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Research Article

Advanced Interactive Holographic Display Technology (AIHDT)

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ABSTRACT

In this paper, I present "Advanced Interactive Holographic Display Technology (AIHTD)" an attempt to bring one of the interactive display innovations. These Advanced Interactive Holographic Displays provide human computer interaction in free space. In future everyone will start browsing data in free space. It can be better than all other existing touch screen display technologies. My intention is to bring out a display technology in air with real time interactive touch experience.

1. INTRODUCTION

Recently released movies like "Iron Man" have shown mid-air displays, which give an idea about displays in free space.

My objective is to propose a virtual display with real time touch experience. This AIHDT can provide interaction with tactile sensation on touching AIHD. AIHDT makes use of technologies like holography [1], tactile force feedback [2] and finger tracking mechanism.

2. PRINCIPLES USED IN AIHDT

2.1 Holographic screens/displays

Holographic screen/display [3] is a display technology that uses coated glass media for the projection surface of a video projector. "Holographic" refers to the coating that bundles light using formed micro lenses. The lens design and attributes match the holographic area. The lenses may appear similar to the Fresnel lenses used in overhead projectors. The resulting effect is that of a free space display because the image carriers appear very transparent. Additionally the beam manipulation by the lenses can be used to make the image appear to be floating in front or behind the glass, rather than directly on it.

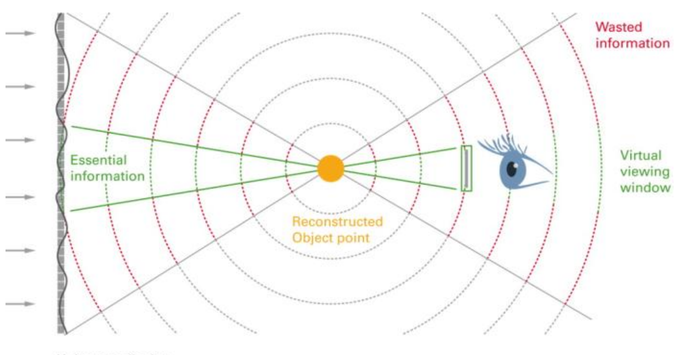

Fig.1. Working of holographic screen.

By using holographic screen we can make a virtual display which seems to be floating at 30c.m. away from the holographic screen.

2.2 Finger tracking

All usually use forefinger to touch screens. I would also suggest you to use forefinger to touch screen in case of AIHDT, for several reasons discussed at the end of this research paper. Here in AIHDT finger tracking is done with Infra-Red (IR) LED array, which is embedded in a small ring. I am calling this can be used to calculate the {x, y, and z} coordinates of the finger with IR ring, via triangulation mechanism. How this is integrated with AIHDT is explained in the prototype section further. A software program will be used which uses above information and process the information, to do necessary tasks according to the user input via touch interactions. This IR ring concept is used for finger tracking, which is necessary in AIHDT. Infrared filters in IR camera are used to block visible light and pass only infrared.

2.3 Acoustic radiation pressure

It is based on a nonlinear phenomenon of ultrasound: Acoustic radiation pressure [4], [5]. Assuming a plane wave, the acoustic radiation pressure P [pa] is described as,

$$P = \alpha E = \alpha\, I/c = \alpha p^2/\rho c^2 \qquad (1)$$

WKT, Density = Mass/Volume [kg/m^3] (2)

Here I use air as medium of ultrasound in the paper. The characteristic acoustic impedance of skin (soft tissue) Z_s and that of Z_a are 1.63 × 10^6 and 0.0004×10^6 N respectively [6]. In this case, the reflection coefficient R is determined to be,

$$R=| Z_s-Z_a / Z_s+Z_a | = 0.9995 \qquad (3)$$

Since 99.95% (i.e R/1 × 100)

(= 0.9995/1 × 100) of the incident acoustic energy is reflected at the skin surface, air borne ultrasound can be directly applied on to skin with acceptable invasion as experimented in [9].

