is the approximately reachable range of the user's hand.

Figure 22: The Reachable Range of the User's Hand

Because of the distance between each button is not equal. The distance between the target button and the current position too large. It may cause the operation time being enlarged and there is a possibility that the distance is too large that the user cannot use his hand to move such a distance. As long as the button increases in the touch panel, the distance to size ratio will keep get greater as the number of buttons in rows and columns increases. The possibility of the user cannot reach the target button will be greater if there is more button.

4.3 Circular Design

As long as the matrix design is not fit for the virtual touch panel user interface. We considered and designed a new design that can fit for the virtual touch panel user interface.

The main concept of the design is to avoid pass through other button when move from the start position to the target button, reduce the importance of the distance and reduce the number of the button surround the target button. Finally, we make up a design that make all the buttons in a circular ring around the start position. A sample of circular design is shown in Figure 23.

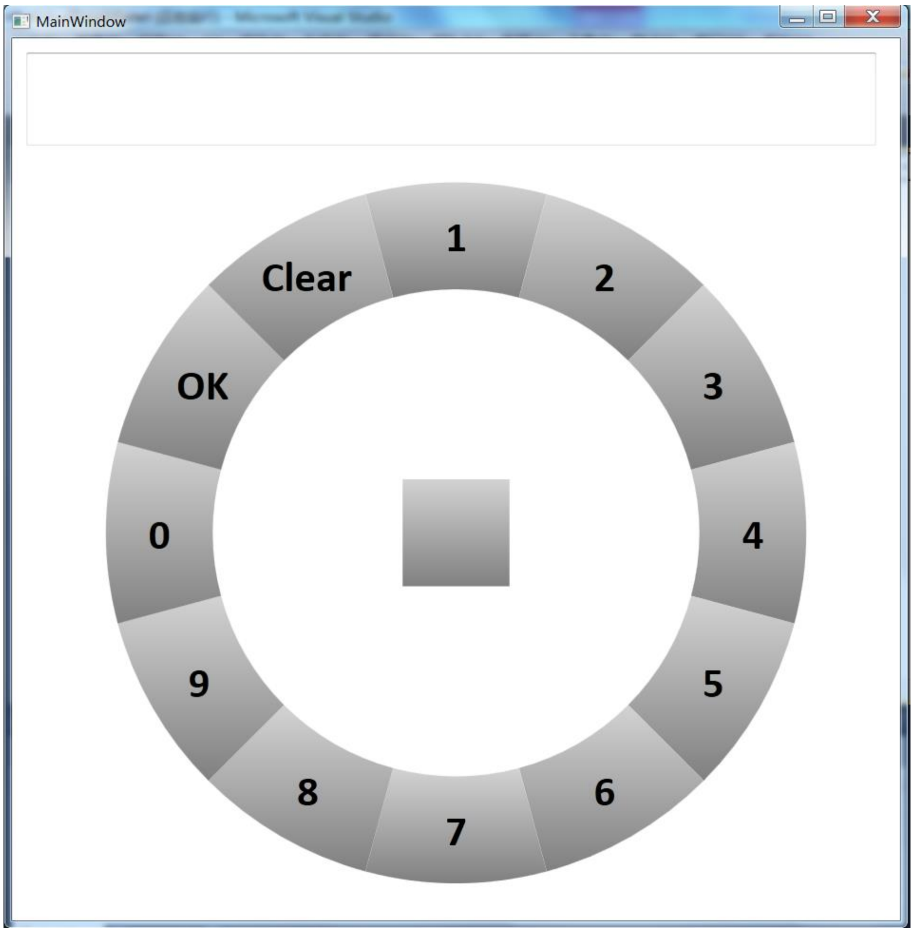

Figure 23: A Circular Design of Button

Because the button is next to each other, if we just use a cursor to indicate the current position, the user may get confused when the cursor is just on the border of button. Therefore we highlighted the current button that the cursor is on. A working sample of circular design is shown in Figure 24.

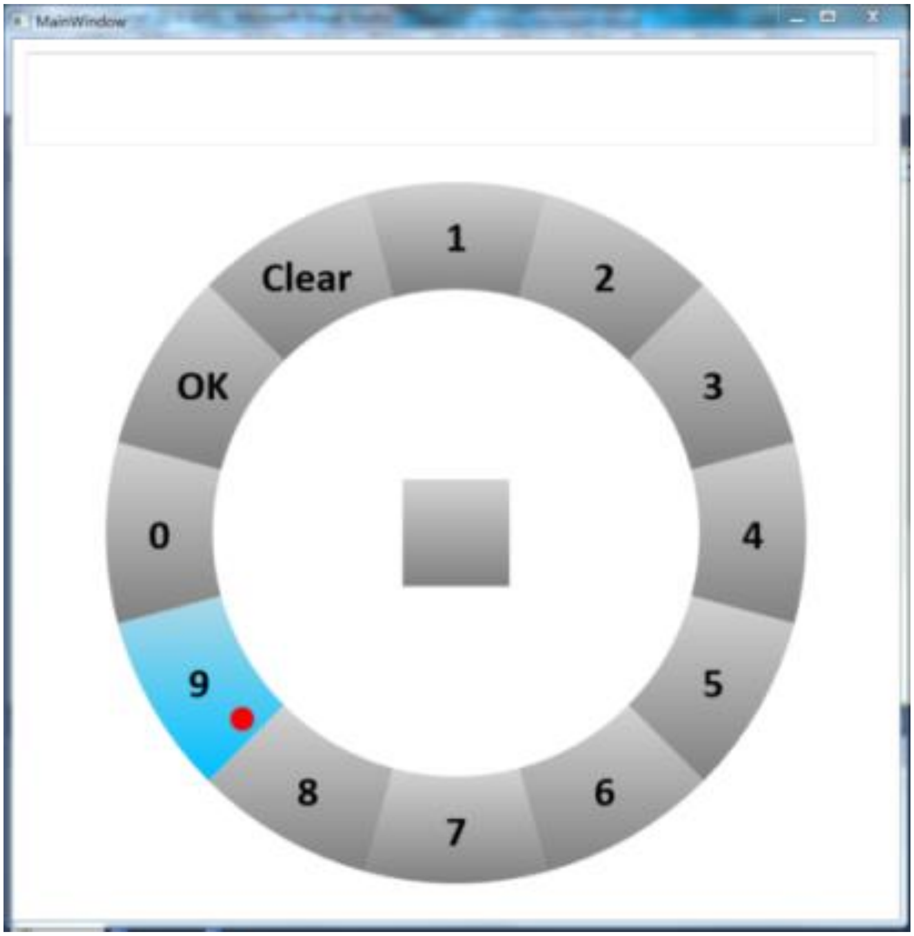

Figure 24: A Working Example of Circular Design

The characteristic of circular design is that the buttons is on a ring which center is the start position. The button shares and separate the full 360° from the start position. When the user move his/her hand to the specific direction, the cursor will be on the specific button on the same direction the user's hand moves. In the case of the situation, the range of the direction for a button is an angle of 30°. If we treat the positive direction of y axis as 0°, ±15° will be button "1", 15° ~ 45° will be button "2" etc.

In a circular design, the border of range of the panel is to the outside border of each button. The cursor cannot move outside the rings. Therefore, no matter how far the user moves his hand away from the start point, the cursor will be on the buttons.

4.3.1 Advantages

Compares to the traditional matrix design, the circular design have several advantages in a virtual touch panel interface.

4.3.1.1 Advantage 1: Only direction is needed to select a specific button.

As we previous discussed, the user operate a system indirectly with a cursor, the user cannot handle the distance of the cursor's movement at the very first time because the user doesn't know or use to the speed of the cursor. But the direction of the cursor's movement can be handled in the very first time because the cursor will move to the same direction of the hand's movement and user can control the direction of his/her hand movement.

