Design Challenges in Creating a High Resolution LCD-based Multi-Touch Display

Abstract

Museums and researchers both have a need to display and interact with high-resolution data. There is great interest in using multi-touch tables, most of which are projector-based. However LCD-displays are becoming an attractive alternative to projectors because of their low cost of maintenance and image clarity. While touch screen overlays have been available for LCD panels for some time, these overlays were only able to register at most two touches. In contrast our project's goal was to create a touch table that is both LCD-based and can register an arbitrary number touches. This paper will provide the technical details of how to build such displays, one of which was HD (1080p) resolution while the other was 4-Megapixel resolution. This paper will also discuss how we plan to extend this technique to develop a multi-touch autostereoscopic display.

1. Introduction

Researchers have a growing need to view high-resolution data at its full native resolution. Displaying these high-resolution datasets on multi-touch displays is becoming increasingly popular as this creates a collaborative environment where users are able to interact with the data in an intuitive manner. Currently there are approaches to meet this need by using projector-based tables and LCD touch screen overlays, both of which have limitations. Projectors are costly to maintain, and touch overlays are limited to registering two touches simultaneously. Our goal was to create an LCD-based multi-touch table that overcame these limitations, creating a powerful tool for the research community. This paper will present a detailed description of our design process and the critical challenges the project needed to overcome. The paper will discuss challenges in building a 30-inch and a 52-inch LCD-based multi-touch table, as well as challenges faced when deploying these devices in public venues. In addition we will discuss how this design could be extended to create an autostereoscopic multi-touch table.

2. Background

There are two main categories of multi-touch tables: projector based tables, and LCD touch overlay tables.

The most famous projector based multi-touch table is the Microsoft Surface. The Surface uses an IR illuminator to illuminate the outside surface of the table with light. The IR light operates at 850 nm, matching a pass filters on the cameras. By doing this, the Surface is able to track fingers in non-visible light, which helps the cameras to determine light coming from the IR illuminator and other sources. The tracking method used by the surface is called Diffused Illumination (DI). When users put their hands over the surface, their hands are illuminated by IR light. This

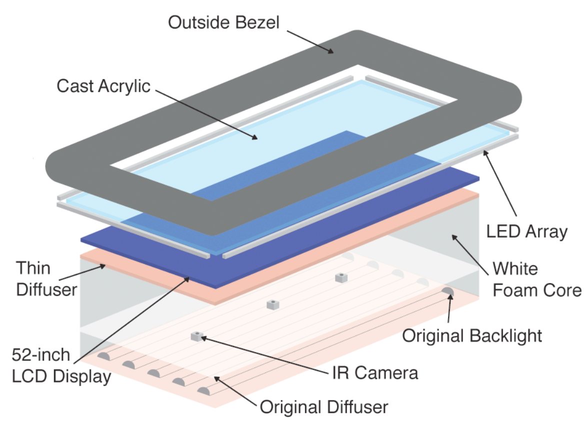

Figure 1: Diagram of a LCD-based multi-touch table

light is reflected into the table below, allowing multiple cameras below to capture images of the illuminated hands. These images are passed through an image-processing pipeline where the positions of the fingers are determined. The display uses a short throw projector that operates at 1280x960 resolution. The projection screen is a proprietary solution that is low reflection and smooth to the touch.

There are a number of issues in deploying this design to researchers and museums, who require a device that is extremely robust and requires little to no attention. Maintaining a projector becomes costly due to the bulb life. An average projector bulb lasts two thousand hours whereas an LCD lasts fifty thousand hours on average. As projectors become larger, the need to dissipate heat and the noise from the fans grows. In addition, most projectors need a throw distance larger than the size of a standard table. A mirror can be used to compensate, but then precise calibration becomes an issue. Our solution leverages the benefits of similar multi-touch tracking techniques, but does not incur the limitations imposed by projectors.

Touch overlays attached to an LCD screen are also a popular solution to create a touch display. Two common technologies are Resistive technology and Digital Vision Touch Technology (DViT). Resistive Technology works by combining a flexible top layer with a hard bottom layer. On the back of the top layer, and the front of the bottom layer, there is a resistive film covering. When the screen is touched the two layers contact each other sending a signal that indicates a touch. DViT works by hiding cameras inside the bezel of the overlay. These cameras can detect touches, and software is used to map blobs seen by the cameras to the screen coordinates. Touch overlays are limited to two fingers. Unfortunately, this solution limits the number of touches that can be simultaneously registered to two. This severely limits the collaborative nature of the multi-touch table.