2.4 Phased array focusing technique

Phased array focusing technique can be used as explained in [9]. [Phase is the particular point in the cycle of a waveform measured as angle in degrees]

'IR ring'. I will use this word throughout my paper. This IR ring has to be worn on the finger that user uses to touch the Advanced Interactive Holographic Display (I would suggest you to use forefinger). IR-LED array is used for tracking 3D coordinates {x,y and z} of the finger with IR ring using stereo vision mechanism. Two USB cameras with IR pass filters

It is also employed to generate localized audible sound spot in a 3D space [7].

3. DETAILS OF ULTRASONIC TRANSDUCER

Here I am using commercially available 40 KHz ultrasonic transducers which are usually used for measuring distances. The sound pressure p' [pa] from each transducer is 20pa at a distance of 300m.m. whereas using (TA 010A1 [8] Nippon ceramic co. Ltd.) provides 24pa at the normal rated voltage ($10V_{rms}$). By using these transducers Takayuki Hoshi, Takayuki Iwamoto, Hiroyuki Shinoda, Masafumi,Takahashi have experimented and got quite good results in [9].

4. PROTOTYPE OF AIHDT

My research prototype consists of some ideas proposed and experimented by Takayuki Hoshi and team in [9] and [12]. I am also taking some of the experimental results of [9] and [12]. I am using 324 ultrasound transducers. The resonant frequency is 40 KHz. The phase delays and amplitudes of all the transducers are controlled individually to generate one focal point and move it three dimensionally. As it is mentioned in [9] the DC output force at the focal point is 16mN and the focal point is 20m.m. and the vibrations produced by their prototype was up to 1 KHz.

4.1 AIHDT Box

My prototype consists of a box which provides a virtual display in the free space inside AIHDT box. The box dimensions are mentioned below.

- Box height = 45c.m.
- Box thickness = 15c.m.
- Box width = 45c.m.

Box thickness is kept 15c.m. so that the ultrasound transducer array houses can be fit into 4 sides of the box.

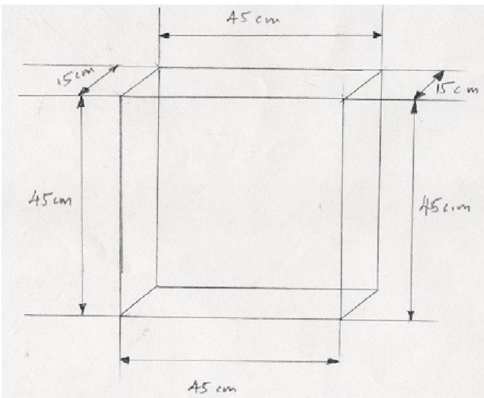

Fig.2. Box used in AIHDT (AIHDT Box).

4.2 AIHDT Box with finger tracking

As I explained in 2.2 section IR cameras will be used for finger tracking/ hand tracking in my research prototype. It will be fixed to the top left most corners and another will be fixed to the top right most part of the AIHDT box. IR-LED ring will be worn on the fore finger/any other finger. This IR-LED ring contains maximum 6 IR-LEDs with a small lithium coin cell. This coin cell can provide a voltage of 3volts, each IR-LED requires 0.7-1volt so I will be connecting these IR-LEDs in parallel and it is embedded into a small ring with small lithium coin cell as the source of power.

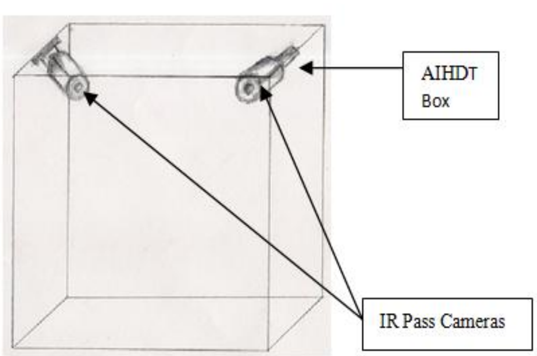

Fig.3. AIHDT Box with 2 IR cameras fixed to left and right corners.

