DeskTop: A Design Guideline to Creating a Multi-touch Desk Prototype

Jerome McClendon[1], Joshua Ekandem[1], Austen Hayes[1], Amy Ulinski[2], and Larry F. Hodges[1]

[1] Clemson University, School of Computing, Clemson, SC 29634-0974
{jmcclen,jekande,ahayes,lfh}@clemson.edu
[2] University of Wyoming, Department of Computer Science, Laramie, WY, 82071
aulinski@uwyo.edu

Abstract. In many multi-touch tables, a projector is used to project an image onto the surface and a camera is used to detect user touches. The optical paths for both the camera and projector limits the physical design of multi-touch tables. Our research focuses on the creation of a multi-touch desk that improves on the physical design of past multi-touch tables by using a combination of multiple cameras and a liquid crystal display to create a physical design that is ergonomic, mobile, collaborative/scalable and simplistic in design.

Keywords: Multi-touch tables , Ergonomic design.

1 Introduction and Motivation

The idea of tabletop computing has been around since the late 80's with Myron Krueger's invention of the Video Desk [14]. Revolutionary for its time, users could use their arms, hands, and fingers as input [14]. Whereas most systems during that time required users to input information using a keyboard, the Video Desk used a video camera stationed above the surface to capture the user's motions [14]. With Kruegar's system, users were allowed to draw and manipulate objects using a set of gestures similar to what we see in modern day multi-touch systems. Unlike modern day touch screen systems the Video Desk did not allow direct manipulation of objects [14]. The user did not directly touch the object they were to manipulate; instead, they looked at monitors positioned around the table for output while using the surface as input.

In 1991, Pierre Wellner expanded on the ideas of Kruegar, with the creation of his Digital Desk system. Unlike the Video Desk, monitors no longer sat around the table surface. The output was projected onto the surface of the table from a projector mounted above, allowing users to directly touch and manipulate objects appearing on the table, creating one of the first true multi-touch tables [19].

More research was done in the 80's and the 90's on multi-touch tables, but not until the 2000's did a significant surge in multi-touch table hardware and software

M.M. Robertson (Ed.): Ergonomics and Health Aspects, HCII 2011, LNCS 6779, pp. 209–217, 2011.

emerge. The creation of devices like the Diamond Touch, Perspective Pixel, and Microsoft Surface exemplify this trend [7]. While these current systems have made significant progress in the area of finger/object tracking and collaboration, their physical design has kept them from having a significant impact on the consumer market [10], [8], [16] .

The physical design of many multi-touch tables requires that users stand beside the system, causing fatigue in the user's lower extremities. According to the National Health and Nutrition Examination Survey 2009-2010, approximately 18% of Americans 18 or older express that they experience physical discomfort when standing for two hours or more [3]. In respect to the physical design, this observation elucidates the need for a better approach, which will allow the user to sit in a comfortable position while using the table. Achieving such a design is complicated due to the systems heavy dependence on two hardware components, the projector and the camera.

Multi-touch tables use a projector to project an image onto the table surface and a camera to detect when a user has touched the surface [17]. The length of the optical path, i.e., the distance needed between the table surface and the lenses of both the projector and camera, determines the size of the display [7], [8]. One implication of this design is that it requires users to stand beside a large box to use the display.

Systems, such as the Microsoft Surface, use a short throw projector and multiple cameras to reduce the optical path of the camera and projector. This approach reduces the overall height of the table allowing users to sit down [1]. It also causes the users to bend over the table and sit awkwardly because of the bulky box needed to store the system components [9]. Research conducted in the area of occupational ergonomics recommends that, "The user work level should be at a height where the body takes up a natural posture, slightly inclined forwards, with the eyes at the best viewing distance from the work" [13]. Figure 1 illustrates the ideal sitting posture compared to, Figure 2 where the user is forced to lean more than "slightly forward" in order to use the multi-touch surface. This is because the height of the table along with the bulkiness of the box stops users from sitting with their legs underneath the system causing an unnatural posture for the user. Mapping the user's posture in Figure 2 to the Range of Motion Diagram in Figure 3, the user's posture would be placed in the *red zone*—meaning they are putting great strain on their muscles and joints [5].

One possible solution is to remove the box and use a front projected system where the camera and projector are positioned above the surface, thus allowing the user to sit at a regular table. The drawbacks to systems like these are that they are immobile. If the user wants to move the table then they would also have to reposition the projector and camera [4].