In circular design, the buttons is allocated in a ring which center is the start position. When the user move his/her hand to the specific direction, the cursor will be on the specific button on the same direction the user's hand moves.

Therefore, the user can operate a virtual touch panel interface with the circular design without needing any previous experience to the system. The user can operate the system with circular design more easily than a system with the matrix design in the very first time because there is no need for the user to handle how much distance the user needs to move his/her hand.

4.3.1.2 Advantage 2: The size of the button can be treated as unlimited.

In the circular design, the border of the panel is the outside border of each button. The cursor cannot move outside of the button. Therefore, no matter how much the user move his hand far from the start position, as long as the direction to the start position is in the range of the target button, the cursor is on the button. Therefore, the size of the button can be treated as unlimited within the sensing range of the camera or the reachable zone of the user' hand. Figure 25 shows the size of each button in the sensing range of the camera. The whole image is the infrared image get by the Kinect sensor, where the pink is the user detected and recognized by the system. The place of the empty button in the center is the user's left hand position detected by the system. The big red circle is the approximately reachable range of the user's hand. The red block separated by the blue line is the size of each button.

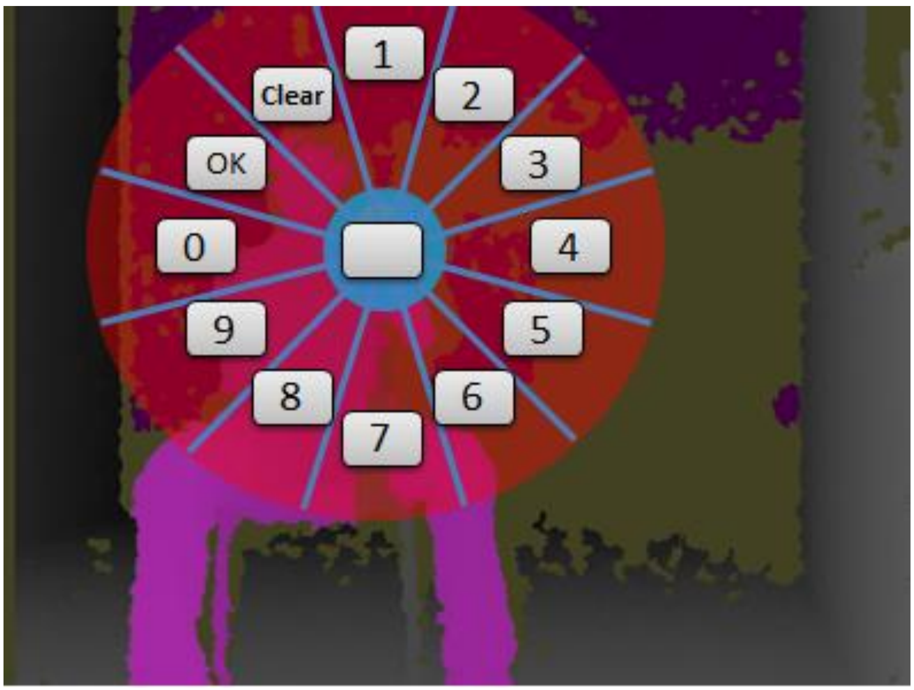

Figure 25: The Hand Cover Range and the Size of the Button

The user can move the cursor to the button more easily than the traditional matrix design.

4.3.1.3 Advantage 3: Won't pass through other buttons when moving to the target button.

As we previous discussed, in this system, both the cursor movement and button activation requires the user to move his/her hand. When the user want to move a cursor, the ideal situation of the operation is to change the X and Y value and not change the Z value. But such operation is impossible to be done as when the user move his/her hand, the direction is always not absolute parallel to the axis. The hand movement done by the user often is a curve and had a big change of Z value. This may cause a problem that there is a chance the system will misjudge the cursor moving operation to a button activation operation. Therefore if there are buttons between the current position to the target button. The system may activate the wrong button by miss.

In a circular design, the button is specified in each direction, there won't be any button to be passed by when the user moves the cursor from the start position to the target button as long as the user doesn't move the cursor to the wrong direction. If we compare the system with the circular design to the traditional matrix design, we can see that also the machine error still affect and cause the system to activate the wrong button, the possibility of activating wrong button when the user is doing cursor moving operation is significantly reduced.

4.3.1.4 Advantage 4: The button is only surround by 2 buttons.

As we previous discussed, in this system, both the cursor movement and button activation requires the user to move his/her hand. When the user want to push his/her hand forward and activate the target button, the direction is always not absolute parallel to the axis and the movement is a curve. The hand movement done by the user often had a big change of X and Y value. This may cause a problem that after the hand movement, the cursor is outside the target button. If there are buttons surround the target button, there is a chance that the cursor is end up in another button and the system recognize the wrong button. The possibility of this problem happening is positive related to the number of the buttons surround to the target button.

In the circular design, the number of the neighborhood button is 2, which means the number of neighborhood button is reduced as $\frac{1}{4}$ of the number in matrix design. The possibility of problem that the system activate the wrong button when user is doing the button activation operation is significantly reduced.

4.3.1.5 Advantage 5: The distance between each buttons is same and can be tweaked。

In the circular design, different to the traditional matrix design, the distance between the start button and each button are the same. The average operation time can be controlled.

Although the distance of pixels between the buttons in the display is a fixed value that depends on the resolution of the display. The distance that the user need to move his/her hand can be tweaked by tweaking the cursor speed of the system.

So after the appropriate adjustment, there won't be button that will be out of reach of the user if the user can reach the distance of the radius of the ring, the user can reach all the buttons. Also the distance won't be too small that the cursor is too sensitive that make the system difficult to operate.

4.3.2 The Best Length of Radius

In the circular design, the radius of the menu in the display is a fixed value that the panel in the display will be a fixed size. The real radius between the buttons that the user need to move his/her hand can be tweaked by tweaking the cursor speed. If the radius is set too big, the user will use more time to reach it. If the radius is set too small, the cursor will become too sensitive and the user will be difficult to operate it.

In order to know the best length of the radius of the system, we make an experiment to compare between different radiuses.

In this experiment, we set the Kinect and a display on a table, the height of Kinect (camera's center) to the ground is 80cm. The height of the display (display's center) to the ground is 96cm. We let the user sit in a chair, 1.8m away from the center of the Kinect.

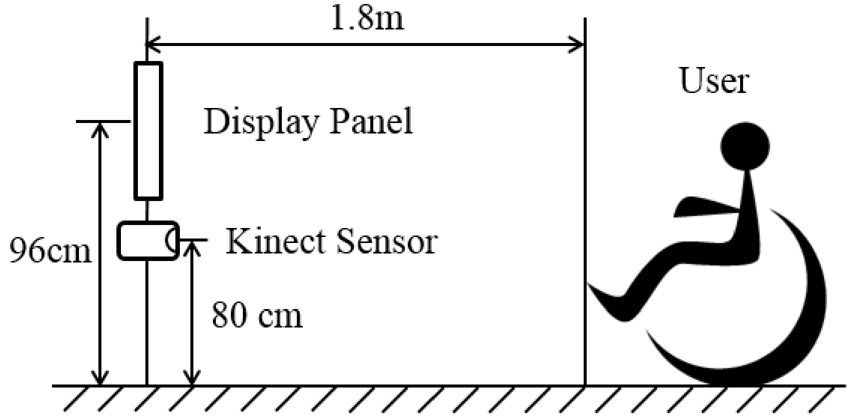

Figure 26: The Environment of Test on Different Radius

In the experiment, the user need to operate the system which radius of the menu is set in different value. The user need to input the button 0-9 in a randomized order generated by the system. After the user sit in the chair in front of the camera and put up his/her hand, Kinect will recognize the user and feedback the position of the user's hand to the system. The system will show a cursor in the start position and show the number of the target button which the user need to activate and the timer is start at the same time. After user pushed a button, no matter the button is right or wrong, the timer is stopped. Then the system reset, and recognize the user, then shows a different target button. The process will looped until all button has been test. The operation time will be recorded as data.