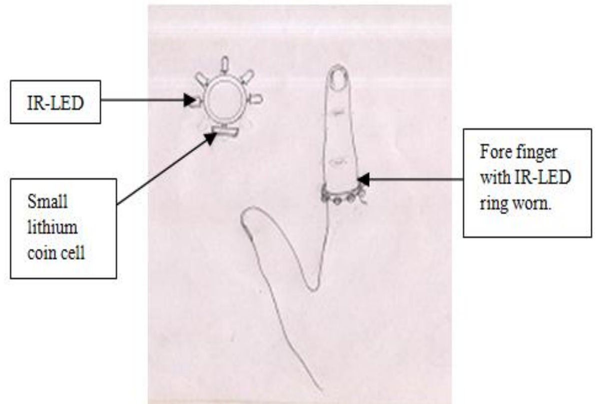

Fig.4. IR ring to wear to forefinger/any other finger that the user uses to interact with AIHDT.

4.3 Ultrasound transducer matrix house

I am keeping 4 ultrasonic transducer array houses. These 4 ultrasound transducers are fixed to 4 sides (top, bottom, left side and right side) of AIHDT box. The ultrasound transducer array is made by embedding all the transducers in one flat surface like structure which can hold these transducers in rows and columns. The ultrasound transducer house can be called as ultrasound transducer matrix house. Each embedded ultrasound matrix house consists of 324 transducers arranged in 9×36 rectangular matrix fashion, so that the transducer matrix house can be fitted to 4 sides of the AIHDT box. Each matrix house contains 9 rows and 36 columns. Columns in the matrix house are divided into groups for convenience. 3 columns belong to one group. Total 12 groups i.e. 12×3 = 36 columns.

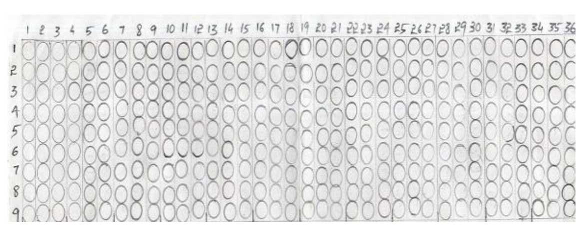

Fig.5.1 Ultrasound transducers matrix house.

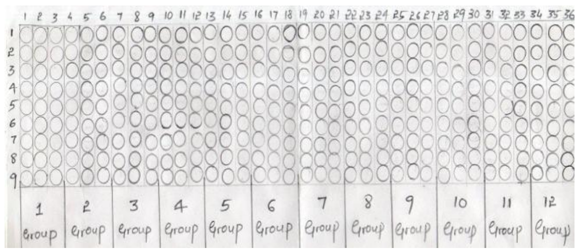

Fig.5.2. A position number given to each set of ultrasound transducer arrays in each ultrasound transducer matrix.

This ultrasound transducer matrix house is designed in such a way that it can be fitted to 4 sides of the AIHDT box.

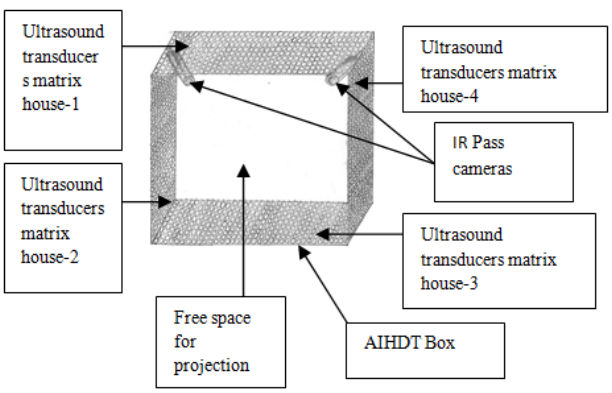

Fig.6. AIHDT box with 4 ultrasound transducer matrix houses are fixed at 4 sides of the AIHDT box, and 2 IR cameras fixed top left and top right corners.

From the viewpoint of human tactile properties the bandwidth up to 1 KHz is sufficient for tactile display [10]. My ultrasound based method has a possibility to produce various kinds of texture feelings because the carrier frequency, 40 KHz is much higher than the required modulation bandwidth 1 KHz.

4.4 Holographic screen/display

Usage of powerful holographic displays, which can produce the virtual objects at a distance of 30c.m. from the screen, would be preferable. It should be kept behind the AIHDT box (About 25c.m. behind) so that the virtual object of the screen falls right into the AIHDT box.