By identifying the challenges of using projectors or touch overlays, we have been able to create a robust LCD-based multi-touch table that addresses these problems. By combining the tracking methods of projector-based tables and the reliability and low maintenance of LCD's, this new table creates a reliable multi-touch environment that meets the needs of museums and researchers alike.

The MultiTouch Cell [6] is a commercial LCD-based multi-touch solution. This proprietary multi-touch display shares many of our design's characteristics, supporting a high-resolution LCD display with IR tracking. We choose not to use this product because our goal eventual was to create an autostereoscopic multi-touch LCD-based table display

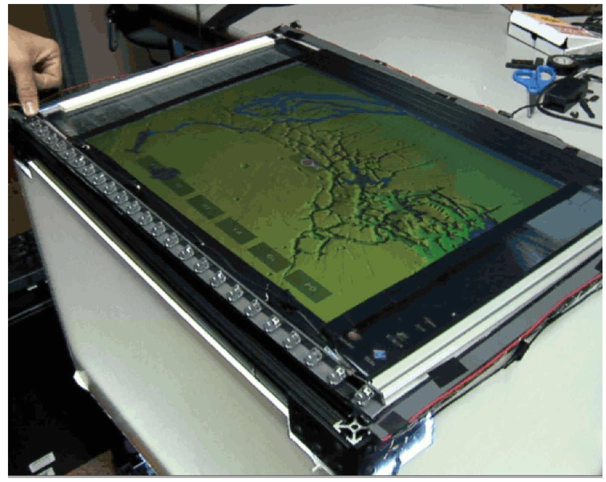

Figure 2: 30-inch multi-touch table. The display bottom LED array is raised so show large LED's.

Figure 3: 52-inch multi-touch table. Taken at SC '08

which requires layering two LCD displays on top of each other. This paper will discuss the process of building such a multi-touch LCD-based table.

3. Goal

The goal of our project is to create a tool for researchers to easily interact with scientific visualizations in an intuitive way that aids scientific discovery. This was accomplished by merging popular multi-touch tracking techniques with the benefits of a LCD display. The environment that is created is high resolution and supports multiple people interacting with the table simultaneously. The use of an LCD has the following advantages: high-resolution, high contrast, clear images, low heat, low maintenance cost, and shallow depth.

Through the use of LCD screens we are able to implement the Dynallax [4] approach to create a 3-D table display that allows viewers to see 3D without the need to wear special glasses. The project has two phases, first to build a functional LCD based multi-touch table, and second, to add a second LCD to create an autostereoscopic display. This paper focuses on the design challenges in the first phase - creating a LCD based multi-touch display.

The first phase uses the design shown in Figure 1. The touch screen is built by placing a piece of acrylic on top of a LCD screen. Surrounding the acrylic are four arrays of IR LED's. This top layer uses Frustrated Total Internal Reflection (FTIR) for finger tracking [1]. Under the acrylic we place the LCD screen. Under the LCD we need to have a diffuser. There is some separation between the LCD and the backlight to allow room for the IR cameras. Under the cameras is the original diffuser that came with the LCD. The backlight for the LCD is placed at the bottom. All of these layers are enclosed in a box that is secure enough to endure the stresses of a museum floor. This design is scalable as new high-resolution and large displays become available.

To create an autostereoscopic display we are using an approach called Dynallax. Dynallax is based on parallax barrier technology found in Varrier [5]. However, the Dynallax replaces the traditional static linescreen printed on a pane of glass with an LCD. This results in two LCD's on top of each other. In a standard Varrier approach, the static linescreen restricts the entire display to either a 2-D or 3-D image. The introduction of the front LCD allows the linescreen to be rendered dynamically. This allows users to have areas of 3-D or 2-D content on the display. This greatly enhances a user's experience by providing various simultaneous data visualizations. Complex visualizations can be viewed in 3-D, while simultaneously viewing 2-D descriptive text on the same screen. In addition, Dynallax has the capability of rendering to multiple perspectives. This further enables collaborative interaction by allowing multiple viewers to see a reasonable 3D image at the same time.