We tested the radius from 10cm to 25cm, at 5 cm steps. 8 tester participate the experiment, the result of average operation time of 1 button by different tester and different radius is shown in Table 4.

Table 4: The Average Operation Time of Different Radius

Radius	10cm	15cm	20cm	25cm
Tester 1	2.74	2.99	3.36	3.17
Tester 2	3.49	2.54	3.18	2.72
Tester 3	2.48	2.55	2.78	3.13
Tester 4	3.02	2.73	1.70	2.63
Tester 5	1.95	1.86	2.57	3.23
Tester 6	2.38	2.16	2.48	3.81
Tester 7	2.14	2.29	2.45	3.63
Tester 8	2.06	2.25	2.25	3.27
Average	**2.53**	**2.42**	**2.60**	**3.20**

(Unit: Second)

We analyzed the data by ANOVA to see if the value of radius is a factor that can take effect on the average operation time of the system.

Table 5: The Result of ANOVA on Operation Time by Different Radius

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2.89577	3	0.965257	4.625222	0.009475	2.946685
Within Groups	5.843434	28	0.208694			
Total	8.739204	31				

The P-value is 0.00947, which means the possibility of the value of the radius isn't a factor of the average operation time is 0.0947%. From the result, we can know that the value of the radius is a factor of the average operation time, the value of the radius does take effect on the average operation time of the virtual touch panel interface.

Figure 27 is the chart we plot the average and the standard deviation of the result into a line chart.

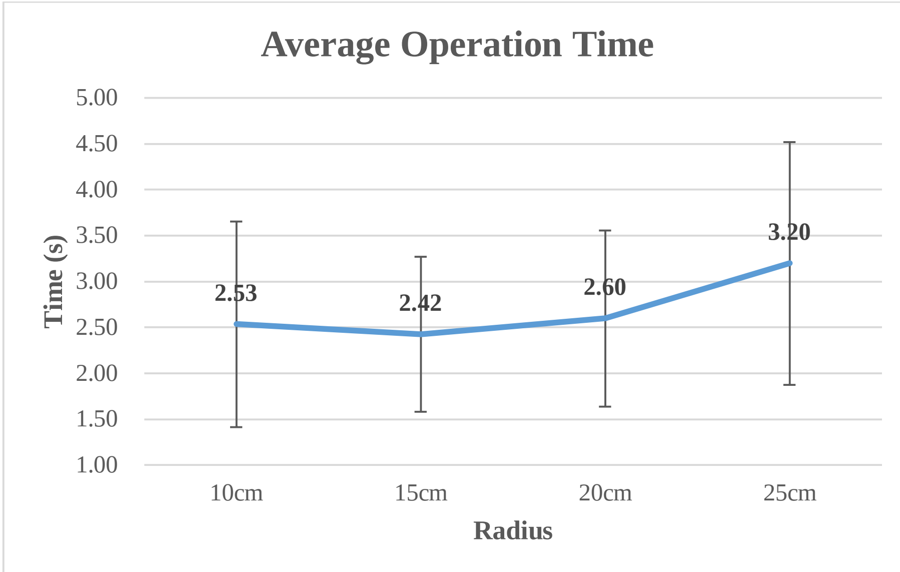

Figure 27: The Result of the Test on Different Radius

From the result, we can see that in the range of 15cm to 25cm, the less the radius, the less the average operation time and fluctuation. But both the average operation time and the standard deviation of 10cm is greater than the ones in 15cm. The reason can be consider as the Kinect has machine error. When the radius is getting too small, the effect of the machine error will affect the system and cause the user harder to operate.

According to the result of the result, we can make a conclusion that the best radius for the circular design in virtual touch panel interface is 15cm.

4.4 Compare between Matrix Design and Circular Design

We discussed the disadvantages and advantages of the traditional matrix design and the circular design. The circular design is more proper to the virtual touch panel than the matrix design in our theory. We need to know how both the design's real performance in the system to know if the circular design is really better.

We make another experiment to compare the 2 designs. The environment is the same as the experiment we do in Section 3.3.2 in order to know the best radius of the circular design. We set the Kinect and a display on a table, the height of Kinect (camera's center) to the ground is 80cm. The height of the display (display's center) to the ground is 96cm. We let the user sit in a chair, 1.8m away from the center of the Kinect. (See Figure 26)

Figure 28: A Tester is Operating the System

The user need to operate the system in different design. The operation of the user is the same as the experiment in Section 3.2.2. The user need to input the button 0-9 in a randomized order generated by the system. After the user sit in the chair in front of the camera and put up his/her hand, Kinect will recognize the user and feedback the position of the user's hand to the system. The system will show a cursor in the start position and show the number of the target button which the user need to activate and the timer is start at the same time. After user pushed a button, no matter the button is right or wrong, the timer is stopped. Then the system reset, and recognize the user, then shows a different target button. The process will looped until all button has been test. The operation time will be recorded as data.

Additionally in this experiment, we want to know if the circular design has more accuracy on the operation. We mark the operation with tags. If the operation ends up with activated the correct target button in less than 5 seconds, the operation will be marked "Correct". If the operation ends up with activated the wrong button, the data will be marked "Incorrect". If no button is activated in 5 seconds, the operation will be marked "Fail".

Both of the design is set in a 30cm x 30cm square from the start position. In the circular design, we set the radius of the menu as 15cm. In the matrix design, we allocate the button equidistantly as the space between each button is 1/5 of the button's width.

4.4.1 Average Operation Time

5 Tester participated the experiment, the average operation time of 1 button by different tester and different design is shown in Table 6.

Table 6: The Average Operation Time of Different Design

Tester	Matrix Design	Circular Design
1	3.07	2.45
2	3.16	2.78
3	2.74	2.48
4	2.84	2.36
5	2.52	1.86
Average	**2.86**	**2.39**

(Unit: Second)

We analyzed the data by student-t test to see the average operation time of matrix design and circular design are different in the system.

Table 7: The Result of Student-t Test on Operation Time by Different Design

	Matrix Design	*Circular Design*
Mean	2.86435	2.385032198
Variance	0.067443	0.11181169
Observations	5	5
Pearson Correlation	0.87444	
Hypothesized Mean Difference	0	
df	4	
t Stat	6.476706	
P(T<=t) one-tail	0.001464	
t Critical one-tail	2.131847	
P(T<=t) two-tail	0.002929	
t Critical two-tail	2.776445	

The P-value is 0.00293, which means the possibility of the average operation time are same in different design is 0.0293%, which can be treat as impossible. From the result, we can know that average operation time on matrix design and circular design are different in virtual touch panel interface.

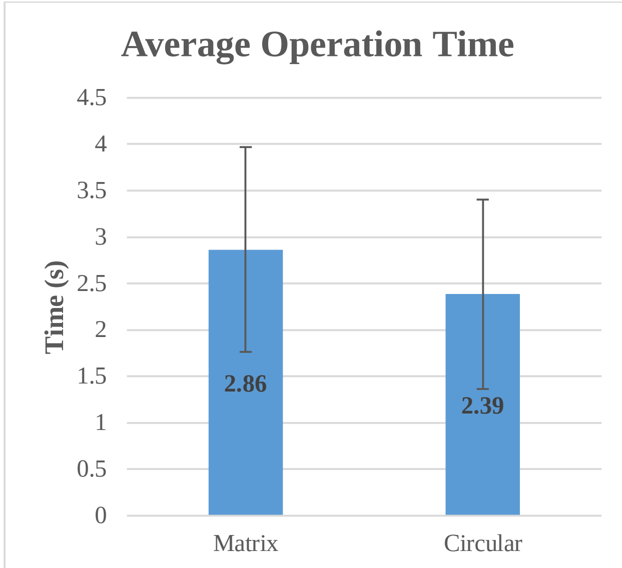

Figure 29: The Average Operation Time on Different Design

Figure 29 is the result of average operation time plot in a bar chart. From the chart we can see that average operation time of the circular design use 16.4% less time than the traditional matrix design.