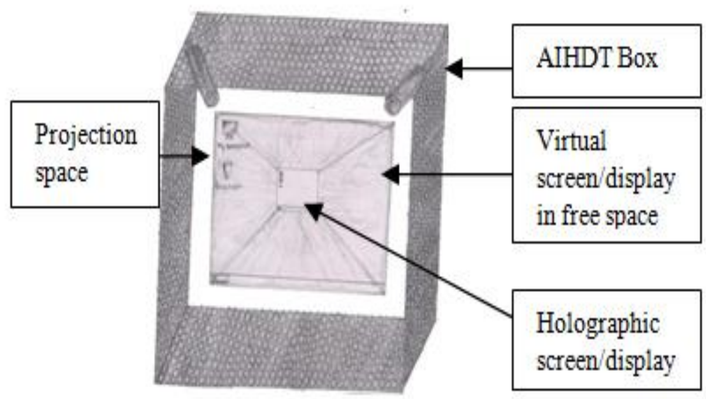

Fig.7. Holographic screen kept behind AIHDT box the arrangement is as shown.

4.5 Video projector

Video projector [11] is required to give input to the holographic screen display and kept behind the holographic screen. The video projector is directly connected to the CPU using VGA cable. Once we start the CPU and video projector the output from the video projector will fall on the holographic screen. Here I am using CPU just to give input to the video projector. We can also use other devices such as DVD players / CD players instead of CPU, which can be connected to the projector.

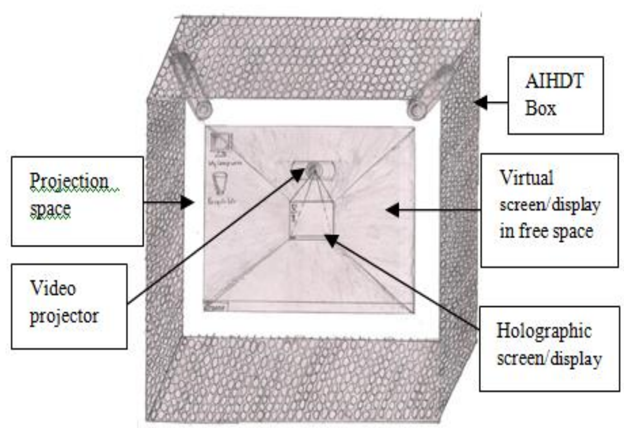

Fig.8. Video projector kept behind holographic screen the arrangement is as shown.

5. COMPLETE SYSTEM SET UP

This section explains system set up. Numberings are made to each set in each ultrasound transducer matrix house. (There are 4 ultrasound transducer matrix houses fixed at top, bottom, left side and right side of the AIHDT box). Each set of ultrasound transducer arrays consists of 9×3 = 27 ultrasound transducers. A position number will be given to each set of ultrasound transducer arrays in each ultrasound transducer matrix house as shown above in fig 5.2.

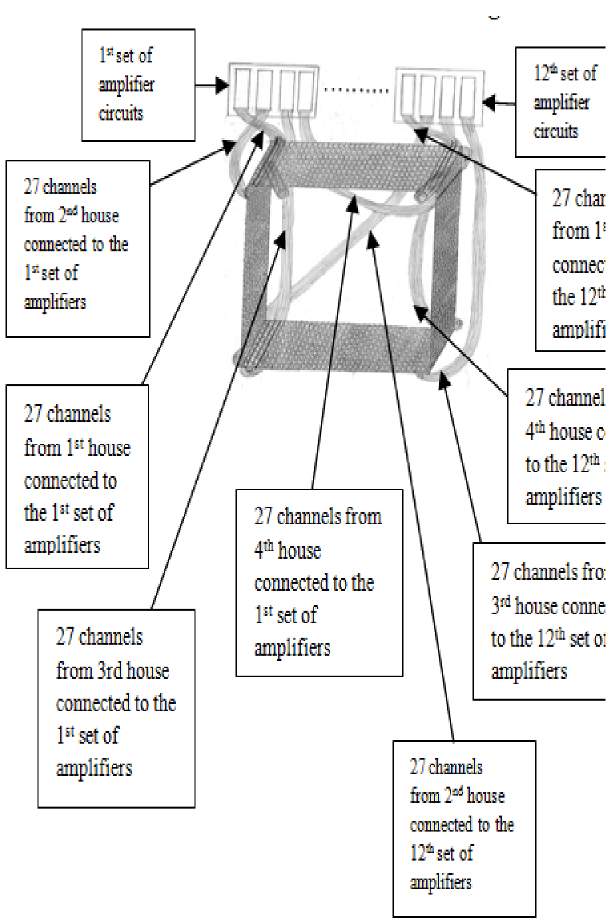

Fig.9. Four sets of ultrasound transducer arrays, one set from each ultrasound transducer matrix house (Totally there are 4 ultrasound matrix houses fixed at top, bottom, left side and right side of the AIHDT box) will be connected to particular set of amplifier circuits as shown above.