4. Our Process

We make use of Jeff Han's FTIR [1] approach and how it is applied to multi-touch tables. FTIR works by directing infrared light into a piece of acrylic. This light is trapped inside the surface and is internally reflected. When a finger is placed on the acrylic surface the refractive index changes and the IR light is reflected off the finger. FTIR is attractive to use with LCD's because IR light is invisible and is able to pass through a LCD screens, it does this without interrupting normal viewing of the display. Also a touch is only detected when someone actually touches the display. This helps minimize accidental touches.

The OptiTrack Slim:v100 cameras from Natural Point were used in this project. They support 640x480 resolution, 100 FPS, and hardware based image-processing modes including grayscale and exposure control. This camera already included an IR pass filter that operated at 800 nm. These cameras were chosen because of their high performance and compatibility with IR tracking.

The project started with an initial test of the FTIR setup. Arrays of LED's were positioned close to a piece of acrylic, with the camera positioned below. We used 870nm wavelength LED's with 26-degree viewing angle. The LED's were supplied with 100 mA and a 1.35V drop. When a person touched the acrylic, IR light was reflected down into the camera, confirming that FTIR would work in this configuration.

4.1. Software

The project required tracking software that supported the OptiTrack API [8], multiple cameras, and FTIR tracking. At the time, the most popular multi-touch tracking software was Touchlib [3]. Unfortunately, Touchlib does not support multiple cameras. Therefore, we choose to design and implement new tracking software that supported the use of multiple tracking cameras based on the OpenCV [7] library.

The image-processing pipeline starts by capturing a grayscale image from the camera via the OptiTrack API. A series of filters are applied: first the current image is subtracted from the static background image. The image is then converted from grayscale to a binary by applying a threshold function. After that, a 3x3 median filter is applied to reduce the level of noise in the image. Following this is a connected components analysis revealing finger blobs. The blobs are then filtered by their size discarding blobs that do not fall into a configurable size range. Finally, the location of blobs is mapped from camera to screen coordinates using a calibration grid. Due to the close proximity of the screen to the wide-angle lenses used, the images had a large amount of barrel distortion. To correct this the calibration we employed a grid of 8 x 16 points to calibrate the 52-inch display.

To take advantage of multi-core CPUs, the tracker implemented a separate processing pipeline for each camera. These pipelines run in parallel alleviating the performance overhead incurred by the use of multiple cameras.

The tracker implements a client-server architecture where multiple clients can connect to the tracker at the same time. Client applications connect to the tracker, and receive the location and movement of fingers over the network. This architecture allows the tracking and visualization applications to be split over multiple machines.

4.2. 30-inch multi-touch display

To build the display a Dell 3007WFPt 30-inch 4-Megapixel display was removed from its stand and all of the screws on the back panel and the front bezel were removed. Once the outer casing was off, the LCD was separated from the backlight by unplugging the cable bundle.

The backlight was then unplugged from the component boards. With the LCD, backlight and the components separated, the components were mounted to a table, made out of 80/20, on the display-top side in a vertical orientation close to the top. The LCD was placed into the table at a horizontal orientation allowing a 90-degree angle between the LCD and the components. A mount for the backlight was created 20 inches below the LCD.

In order to connect the backlight, the small cable bundle that connected the backlight to the component boards was extended. The 14-wire bundle and the 20 inches of speaker wire were spliced together. Then the camera was placed in the center of the backlight. The table was finished by adding the acrylic with two arrays of 24 IR LED's on the two long sides and enclosing the table with white foam core.

One-quarter inch acrylic, cut at a 45-degree angle, was used on the two long sides. The acrylic was cut at an angle because the FTIR signal becomes stronger if the LED light enters at an angle. This completed the initial design of the 30-inch LCD multi-touch table.

When the table was turned on it was discovered that increasing the exposure level of the camera would dramatically increase camera sensitivity.