4.4.2 Accuracy

On each design, the user need to activate 10 buttons, the count of operation ended up with different result by different tester on matrix design is shown in Table 8.

Table 8: The Result of Operation on Matrix Design

Tester	Correct	Incorrect	Fail	Accuracy
1	8	1	1	80%
2	7	1	2	70%
3	7	2	1	70%
4	7	2	1	70%
5	10	0	0	100%
Average	**7.8**	**1.2**	**1.0**	**78%**

The result on the circular design is shown in Table 9.

Table 9: The Result of Operation on Circular Design

Tester	Correct	Incorrect	Fail	Accuracy
1	10	0	0	100%
2	10	0	0	100%
3	9	0	1	90%
4	8	2	0	80%
5	10	0	0	100%
Average	**9.4**	**0.4**	**0.2**	**94%**

We analyzed the data with student-t test on the accuracy of matrix design and circular design to see if the accuracy of the different design are different.

Table 10: The Result of Student-t Test on Accuracy of Different Design

	Matrix Design	*Circular Design*
Mean	0.78	0.94
Variance	0.017	0.008
Observations	5	5
Pearson Correlation	0.514496	
Hypothesized Mean Difference	0	
df	4	
t Stat	-3.13786	
P(T<=t) one-tail	0.01746	
t Critical one-tail	2.131847	
P(T<=t) two-tail	0.03492	
t Critical two-tail	2.776445	

From the result, we can see that the P-value is 0.03492, which means the possibility of the average operation time are same in different design is only 3.492%, which can be treat as impossible. From the result, we can know that accuracy on matrix design and circular design are different in virtual touch panel interface.

5 OPERATION ENGINE DESIGN

From Kinect, we can get a time series of hand position, but we cannot recognize what the user is doing unless we have a detection engine. The detection engine needs an algorithm to analyze the time series of position, and output the current operation or user status.

In this system, the detection engine works in detecting whether the current operation is moving cursor, or selecting the button and activate it.

5.1 Algorithm of Operation Engine

A very simple algorithm is monitoring the Z value. If the Z value reduced such a value in a short time, we can consider the user is “pushing”.

But as we discussed before, in a virtual touch panel interface, the direction of the hand movement is not directly along the absolutely axis. When the user want to move the cursor horizontally and vertically, the hand movement also may cause a change of the Z value.

And in an extreme situation when user is too desire to push the button that he moves his hand so fast, it may sometimes meet the requirement of “Z value reduced such a value in a short time”, and lead the system to a misdetection.

We need a constraint to limit the direction of push action. The most proper parameter is the angle between the moving direction and the direction of Z axis. When a person tried to move his hand forward, the hand actually doesn’t go absolutely the direction of Z axis, there is an angle between moving direction and the Z axis. In this system, we consider 45°

is the borderline between both actions. When the angle is less than 45°, we consider the user is "pushing forward", otherwise we consider the user is "moving between buttons".

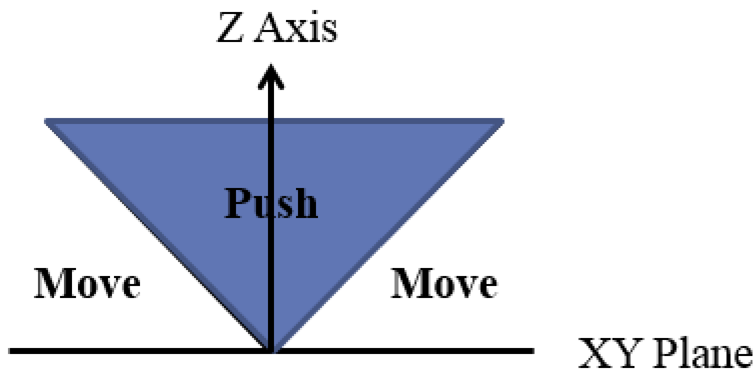

Figure 30: The Movement Direction and the Operation

Also, we need a constraint to limit the speed of push action. If the user is moving his hand but the speed is too slow, we should consider this operation as an unconsciously hands movement other than a push operation. In this system, we use 0.3m/s as the boundary. If the user move his/her hand over 0.3m/s and the angle between the direction of the hand movement and the Z axis is less than 45 degree, the operation will be considered as a push operation.

5.2 Noise Cancellation

The Kinect is a tracking device. As all the tracking devices do, the position feedback by the devices is not 100% accurate. The inaccuracy include: misdetection of hand by other body part like arms, lose detection of the user etc. which can be treated as noise in the system.

In order to remove the noise, firstly, we need to remove the inaccurate data which is the position of the other part of the user due to misdetection.

Normally, the time of the misdetection is short and the inaccurate data is an isolated point in the time series. There is several mathematical method to judge it. But in order to make it as simple as we can and know it in real time without affecting the performance of the system, we use the distance between current position and the average of previous frame and next frame to judge if the frame is inaccurate. If the distance is too big that no one can move that by hand in 0.1s, which is the time of 3 frames, we consider this point as an inaccurate point, and replace the data of the frame with the average value of previous frame and next frame.

The second part of reduce difference between the real hand movement direction and the direction detected by Kinect sensor because of the machine error.

Because of the machine error, the track of the hand movement we get from Kinect sensor is not a smooth line. Normally, it is a polylines. Figure 31 shows an example of the real hand movement and the data got by Kinect sensor.

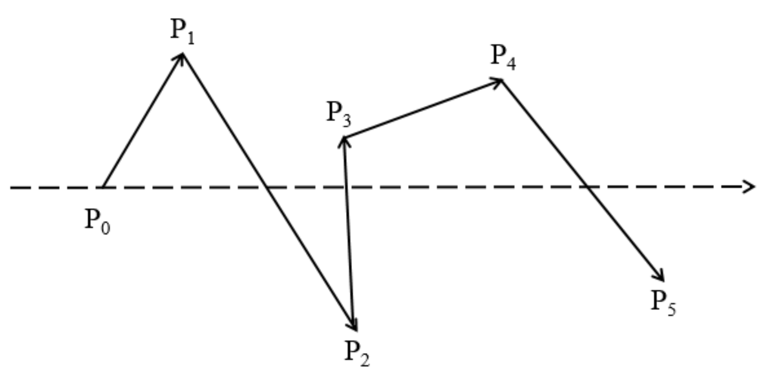

Figure 31: Real Hand Movement and Hand Position Got by Kinect Sensor

In Figure 31, the dash line is the track of the hand movement by the user. P_0~P_5 is the hand position got by Kinect sensor per every frame. We connect the hand position with arrows. From Figure 31, we can see that the direction of hand movement got by Kinect sensor is an unsmooth polylines and the direction of the movement in each frame has a significant difference to the real direction of the user's hand movement. Therefore, we need a noise cancellation method to reduce the error.

We have a lot of way to reduce the noise and remove data if the data is inaccurate, such as judging an isolated point in the time series. But as our system is running real time and all the data need to be processed with no delay of the user's hand movement, we prefer a simple method that don't effect the performance of the system.

From Figure 31, we can see that, although the point of the hand position we got from the Kinect sensor is not that accurate, but it is still with an error range of the real position. The error range is in a limitation according to the specification of the Kinect sensor. If we the start point and end point of an direction have a big distance between each other, the affection of the machine error will be reduced, the angle between the real direction and the direction we get from the sensor will get smaller.