A digital I/O card, a master circuit, 12 slave circuits and 12 sets of amplifier circuits (Each set consists of 4 amplifier circuits) are used in my research prototype. One slave circuit is connected to one set of amplifier circuits (one set consists of 4 amplifier circuits). This one set of amplifier circuits is connected to 4 sets of ultrasound transducer arrays, one set of ultrasound transducer arrays from each ultrasound transducer matrix house (There are 4 ultrasound transducer matrix houses fixed at top, bottom, left side and right side of the AIHDT box). As numbered in fig. 9, 1st set (ultrasound transducer arrays set numbered as 1) from each ultrasound transducer matrix house are connected to the first set of amplifier circuits (One set consists of 4 amplifier circuits) which will be connected to the first slave circuit. In the same way there are 11 more ultrasound transducer sets in each ultrasound transducer matrix house which will be connected to 11 other sets amplifier circuits which will be connected to 11 other slave circuits.

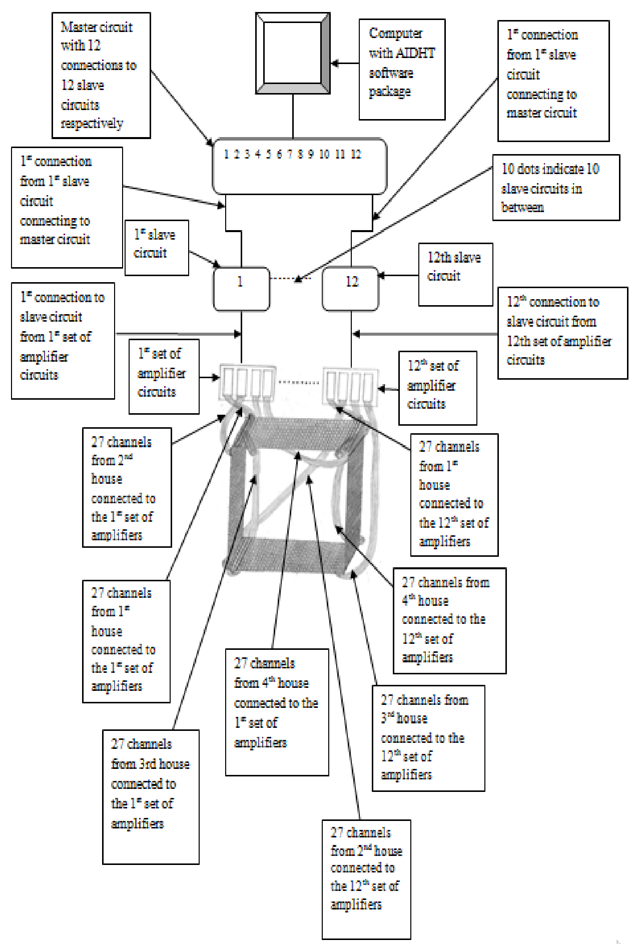

Fig.10. Four sets of ultrasound transducer arrays, one set from each ultrasound transducer matrix house (Totally there are 4 ultrasound matrix houses fixed at

top, bottom, left side and right side of the AIHDT box) will be connected to particular set of amplifier circuits, this is connected to particular slave circuit and all 12 slave circuits is connected to a master circuit, this master circuit is connected to a computer with AIHDT software package installed, as shown above.

Dots shown in the figure 10 tells the repetition of connections same as that of 1st and it will be continued till the 12th circuit. It is very simple as explained: " nth set (set numbered as n) of ultrasound transducer arrays from each transducer matrix house (Totally there are 4 transducer matrix houses fixed at top, bottom, left side and right side of AIHDT box) will be connected to the nth set of amplifier circuit which will be connected to the nth slave circuit".