Since the LCD is transparent, a diffuser was needed directly below the screen to block the interior view of the box. While working with the Science Museum of Minnesota we experimented with a thinner diffuser and found that photography studio light diffusing film, GAM's Light GamFrost #15, was thin enough to let the IR light through but still diffused enough light to hide the interior of the box. To mount the diffuser the

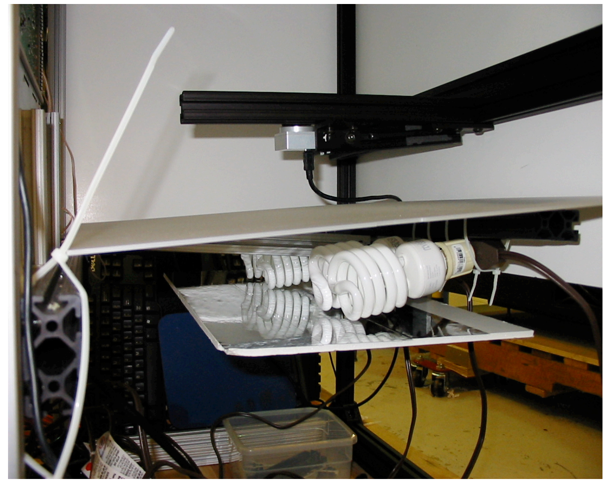

Figure 4: Layering of components in a 30-inch multi-touch table. From the top: camera, diffuser, CF-bulbs, reflective bottom.

museum helped build an aluminum frame. The frame stretched the diffuser across the underside of the LCD eliminating any wrinkles and prevented it from drooping in the center. Larger LED's were added to increase the signal strength. The larger LED's were 850nm wavelength with 30-degree viewing angle. The LED's were supplied with 140 mA and a 1.4V~1.5V drop.

The IR light from the blobs was bright enough. However, when the original backlight was turned on, it caused this signal to be washed out, as the backlight produced a significant amount of IR light. Alternate light sources were researched and it was discovered that by using CF bulbs the IR light inside the box could be reduced. Eight 26 Watt – Stark White FE-IIS-26W/50k from Longstar Lighting created illumination equivalent to the original backlight.

It is important to note that 50k color temperature was used. This gives a florescent white color. Other bulbs can be orange, blue, or pure white, however it was felt that the 50k color produces the closest light color to the original backlight. We built an array of CF bulbs using extension cords and bulb sockets that could plug into a standard AC outlet, which was mounted below the original diffuser. Below the CF bulbs a board was added with highly reflective aluminum tape to close out the bottom and reflect visible light back up.

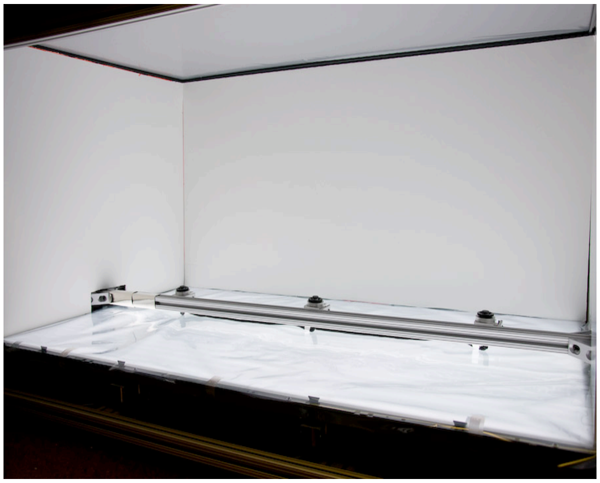

Figure 5: Layering of components in a 52-inch multi-touch table. From the top: thin diffuser, foam core walls, cameras, IR cut filter, original LCD backlight.

While working with the Science Museum of Minnesota, this table was tested on the museum floor. We noticed that people would bump and kick the table causing the outer walls to shake. The cameras would see the walls shake and generate tracking errors. In Figure 4 it is possible to see the outer walls that users would shake and disrupt tracking. To solve this an enclosure was built for the table. The initial enclosure inspired future development in the larger table.

These were the challenges that were overcome in creating a 30-inch LCD multi-touch table. Larger LED's were used to increase finger blob signal strength. A thinner diffuser was added to allow the IR blobs to pass through while still hiding the interior of the table. A custom backlight was added to reduce the IR light inside the table. With these modifications we had a fully functional prototype of a 30-inch 4k LCD based multi-touch table. This led to the second phase of the project where a larger 52-inch HD version of the table was built.