If we draw an arrow from P_0 to P_5 in Figure 31 (See the blue arrow in Figure 32), we can see that the direction is much closer to the real direction, the noise is reduced.

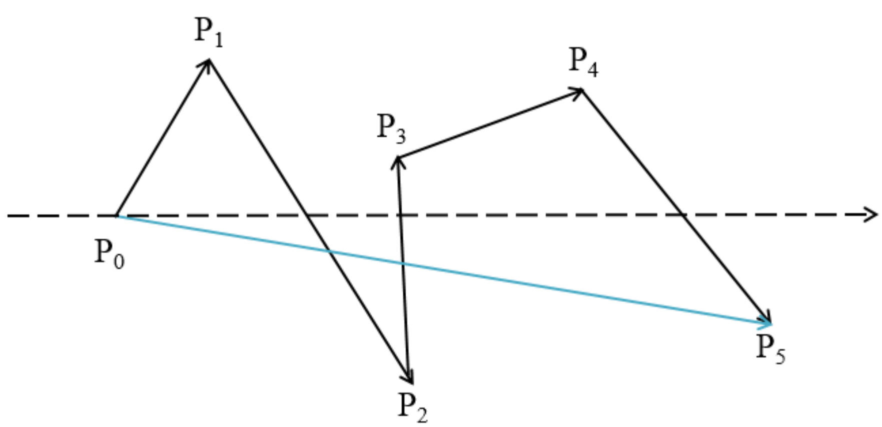

Figure 32: Noise Reduction

In this system, we calculate the direction between the current position and the one we get 5 frames ago to reduce the noise. This method doesn’t need any iteration and complex calculation and doesn’t have delay to reduce the noise.

6 LOGGING FUNCTION

In this system, there still are spaces for the accuracy and operation time to be improved. In order to make the further optimization possible, we want to log some data that we can use it for future improvement. We need to log a large amount of data for all the time the system is working.

Microsoft, the producer of Kinect, provides a product called Kinect Studio which can record all the data got by Kinect. The data can be used for playback in the Kinect program. The product is fully functioned, but there is a very big problem that it will record all the data get from the Kinect in order to playback with fully function of Kinect. So the data is too large. It will take approximately 30MB for just 1 second, 108GB for an hour, which is impossible to be used by taking the log for a long time. So obviously, the Kinect Studio is out of our option.

In this system, we only need the video or image data taken from camera, along with the detection data of user’s hand. Therefore, it is able to have a log function to taking all the data we need and do not use a lot of spaces.

We made the logging function ourselves. For the data from camera, we log 1 jpeg image for each 5 frames, which means 6 files per second. This will take approximately 200kB for 1 second, 720MB for an hour.

For the hand detection data, we only log the 3 value of X, Y and Z coordinates. It will only take 7MB for an hour.

Our logging function only takes less than 1G for an hour, which is less than 1% of the data recorded by Kinect Studio. Therefore we can use this to record the data of the system when it is being used and make further optimization to the system by these data.

7 VERIFICATION AND VALIDATION

7.1 Verification Test

In order to know if our system is useable and the accuracy of the detection algorithm, and which height of the camera is best. We conducted experiments to test the system on different heights of the system.

Normally, when a person put out his hand, the height is around the height of a human's chest. When sit on a chair of 40cm, the height of chest is around 80cm to 90cm. According to a building regulation of accessible toilets, the height of washing basin for unisex wheelchair use is 72cm-74cm [12]. In this experiment, we are going to test the system with the height of the Kinect sensor is 75cm, 80cm, 85cm and 90cm. A 15" display is set as the height of the display is 96cm to the ground. The user sits in a chair with a distance of 1.8m between front wheels to the center of Kinect.

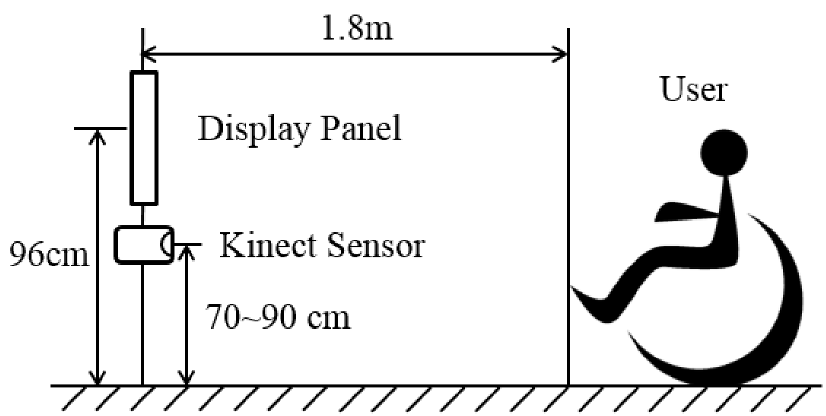

Figure 33: The environment of the Verification Test

In the test, the user need to operate the system which radius of the menu is set in different value. The user need to input the button 0-9 in a randomized order generated by the system. After the user sit in the chair in front of the camera and put up his/her hand, Kinect will recognize the user and feedback the position of the user's hand to the system. The system will show a cursor in the start position and show the number of the target button which the user need to activate and the timer is start at the same time. After user pushed a button, no matter the button is right or wrong, the timer is stopped. Then the system reset, and recognize the user, then shows a different target button. The process will looped until all button has been test. The operation time will be recorded as data.

11 tester participate this test and the average accuracy by different heights is shown in Figure 34.

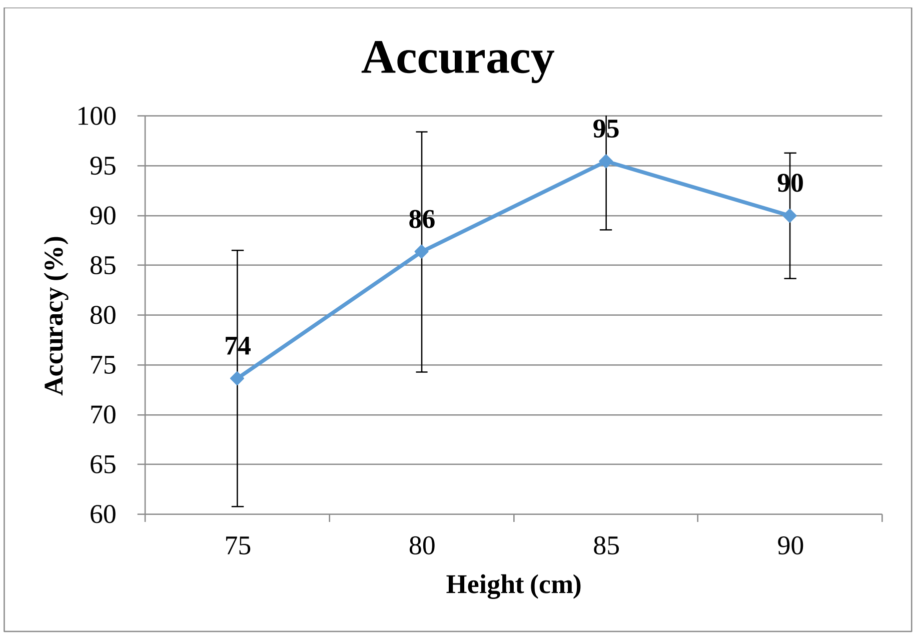

Figure 34: Accuracy by Different Heights

Figure 35 shows the average and standard deviation of operation time on each button by different heights.