6. DESCRIPTION OF SOME OF THE COMPONENTS

6.1 Master circuit

The master circuit has an FPGA (Field Programmable Gate Array) and a 25.6 MHz oscillator which acts as the system clock. The master circuit receives commands or data from the PC through the digital I/O and broadcasts it to slaves.

6.2 Slave circuit

Each slave circuit has 4 FPGAs (FPGA stands for Field Programmable Gate Array, it is an integrated circuit designed to be configured by the customer or designer after manufacturing, Hence "Field Programmable". The FPGA configuration is generally specified using a HDL (Hardware Description Language).

6.3 Set of amplifier circuits

Each slave drives 27×4=108 ultrasound transducers individually through the set of amplifier circuits. This set of amplifier circuits consists of 4 amplifier circuits. Each amplifier circuit is 27-ch; each ch (channel) is connected to one ultrasound transducer in ultrasound transducer arrays set present in one of 4 ultrasound transducer matrix house. The driving signal into the ultrasound transducer is 24 V_{p-p}; 40 KHz rectangular wave whose DC component is cut by an HPF. HPF (High Pass Filter) is a circuit which only passes signals above the selected cut-off point; f_c (Cut off frequency).Amplifiers with 27-ch and HPF is commercially available. 27-ch is required because each set of ultrasound transducer array contains 27 ultrasound transducers.

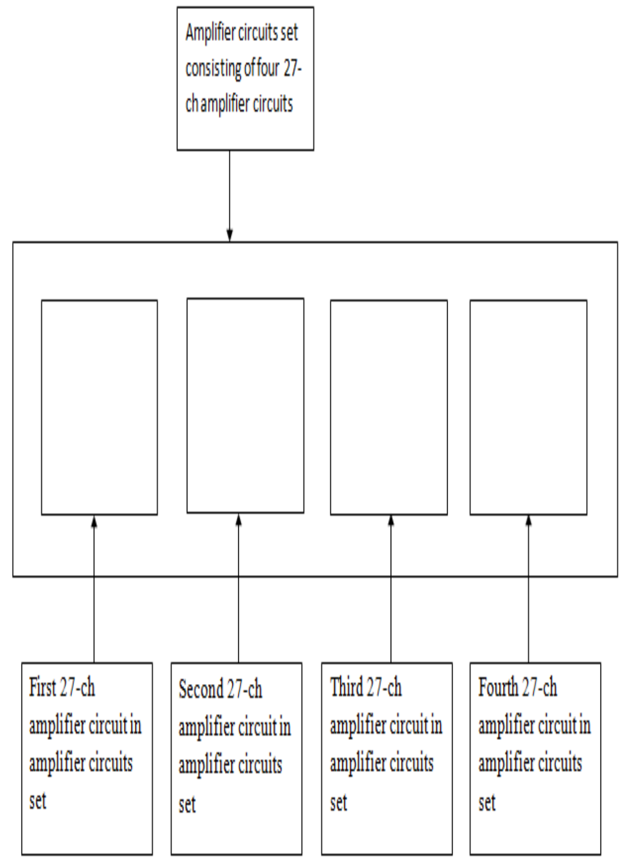

Fig.11. Set of amplifier circuits consisting of four 27-ch amplifier circuits.

7. SYSTEM PROCESS

Steps involved at the user side:

1. Start the CPU/Switch on the CPU.
2. Switch on the video projector.
3. Switch on the holographic projector.
4. Switch on the system.

The virtual screen is displayed inside AIHDT box. User has to wear IR-LED ring as described in the section 2.2. The IR camera tracks the exact position where the user is touching through the calculations. These calculations will be done by a software/program installed in the computer. Other programs will be installed in the CPU which takes care of the works that has to be done according to the user input (example: Touch on 'my computer' to open 'my computer'; Clicking on the close button on the window to make a window etc.). We can make use of virtual keyboard software which should be preinstalled in the CPU. The virtual keyboard will be displayed on the virtual screen inside AIHDT box. We can use forefinger with IR-LED ring to type something on the screen. All these processing will be taken care of another software system.