Our goal was to create a physical design that has a form factor that can be moved as easily as a regular table or desk and that allows a user to sit comfortably while interacting and collaborating with others on the surface of the table. In this paper, we will explain our design objectives through the prototyping of DeskTop, our mutli-touch desk system.

Fig. 1. Ideal posture

Fig. 2. User of multi-touch table

Fig. 3. Range of Motion [2]

2 Background

DeskTop is a prototype of a multi-touch desk system that is meant to improve on the physical design of multi-touch tables. In order to improve upon the physical design of previous multi-touch tables our design required that we either replaced the projector and camera, or that we shortened the optical path of both the projector and camera. Initially this led us to examine touch screen approaches that do not use cameras and projectors such as resistive and capacitive touch screens. Most resistive touch screens are single touch devices. Capacitive touch screens allow for a limited number of simultaneous touches but are not considered true multi-touch displays [12].

Techniques that create true multi-touch displays rely on optical techniques such as frustrated total internal reflection (FTIR), diffused illumination (DI), and diffused surface illumination (DSI). These optical techniques consist of two main components, infrared emitters and infrared detectors, usually found in the form of infrared light emitting diodes (LEDs) and infrared cameras. When users touch the display surface, infrared light is produced and can be tracked by the infrared detector allowing for n amount of touches, where n is not bounded, so that the system can track as many fingers/objects as can fit on the screen.

Optical based systems that use infrared cameras must include enough space in their design to satisfy the length requirements needed for the optical path of the camera. This causes them to have a large physical form factor [7], [8]. An exception to this is Fiberboard, which uses traditional camera based techniques accompanied with an array of optical fibers to create a device much smaller than other camera based displays. The developers of this system used a bundle of optical array fibers to channel infrared light created from the user(s) touching the top of the surface to the camera. The camera is now free to be placed anywhere, thus reducing the depth of the desk and creating a thin form factor [12].

Thinsight and FlatIr, like Fiberboard, are also a set of new emerging technologies focusing on the advancement of thin displays that can be used for table top systems. Using a grid of infrared emitters and detectors Thinsight is a true multi-touch display capable of detecting multiple touches while being thin enough to fit behind a LCD screen [7].

Similar to Thinsight, FlatIr also uses a grid of infrared sensors positioned behind an LCD screen. With infrared light placed in front of the screen and the sensing grid positioned behind the screen, the user's touch triggers the same optical effect found in FTIR that can be detected and tracked [8].

3 Design Considerations

Our design choices were guided by four essential factors:

- ergonomics
- degree of mobility
- collaboration /scalability
- design simplicity

In the following sections, we will discuss the each of these factors and the role that they played in the creation of DeskTop.

3.1 Ergonomics

In section 1, we identified two problems currently found in multi-touch tables: users working from an unnatural posture, and systems with a very low degree of mobility. This identification led us to review the design of office furniture for the workplace where people are often required to sit at their workstations for long periods of time. Closely following the design guidelines described in *Ergonomics and Design A Reference Guide Book*, we looked at the following three design specifications when creating our prototype: height for thighs, depth for knees, and depth at foot level [5]. The first specification, height for thighs, should be at least 26.8" high (see Table 1). Depth for knees should be no less than 17". Depth at foot level should be no less than 23.5". Table 1 summarizes these specifications.

Table 1. BIFMA guidelines for desks and worksurfaces [2][5]. Measurements can be nvisualized using Figure 4.

		Letter	Specifications	
			Measurement	BIFMA Guideline
Seated Work	Height for Thighs	A	Thigh clearance + Shoe allowance + Popliteal height	At least 26.8"
	Depth for Knees	B	Buttock-knee length – Abdominal extension depth	No less than 17"
	Width for Thighs	Not Shown	Hip breadth sitting + Movement allowance + Clothing allowance	No less than 19.8"
	Height at Foot Level	C	Lateral malleolus height + Show allowance	4.2"
	Depth at Foot Level	D	Buttock-popliteal length + Foot length – Abdominal extension depth	No less than 23.5"

Fig. 4. Sitting at Desk

3.2 Mobility

With current multi-touch tables there is a design trade-off between mobility and user comfort. Rear projected systems like the Microsoft Surface come in one single unit allowing for the placement of casters on the bottom of the system for ease of mobility. However, the single unit design contributes to user fatigue and poor posture because the user is leaning over a large box [8]. Systems where the camera and projector are mounted above the display surface allow the user to sit at the table as they would at a regular desk since no components are housed below the surface. However, this design is not very compact and when the system is moved, the projector and camera must also move as a unit or be recalibrated. Our prototype aims to create a self-contained unit that allows a user to sit comfortably and that has a compact and mobile design.