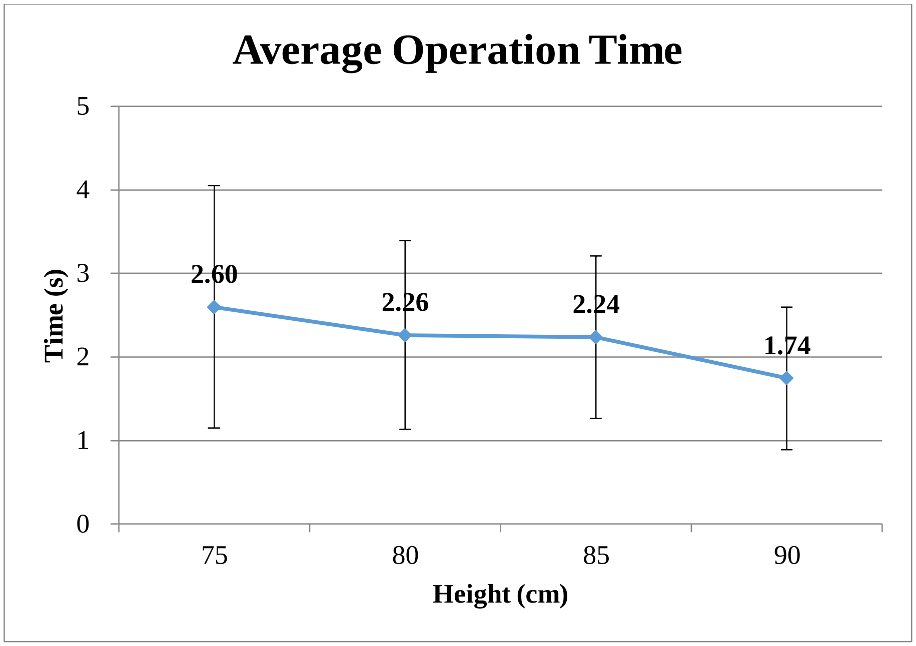

Figure 35: Average Operation Time by Different Heights

From the result, we can see that 75cm is too low that the accuracy for the Kinect sensor is not very good. The accuracy for the other height is good enough to be used as an input method. The average operation time is around 2 seconds which is acceptable as an input method by the user. This performance is shown that this system reaches the standards that can be used.

7.2 Validation

We interviewed Ms. Qiu again to ask if the system can help handicapped people as an input method. We described our system to Ms. Qiu and show her our verification result. The detail of interview is in Table 11.

Table 11: The Second Interview of Ms. Qiu

Q	The last time we interviewed you, you mentioned about if there is an input method that allows the user to operate button without touching it, it should help the handicapped people, right?
A	Yes, that’s true.
Q	We have made some research on such method, now we designed a system. The system is called Virtual Touch Panel. The detail of the system is ……. (Minutes of description of the system). How do you think of this system?
A	This system looks cool. It should help the handicapped people I think if the accuracy and operation time is acceptable. Have you done some test on how the performance of the system?
Q	Yes, after the verification test, the accuracy can be up to 95%, the average operation time is about 2 seconds.
A	That’s cool, I think it should help the handicapped people. Thank you for the research. We actually hope more student like you can make research on the helping the handicapped people. Thank you again.

From the interview to Ms. Qiu, we can know that the system meet the requirement of the handicapped people.

8 DISCUSSION

Still, there is some interesting thing we need to discuss about the system.

8.1 Compare between Buttons

In the verification test, we let the user operate the button in a randomized order to calculate the time and the accuracy of the system in different height.

The button is in the same distance to the start position with different directions, the difficulty of operation each button should be the same theoretically. But in the real world, because the system is operated by human's hand and the human's body is connected by joints, the difficulty of move the hand in different direction may be different.

In order to know if the direction of the button take effect on the average operation time and accuracy of the system, we grouped the test result of verification test by different buttons. The result of the average operation time of different buttons by different heights is shown in Table 12.

Table 12: The Average Operation Time of Different Buttons

`	75cm	80cm	85cm	90cm	Average
Button 1	2.24	2.51	2.50	1.41	**2.16**
Button 2	2.91	2.56	2.32	2.08	**2.47**
Button 3	2.43	2.64	2.18	1.56	**2.20**
Button 4	1.86	2.31	1.92	1.82	**1.98**
Button 5	3.17	2.18	2.07	1.77	**2.30**
Button 6	3.00	2.27	2.55	2.15	**2.49**
Button 7	3.09	1.92	1.96	1.52	**2.12**
Button 8	2.95	2.29	2.58	2.08	**2.47**
Button 9	2.46	2.19	2.23	2.14	**2.25**
Button 0	1.86	1.77	2.08	1.98	**1.92**

(Unit: Second)

We plot the data into a line chart, with the standard deviation as the error range. The figure is shown in Figure 36.

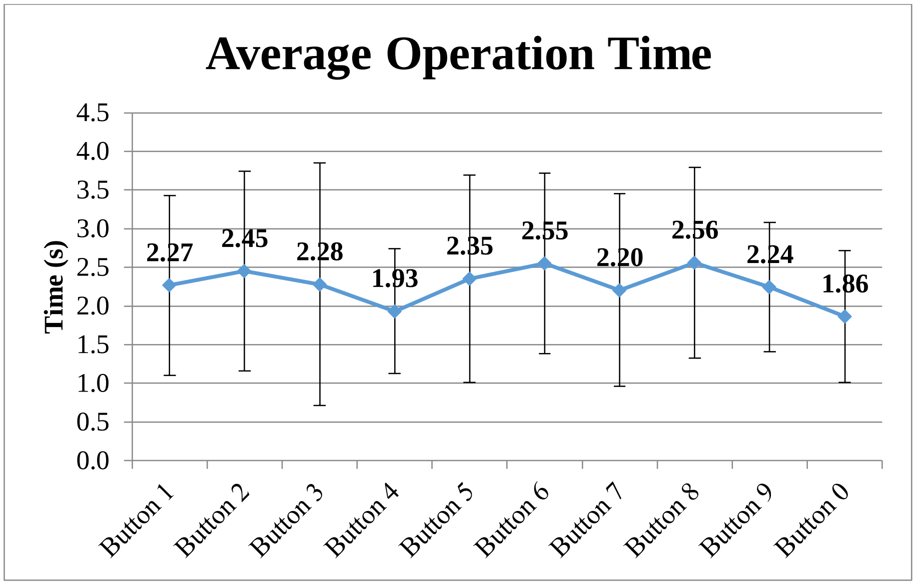

Figure 36: The Average Operation Time of Different Buttons

From Figure 36, we can see that there is clearly some difference between each buttons. But in order to know if the average operation time between each buttons are different in statistical. We analyzed the data with ANOVA, the result of the ANOVA is shown in Table 13.

Table 13: The Result of ANOVA on Operation Time by Different Buttons

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.46261	9	0.162512	0.894234	0.542014	2.210697
Within Groups	5.452005	30	0.181733			
Total	6.914615	39				

The P-value is 0.54, which means the possibility of the average operation time are same between different buttons is 54%. We can say that the average operation time is the same. The direction of the button doesn't take effect on the average operation time of the system.

The result of the accuracy of different buttons by different heights is shown in Table 14.

Table 14: The Accuracy of Different Buttons

`	75cm	80cm	85cm	90cm	Average
Button 1	73%	100%	100%	86%	**90%**
Button 2	55%	82%	100%	86%	**81%**
Button 3	55%	91%	100%	71%	**79%**
Button 4	91%	91%	100%	86%	**92%**
Button 5	82%	73%	91%	86%	**83%**
Button 6	73%	73%	91%	71%	**77%**
Button 7	82%	82%	91%	100%	**89%**
Button 8	55%	91%	100%	86%	**83%**
Button 9	91%	91%	91%	71%	**86%**
Button 0	82%	91%	91%	86%	**87%**

We plot the data into a line chart, with the standard deviation as the error range. The figure is shown in Figure 37.