4.3. 52-inch multi-touch display

4.3.1. Extension of the backlight. During the first phase of the project, the major focus was proving that it would be possible to create a LCD based multi-touch table with a high resolution 4-Megapixel display. We used a Sharp Aquos LC-52D64U HD resolution LCD TV for the larger table, but the same principles would apply for both designs. However, a number of new challenges had to be overcome with the larger display. First was the extra IR light that was emitted by the

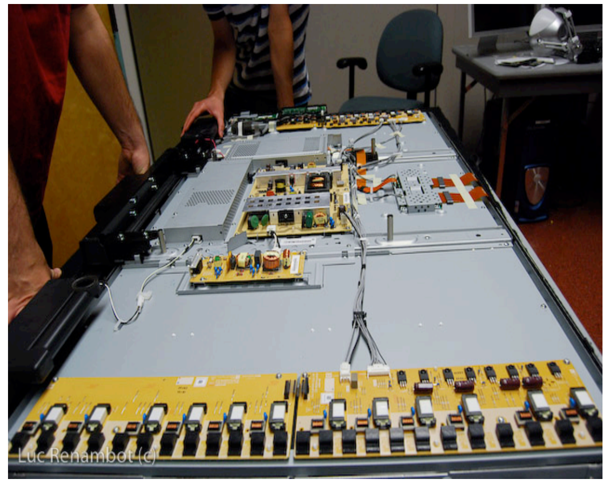

Figure 6: Backside of a Sharp Aquos 52-inch LCD TV.

backlight. Using a custom light source originally solved this issue in the 30-inch table. However, using CF in the 52-inch required a large number of bulbs, increasing the potential for heat buildup and bulb failure. Another challenge stems from the larger surface area of the 52-inch display. In the 30-inch display, only one camera was needed. The 52-inch required 3 cameras to cover the entire surface. Finally, the issue of finger dragging had to be addressed to make the table more useable. Dragging a finger across the surface created a lot of friction between the finger and surface. This caused issues with tracking and created an unfriendly user experience, when compared to other multi-touch devices, where dragging is a major component of the functionality.

To start the process the base of the TV was removed, and the back cover was removed exposing the component boards. Two methods of separating the backlight from the LCD were quickly identified.

First we identified two ribbon cables connecting the LCD to the electronic components that needed to extend to create space for the cameras. This was the most promising because nothing needed to be modified. This method was chosen for the project.

In another method, the backlight is left attached, but is oriented vertically at a 90-degree angle to the LCD screen. This was by far the easiest, but increased the height of the table to at least 27-inches, based on the height of the LCD backlight. Also this orientation would require a mirror positioned inside at a 45-degree angle to reflect the light back into the display.

4.3.2. Disassembly. To continue the disassembly, the front bezel was removed and the screws connecting the LCD to the backlight were removed. Two ribbon cables that connect the backlight to the LCD were unplugged and the LCD and the backlight were separated. The LCD was placed on a table, the ribbon cables were reconnected and the display was turned on. This was used for the initial testing while waiting for Cordova Printed Circuits too produce two extended ribbon cables. Next a frame from 80/20 was created. While 80/20 is more expensive than other construction solutions, the entire frame could be created in AutoCAD making it easily reproducible. Strength was added to address the concerns of creating a standalone exhibit on a museum floor. The design enclosed all of the multi-touch table components inside a 30x50x24 inch box, and then legs were added to the table design. This allows a modular design where we were able to orientate the table horizontal, 45-degree, or vertical depending on the need. The top bezel was extended two inches on all sides to reduce bumping that causes error in the tracking on he 30" prototype. The extended bezel can be seen in Figure 3. By extending the bezel people could rest against the bezel rather than the table itself, plus it allowed two more inches on the floor to reduce kicking. Another goal was to make the table easy to ship and deploy for conferences. This required us to keep in consideration movement during shipping, standard door sizes, and minimizing the assembly required during unpacking.