3.3 Collaboration and Scalability

By scalability we mean the design should support the transition between personal and group work so that users can work individually and then come together to collaborate [9], [18]. By collaboration we mean that multiple users can interact with the surface at the same time. Collaboration requires multi-touch capability plus a large touch surface [9]. With collaboration tasks ranging from multiple users browsing and sharing photos to playing musical instruments together, it was important that our design considers the size of the touch surface so that we can have a large number of touches on the screen at the same time. However, increasing the touch surface will also increase the depth of the system, because a longer optical path is required for the projector and camera.

3.4 Simplicity of Design

We wanted to create a design that is straight-forward and can be reproduced by others. Technologies such as FlatIR and ThinSight show a lot of promise in that they support true multi-touch capabilities, as well as being thin and mobile, but they are based on complex custom electronic sensor arrays for which very little technical information is easily accessible. While the construction of Fiberboard is straightforward, specialized software is required to make the system work. Although camera and projector systems have the problem of long optical paths that often result in bulky form factors, this approach does allow for simple designs from inexpensive commercial components [8]. In the end we concluded that although several technologies were viable, an optical approach was the least complex design that allowed us to meet our other goals.

4 Design of DeskTop

The critical step in creating DeskTop was to develop a method that significantly reduced the overall optical path needed for both image generation and touch detection on the display surface. Doing this would allow us to create a thin display cabinet incorporated into a desk design that meets appropriate ergonomic specifications. Our first step was to choose the appropriate technology for touch detection.

As mentioned earlier there are various types of technology for detecting touches, our design decisions were based on ergonomics, degree of mobility, collaboration/ scalability, and design simplicity. Based on these factors we decided to go with a traditional optical based system allowing us to incorporate techniques such as FTIR, DI and DSI. These techniques are well researched and commonly used within the multi-touch community allowing us to concentrate on the physical design of the system [8], [6], [17].

When choosing which optical technique we planned on implementing, we weighed the advantages and disadvantages of each technique. In DI systems the infrared emitters are placed above or below the screen. If the infrared emitters are placed below the screen we reduce the leg room (*height for thighs*) needed for a comfortable sitting position at the desk. If the infrared emitters are placed above the screen we increase the size and reduce the mobility of the system.

In FTIR and DSI the infrared emitters are placed around the edges of the touch surface resulting in a compact design for illuminating the surface of the table. Of these two choices both options allow us to completely remove the projector from the design, eliminating the optical path required to project an image. We chose to use DSI because it also allowed us the option of recognizing fiducial markers. We replaced the projector with a 23 (diagonal) inch LCD flat screen. Placed above the LCD is an acrylic sheet (ACRYLITE® Endlighten) that serves as our touch surface. The acrylic sheet evenly distributes the infrared light produced from strips of infrared light emitting diodes that have been stationed around the perimeter of the touch surface. When a user touches the surface the infrared light is scattered, creating a "blob" that can be tracked by a camera from below [17].

Building on previous work done by Microsoft and others we were also able to significantly reduce the length of the optical path required for the camera by distributing the viewing of the touch surface among multiple cameras instead of using a single camera [1]. Using four cameras, we split our touch surface into four 10 x 5.5 inch quadrants. Each camera is positioned eight inches away from the back edge of each quadrant, four inches away from the top of the surface and centered with respect to the back edge of the quadrant with the camera lens pointing at a 105° angle with respect to the bottom surface (Figure 5 camera position). This positioning allows each camera to see one full quadrant. Then, using a custom image stitching algorithm, we were able to take the four images grabbed by the cameras and stitch them together to form one large image of the desk that could be passed to our image processing module for finger detection and tracking.

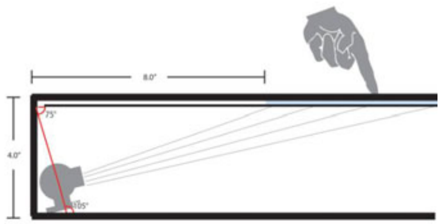

Fig. 5. Camera position

Before detecting and tracking the fingers we must first correct the barrel distortion created from the wide angle lenses attached to the cameras. This can be done using the un-distort methods in the image processing library Open Computer Vision [15], [11]. Once we have fixed the barrel distortion we then pass the image to different image filters, where we adjust the image properties to make the blobs more visible for detection and tracking [15].