Software will be installed in the CPU which contains a pre calculated look up table of phase delays and amplitudes. They are downloaded to the slaves. The position of the user finger is captured and the position of the finger is calculated. According to this position, the target position of the focal point of the ultrasound wave will be set. This will be sent as the command from CPU, the corresponding slave drive the ultrasound transducers at the corresponding phases and amplitudes, based on the table.

7.1 Pressure created at the point of touch

When the user touches the virtual screen, appeared inside AIHDT box for a purpose (ex: closing window, opening a folder etc.) at that time pressure will be exerted on the user's finger.

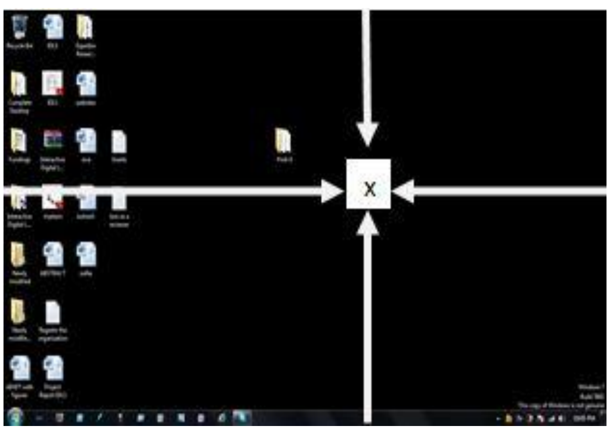

Fig.12. Imagination of virtual screen with 'X' as point of touch inside AIHDT Box.

Think the user touch the virtual screen at a point 'X' as shown in figure 12. With the help of IR LED, IR Pass filter and software installed on the corresponding computer to calculate position within the area, all together helps in calculating exact position of the user finger. The AIHDT Box inserts pressure on the user's forefinger (which is at point 'X') from all the 4 sides (That is top, bottom, left and right sides). This pressure helps in bringing haptic sensation same as that of user touching a real screen. The virtual screen seems like real after operating it with forefinger for some purpose. In this system multiple point of touch is also possible but not recommended. Side by side point of touch may lead to abstraction of one to another.

8. DISCUSSIONS

8.1 Prefer to use forefinger for touching the AIHDT display

In human body skin sensation is through mechanoreceptors. A mechanoreceptor [15] is a sensory receptor (Sensory nerve ending that responds to a stimulus in the internal or external environment of an organism) that responds to mechanical pressure or distortion. There are main 4 types in the glabrous skin (Skin without heir) of humans:

1) Pacinian corpuscles (Lamellar corpuscles) **-** FA 2 (Fast Adapters 2) [13]

2) Meissner's corpuscles (Tactile corpuscles) – FA 1 (Fast Adapters 1) [13]

3) Merkel's discs – SA 1 (Slow Adapting 1) [13]

4) Ruffini corpuscles – SA 2 (Slow Adapting 2) [13]

It is found that innervations (Distribution across the body or particular area) density of Meissner's corpuscles (These are a type of nerve endings in the skin that is responsible for sensitivity of light touch, they have highest sensitivity when sensing vibrations lower than 50Hertz.), Merkel's discs and pacinian corpuscles are more in the fore finger than at any other region on the palm it also given in [14].

Innervation refers to distribution of nerves here. It is clear from research paper [14], using fore finger results in more quick and responsive touch feeling in case of AIHDT.

8.2 Tactile sensation around finger tip

Chances are there that the user feels tactile sensation around his finger rather than on his fingertip. Some improvements have to be made in the system so that tactile sensation will be on fingertip.

9. CONCLUSION

In this paper, I present AIHDT which gives a new idea of touch screens in air. The proposed display technology has several applications and advantages some of them are listed below:

1. Touch screens in air.
2. Human computer interaction in free space.
3. Virtual displays with real time touch feelings.
4. Tele existence through touching objects virtually (Tele touch).
5. Interactive displays in air with real time touch experience.
6. Education through touching virtual objects for blind using AIHDT box & arrangements.
7. AIHDT can be used for interactive learning purposes etc.
8. Mixed reality with haptic sensation using AIHDT box & arrangements.
9. Tactile virtual reality.

AIHDTs may change the world of display technologies after its implementation and more research & development.

ACKNOWLEDGEMENT

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