4.3.3. Increasing IR strength. It was now time to integrate the multi-touch components into the design. We redesigned our circuits to be on a PBC card rather than physically wired together. The total design required 28 PCB cards with 5 LED's each. ExpressPCB printed the circuits. The use of PCB boards minimized the messy wires and potential for failure. From our experience from the prototype we knew that thicker acrylic might be better for a museum floor design so three quarters inch thick acrylic was used for the larger design. Thicker acrylic ensured that there would be no bending in the middle of the display and it would be less likely that the LCD screen will be damaged by excessive pressure. Cast acrylic was chosen for the large table because it has much better light transmitting qualities than extruded acrylic, and has less friction. Tracking during dragging is maintained and the table is much more sensitive. Blobs are brighter than outside ambient IR light which increased sensitivity when operating with normal lights and during conferences, which produce an extremely noisy IR light condition.

In contrast to our smaller prototype our goal was to use the original backlight, which required us to suppress the excess IR noise. A window treatment was identified that filtered out IR light but allowed visible light to pass through. It was found that using three layers of the 3M Prestige 70 was able to cut the internal IR light by more than half. To help diffuse and reflect the visible light we added foam core walls as before. This time we placed the foam core between the plastic housing of the LCD and the edge of the backlight to minimize the shadows inside the box. By placing the foam core inside the outer wall we ensured that the tracking would not be disturbed by bumps or kicks to the table. For diffusing the visible light inside the table, the original LCD diffuser was placed directly on top of the backlight, then the same thin diffuser from the 30-inch prototype was paced close to the LCD screen. Instead of building a aluminum frame, we placed the LCD panel upside down on a table, removed the screws that held the plastic LCD mount to the aluminum frame, then we lifted up the plastic mounting (be aware that the LCD can shift out of position, and there are ribbon cable that run through the display top side), and placed the thin diffuser on top of the LCD panel (the diffuser should be cut to the size of the LCD panel to reduce the ripples that will form when the plastic is remounted). This allowed us to mount the thin diffuser close to the LCD panel without any extra mounting.

From the construction process we learned several things. Cast acrylic is much better than extruded acrylic when using FTIR. It was thought that using Mylar would help reflect the visible light inside the table. While it does reflect visible light it also reflects the IR blobs. It is possible to eliminate these extra blobs through tracking the initial calibration would be impossible. This process produced a LCD-based multi-

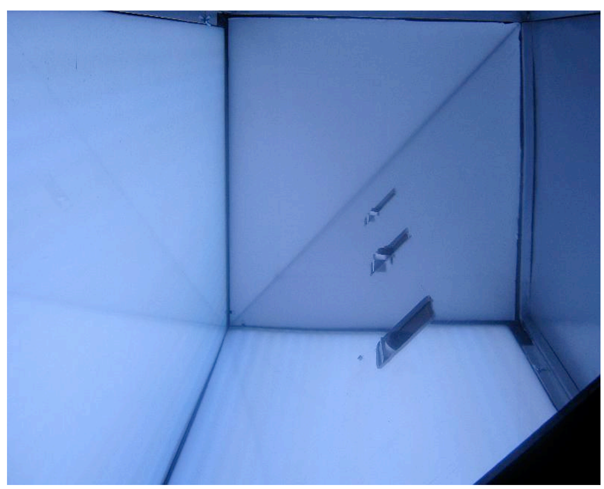

Figure 7: SMM 52-inch multi-touch table where they choose to orientate the LCD at a 90-degree angle to the backlight.

Figure 8: Multiple users interacting with the 52-inch multi-touch table at AAAS '09

Figure 9: Canopy covering the multi-touch table at the NSF booth at the American Association for the Advancement of Science Annual Meeting 2009.

touch table that we successfully displayed at two conferences.

4.3.4. Science Museum of Minnesota's implementation. During the construction of our 52-inch multi-touch table the Science Museum of Minnesota was building their own table with our assistance. During the design phase they decided to choose a different method of separating the backlight from the LCD. They choose the method where they position the original backlight at a 90-degree angle to the LCD as they were not limited by a strict depth. They were successful in their construction and displayed their table at the American Geophysical Union meeting in December 2008.