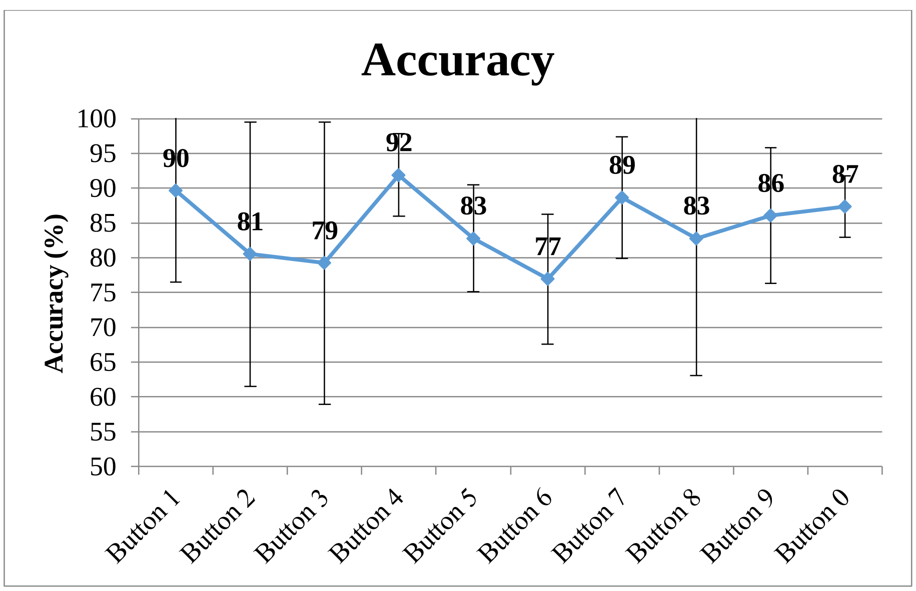

Figure 37: Accuracy between buttons

From Figure 37, we can clearly see that there is difference between the different buttons. But in order to know if the accuracy between each buttons are different in statistical. We analyzed the data with ANOVA, the result of the ANOVA is shown in Table 15.

Table 15: The Result of ANOVA on Accuracy by Different Buttons

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.08587	9	0.009541	0.559125	0.818986	2.210697
Within Groups	0.511933	30	0.017064			
Total	0.597803	39				

The P-value is 0.82, which means the possibility of the accuracy are same between different buttons is 82%. We can say that the average operation time is the same. The direction of the button doesn’t take effect on the average operation time of the system.

From the result, we can know that although the accuracy and time seems to have some difference between each buttons, there is no significant difference in statistical. The direction of the button doesn’t take effect on the performance of the system.

8.2 Compare with Physical Touch Panel

8.2.1 Fitts’ Law

Fitts’ law is a model of human movement primarily used in human-computer interaction and ergonomics that predicts that the time required to rapidly move to a target area is a function of the distance to the target and the size of the target. [13] [14]

Fitts’ law has been formulated mathematically in several different ways. Here we use the common form, the Shannon formulation published by Dr. MacKenzie. [15] [16]

$$T = a + b * ID \quad (1)$$

In this equation, T is the average time taken to complete the operation. ID (Index of Difficulty) is a measure of the difficulty. a is the initial time for the devices, include start time and reaction time before the user start to operate. b is the inherent speed of the device, or “slope”. The a and b is constant for each devices and by comparing the 2 constant, we can compare the performance of different input method.

As we can imagine, the longer the distance the user need to move, the smaller the size the button is, the larger the difficulty, which need more time to operate. According to Fitts and MacKenzie, the equation of difficulty is shown in Equation 2.

$$ID = \log_2(1 + \frac{D}{W}) \quad (2)$$

In Equation 2, D is the distance from the starting point to the center of the target. W is the width of the target measured along the axis of motion.

We can compare different input method and devices by comparing the a and b value in Equation 1.

8.2.2 Equation for Virtual Touch Panel Interface

In order to know the value of a and b in Equation 1 of the virtual touch panel interface. We made an experiment.

In this experiment, we set the Kinect and a display on a table, the height of Kinect (camera’s center) to the ground is 90cm. The height of the display (display’s center) to the ground is 96cm. We let the user sit in a chair, 1.8m away from the center of the Kinect.

Figure 38: A tester is operating the system in the experiment

The task of the User is operate a cursor by moving their hands in front of the Kinect to activate the button in different size, different direction and different distance to the start point in the display. There are 3 kinds of sizes of the button: 10cm, 12.5cm and 15cm. There are 8 kinds of direction: up, down, left, right and 4 diagonally. There are 4 kinds 4 kinds of distance (from the button's center to the start point):15cm, 20cm, 25cm and 30cm. Each of the data above refer to the data in the real space, which is the distance that the hand need to move. The cursor speed in the display is 20 dpi. The tester need to move their hand toward the camera, which can be also treated as "pushing forward", to activate the button.

After the tester sit in front of the system and put up their hands, the Kinect sensor will recognize him and feedback his hands position to the system. The system will mark the current hand position as start position and then shows a cursor (a red dot) to indicate the current hand position, which is in the center at first. The user will then move his hand until the cursor is over the button, and then push forward his hand to activate it. The user have to move his hand back to the start position and then the next button will be shown in the display. The tester shall redo the process above to activate the button until all the button has been activated.

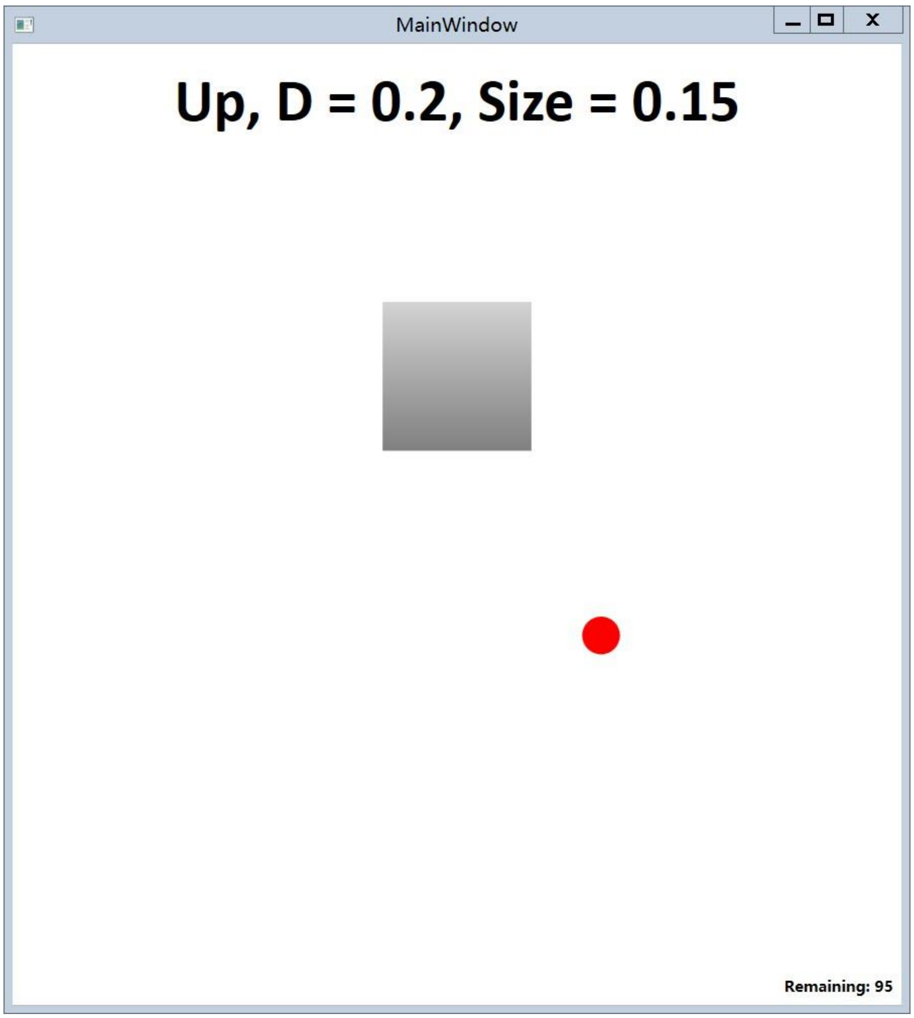

Figure 39: Test for Fitts' Law

The time between cursor in the start position and button has been activated will be recorded as operation time. The first button's operation time is started at the time when the user's hand is being recognized and the cursor is shown, the remaining buttons' operation time is started when the cursor moved back to start position and the next button shows.