Our final prototype of DeskTop, shown in Figure 6, is a multi-touch desk that permits a user to sit in a comfortable position, and supports easy mobility. It also facilitates collaboration and scalability between multiple users by allowing adjacent desks to communicate with each other so that they function as a single large desk.

Fig. 6. Final Design

Acknowledgments. This research was supported, in part, by NSF Research Experiences for Undergraduates (REU) Site Grant CNS-0850695.

References

1. Anderson, N.: What Lurks Below Microsoft's Surface? A Brief Q&A with Microsoft, http://arstechnica.com/gadgets/news/2007/05/what-lurks-below-microsofts-surface-a-qa-with-microsoft.ars
2. BIFMA International, Ergonomics Guidelines for VDT (Video Display Terminal) Furniture Used in Office Workspaces. Document G1-2002 (2002)
3. Center for Disease Control: National Health and Nutrition Examination Survey, http://www.cdc.gov/nchs/nhanes/nhanes2009-2010/questexam09_10.htm
4. Dietz, P., Leigh, D.: DiamondTouch: a multi-user touch technology. In: Proceedings of the 14th Annual ACM Symposium on User Interface Software and Technology, November 11-14, pp. 219–226. ACM Press, New York (2001)
5. Ergonomics and Design A Reference Guide Book, http://www.allsteeloffice.com//NR/rdonlyres/3B6AC489-FC78-4B78-895A-0A5D8A9E888A/0/ErgoHandbook.pdf
6. Han, J.: Low-Cost Multi-Touch Sensing through Frustrated Total Internal Reflection. In: Proceedings from UIST 2005: User Interface Software and Technology, pp. 115–118 (2005)
7. Hodges, S., Shahram, I., Butler, A., Rrustemi, A., Buxton, B.: ThinSight: Versatile Multi-Touch Sensing for Thin Form-Factor Displays. In: Proceedings of the 20th Annual Symposium on User Interface Software and Technology, Newport, Rhode Island, USA, October 7-10, pp. 259–268. ACM Press, New York (2007)

8. Hofer, R., Naeff, D., Kunz, A.: FLATIR: FTIR Multi-Touch Detection on a Discrete Distributed Sensor Array. In: Proceedings of the 3rd International Conference on Tangible and Embedded Interaction, Cambridge, United Kingdom, February 16-18 (2009)
9. Hunter, S.: MemTable – Contextual Memory in Group Workspaces Media Arts and Sciences Master's Thesis, Massachusetts Institute of Technology (2009)
10. Inkpen, K., Hancock, M., Mandryk, R., Scott, S.: Collaboration Around a Tabletop Display: Supporting Interpersonal Interactions. SFU Technical Report (2001)
11. Intel: Open source computer vision library: Reference manual, `http://www.intel.com/technology/computing/opencv/`
12. Jackson, D., Bartindale, T., Olivier, P.: FiberBoard: compact multi-touch display using channeled light. In: Proceedings of the ACM International Conference on Interactive Tabletops and Surfaces, pp. 25–28. ACM, New York (2009)
13. Kroemer, K., Grandjean, E.: Fitting the Task to the Human: a Textbook of Occupational Ergonomics, 5th edn. Taylor & Francis, London (1997); Krueger, M., Gionfriddo, T., Hinrichsen, K.: VIDEOPLACE:–An Artificial Reality. In: Proceedings of the SIGCHI conference on Human factors in computing systems, CHI 1985, pp. 35-40. ACM, New York (1985)
14. Muller, L.: Multi-touch displays: design, applications and performance evaluation, MSc thesis, University of Amsterdam, Amsterdam, Netherlands (2008)
15. Murph, D.: Touchy Remix is the Multitouch Table You Could Actually Use (2010), `http://www.engadget.com/2010/02/10/touchy-remix-is-the-multitouch-table-you-could-actually-use/` (last accessed October 12, 2010)
16. NUI Group Authors: Multitouch Technologies. 1st edn. NUI Group (2009)
17. Scott, S., Grant, K., Mandryk, R.: System Guidelines for Co-located, Collaborative Work on a Tabletop Display. In: Proceedings of European Conference Computer-Supported Cooperative Work, Helsinki, Finland, pp. 159–178 (September 2003)
18. Wellner, P.: Interacting with paper on the DigitalDesk. Communications of the ACM 36(7), 87–96 (1993)