4.4. Multi-touch tables in public venues

At the SC '08 conference in Austin, Texas we knew that ambient IR light would be a problem for reliable finger tracking. It was decided to construct a 10' by 10' ceiling for our booth. This was made out of thick foam core and put together by the workers at the conference. Other multi-touch tables at the conference had similar concerns. One approach was to turn off one or more lights. This helped but there still was a large amount of IR noise and this disrupted their neighbors at other booths.

At the American Association for the Advancement of Science (AAAS) meeting in Chicago, Illinois in 2009 we built a similar canopy. An unexpected source of IR noise was found; almost all convention lights used in booths were halogen or sodium bulbs. These lights are bright enough to reflect light off signage and reflect IR light off our hands while interacting with the table, which disrupted tracking. To counter this the threshold for tracking was increased but increasing the threshold caused the table to be less sensitive. Signs were also moved in attempts to block the major sources of IR. The only viable solution was to increase the threshold. The change to cast acrylic allowed to increase the threshold while maintaining reliable finger tracking.

At both conferences the table preformed well. In particular the last day of AAAS '09 was family day where many children stopped by our booth. It was observed that children instantly understood how to interact with the table and the table maintained their attention for long periods of time.

The 52-inch table was also used in UIC's spring 2009 video game programming class. Students were exposed to programming in a multi-touch environment where they had to create videogames. Some of the development challenges include multi-user interaction, orientation, and getting away from the mouse-pointer design logic.

The completion of this process has generated a robust LCD-based multi-touch table. The performance at SC '08 and AAAS' 09 proved that the table can withstand hostile environments. The Science Museum of Minnesota proved that our design is reproducible. The video game programming class showed that the table could be used as a development platform for interactive applications. The next phase of the project is to convert our display into an autostereoscopic display.

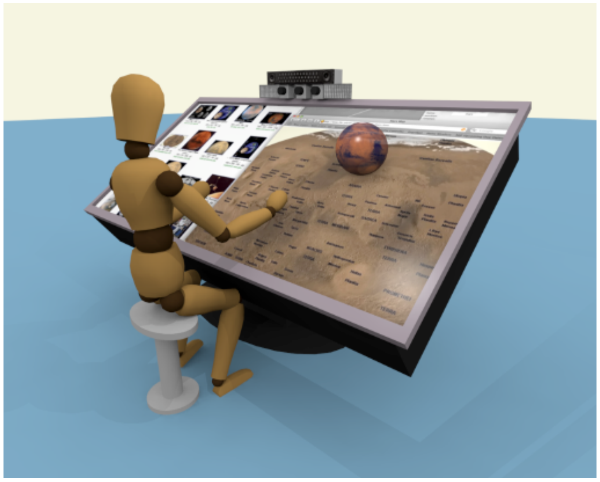

Figure 10: Rendering of OmegaDesk. A autostereoscopic multi-touch table.

5. Future Goals

The last phase of our project will be to combine our current multi-touch table with an autostereoscopic display. This means you will be able to see 3-D without glasses. The reason LCD's are needed to create an autostereoscopic effect is because the top display is used to show a dynamic line screen. The bottom display shows an interleaved scene including the left and right eye views. Separately rendering these two scenes are easy. When combined, to meet our goal of 3-D imaging, there can be no errors in the screens' alignment. Aligning projectors to display these scenes would be nearly impossible. Through the use of LCD's the alignment is controlled through software and much more manageable.

This process will give an autostereoscopic display where 3-D and 2-D images are displayed dynamically that allows users to interact with it on a multi-touch table.

6. Discussion and Conclusion

LCD's are becoming an increasingly attractive solution to build interactive, multi-touch displays that can be used in informal education and visualization applications. These displays overcome the cost and image clarity limitations inherent in projectors. This paper discussed the challenges faced in building LCD based multi-touch displays, and presented a design methodology that addresses these challenges. Our approach combines existing, widely used multi-touch techniques and technologies to design an LCD based multi-touch display that meets the needs of museums and researchers alike. We used this process to construct two multi-touch tables – a 30-inch display with a resolution of 4-Megapixels, and a 52-inch display with a 1080p resolution. Both of these displays have been tested in public venues and museum environments. These tests have shown the robustness of our design and its viability for constructing LCD based multi-touch displays for collaborative informal education and visualization applications.

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