8 testers participate the experiment, the average operation time of different size and time is shown in the table below.

Table 16: Result of Test for Fitts' Law

Distance (m)	Size (m)	Time (s)
0.15	0.1	2.18
0.15	0.125	1.77
0.15	0.15	1.55
0.2	0.1	2.11
0.2	0.125	1.98
0.2	0.15	2.09
0.25	0.1	2.74
0.25	0.125	2.34
0.25	0.15	2.03
0.3	0.1	2.66
0.3	0.125	2.45
0.3	0.15	2.61

If we adapt this data in Equation. The distance between start position and the center of the button will be the D in Equation 2, the size of the button will be the W in the Equation 2. By these data, we can get the ID of in Equation 1 and the time will be the T in Equation 1.

We set the ID as X axis, the T as Y axis and plot the result data in a scatter chart. The chart is shown in Figure 40.

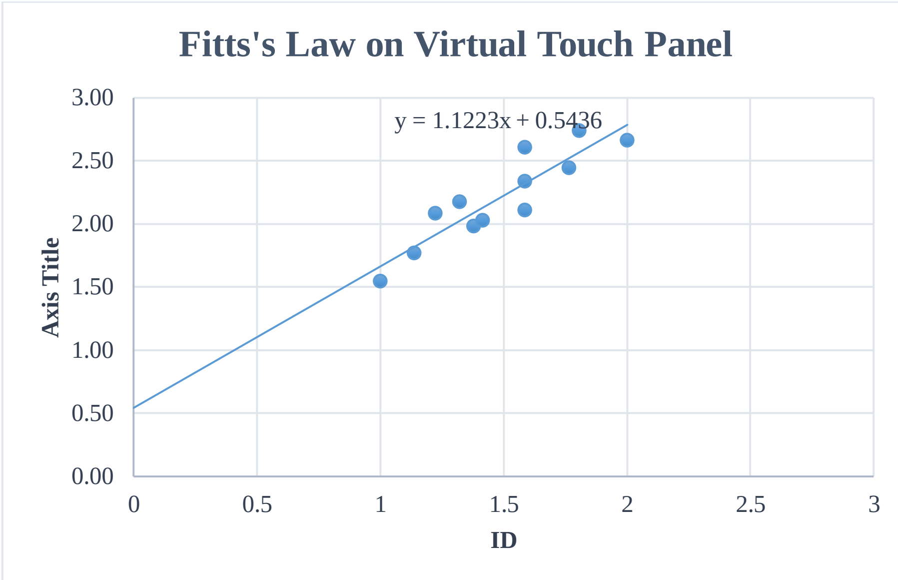

Figure 40: Result of Test for Fitts' Law

From the chart, we can see that the data follow a linear relationship. According to the data, we can know that the operation time in this system is following the Fitts' Law。If we adapt the data in Equation 1. We can get the equation of the expected operation time of the system.

$$T = 0.54 + 1.12 * ID \tag{3}$$

8.2.3 Equation for Physical Touch Panel Interface

Parhi et al. researched on the operation time of several design on a physical touch panel devices with a 3.5" touch display [17].

The result of the operation time on different difficulty is in Figure 41.

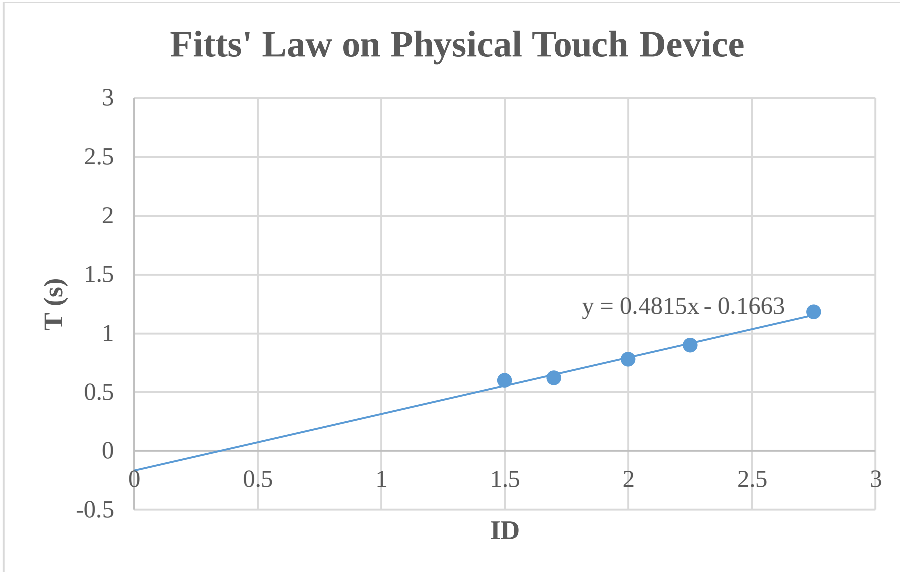

Figure 41: Fitts' Law on Physical Touch Device

The equation of the Fitts' Law is on Equation 4.

$$T = -0.17 + 0.48 * ID \tag{4}$$

8.2.4 Comparison

From Equation 3 and Equation 4. We can make the comparison between the physical touch panel and the virtual touch panel.

From the equations, we can know that the initial time of the virtual touch panel is 0.7s late than the physical touch panel. According to the user experience in the experiment, we find that the delay of the time has 2 reasons. First, user need time to find and confirm the cursor in virtual touch panel while the time isn't needed in the physical touch panel. Second, user need some time to take the action of pushing forward to activate the button in virtual touch panel while the action isn't need in the physical touch panel.

From the equations, we can know that the slope of the virtual touch panel is 2.3 times more than the physical touch panel. The reason can be considered as the all the user operating our system is the first time user without any experience, the user tend to slow down his/her operation to make sure the operation he/she done is correct.

9 CONCLUSION

9.1 Summary

In this research, we presented a novel input method that allows the user to operate a system with their hand gesture instead of only with their fingers. We discussed the detail design of GUI, operation interface and operation engine for a virtual touch panel interface.

From the result of the verification test, we showed this system is practical and feasible. We also provide a way to take the log of system and use it for further optimization.

We get the positive feedback from the representative of official organization for the handicapped people that the system can help the handicapped people with operating the machines.

9.2 Future Work

During the research, we are very regretful that we can't find any handicapped people or real wheelchair user to help us on validating the system by the view of target users.

Although in the experiment, we let the normal people sit in the wheelchair and fixed their legs on the chair to simulate the real handicapped people, the feedback and the result of the real handicapped people and wheelchair user is more helpful in the system. For the future work of this research, we need to let real handicapped people and wheelchair user to evaluate our system and give advices for the system to get better.

Another thing is in Section 8.2, we compare our system with the physical touch panel and find out the performance of the virtual touch panel is a little bit worse than the physical touch panel. The further research on reducing the gap between the virtual touch panel and the physical touch panel is necessary.

PUBLISHED

H. Lu, T. Ogi, Y. Tateyama and H. Lee, "Virtual Touch Panel for Handicapped People," in *ASIAGRAPH Forum 2012*, Tokyo, 2012.

H. Lu, T. Ogi, Y. Tateyama and H. Lee, "Interface Design of Virtual Touch Panel for Handicapped People," in *2012 Asian Conference on Design and Digital Engineering (ACDDE 2012)*, Niseko, 2012.

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