ECE-493 FINAL REPORT

EducáTable:
An interactive Multitouch Table for Young Children

The EducáTable is a new, affordable technology that will be used as the future teaching tool for elementary education. This technology involves a surface computing table that provides a multi-purpose solution for young students to engage in many classroom activities. By implementing EducáTable's new "touch user interface," multiple users at any given time are able to use only their fingers to exercise problems within numerous applications. This allows students to immerse in a fun and intuitive learning environment.

The technology behind the EducáTable is made possible through a system of various techniques. The user's natural finger gestures are simplified by the computer vision system to manipulate applications. A technique known as Frustrated Total Internal Reflection (FTIR) utilizes light in the near infrared spectrum to enhance the detection of each touch. The recognition and tracking of fingers themselves on the table surface is interpreted by a fast processing camera from the underside. The computer vision system translates information to the DLP video projection scheme that creates an enlarged and clear picture onto the surface. The efficiency and stability of this system meets the demands of the interactivity of this new user interface. This system is contained within a table sized for elementary school children and performs in a real-time fashion.

This interactive table is an intuitive alternative to today's teaching tools. It is constructed with materials that are both environmentally safe. It is also designed to ensure the safety of users of all ages and allows for easy transportation. The EducáTable promotes an entertaining element to effective education.

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Executive Summary

This project describes the implementation of multitouch and multiuser technology that has a potential of introducing the new educational teaching tool. While parents spend a lot of money to buy toys or games for their children to enhance their creativity and learning interest, our table provides an inexpensive alternative to those toys and games by providing limitless number of applications all in one table. There are only a very few similar tables available in the market but they are too expensive, typically ranging from around 7k to 10k, and are out of reach for most middle-class parents. The multitouch table in this project can be marketed for as low as $500 and thus is affordable for most users. Therefore, it can not only be used to provide young children with an interactive learning interface, but also to enhance the currently existing educational system by making this technology accessible to a broad range of users.

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1. Approach

The main purpose of the project was to build an interactive learning tool for young children so that they can involve in group learning activities. This tool would have to have intuitive interface and help children develop their motor skills and interactivity. Several approaches were considered in an attempt to fulfill the criteria well. The first design that was contemplated was a set of learning environment books. This idea was based on the improvement of the common elementary workbooks and the purchasable musical books found in many toy stores. As a child turns to a new page, he will be introduced to a new mathematical problem and/or concept. A number pad or a common button function that is attached to the outside perimeter of the book will be available to use for each page. A "talking" function may also be added to the book to provide a user details about each page as well as feedback when entering input to the book. This can be done by introducing a speaker that is always available to the user, much like the functional buttons.

The advantages of this interactive book would concentrate over the price and stability of the hardware design. Its components would be very inexpensive, seeing as there are only several necessary components: sheets of cardboard, ink, a speaker, a set of buttons, several basic circuit components, microcontrollers, etc. Many of the musical books available are made out of enough plastic and cardboard to endure much wear and tear as well as physical abuses. The variety of mathematical problems is limited to the number of pages held within one spine. The intractability and feedback are also limited to the input option, i.e. numbered buttons, and the output function, i.e. an automated voice from the speaker. The book aesthetics would reach a wide range of children, especially the younger readers if this type of book was created in more of that nature.

The next design was a video tutorial. This would use the advantage of graphical manipulation to gauge the user's interest while presenting problems in a fun and exciting way. This would allow the user to choose an answer when a question arises provide feedback as to why an answer is wrong or right.

Since this video tutorial would be made via digital media, its low cost and high durability is an advantage in its design. The shortcomings are present in the intractability, when the video would freeze a certain frame to let the user choose an answer to the given question. This may create a redundancy in the problems and concepts and in turn decrease the user's appeal to use the video, but the graphical advantage can be used strategically to minimize this issue. The digital space that media such as compact discs or DVDs provides is more than enough to provide a large variety of mathematical concepts as well as graphical, video, and musical aesthetics.

The idea of a video tutorial lead to the approach of mathematical tutorial software. This would also strategically use graphics to grab the attention of the user. Because the software's capabilities, besides graphics, are limited by the computer it is installed on and now that computer technology is quite advanced, this can do much more than a video tutorial could ever. Its intractability and variety of mathematical concepts are open to a wide range of possibilities. The software can span from the usage of virtual toy blocks for problems that involve geometrical

problems to drag-and-drop grouping for word problem solving. The ability to present problems with many different creative approaches is where the software aspect shows much appeal to a user. The cost to develop this technology would not be very much. The stability would also come with testing and debugging to reach its final product. A great issue with this idea is the fact that intractability is also limited by the user's mouse and keyboard, which are the only input devices used to engage the software.

Despite several advantages of software, it could be less intuitive for the users because of the mouse and keyboard inputs. This led to the idea of a touch table in which the users can use their fingers to manipulate objects and interact with the system or with other users using the table at the same time. The virtual objects on the table would react the same as the real objects, drawing pad for instance where users can use their fingers to draw on the table and also to choose colors and so on. Implementing this would help avoid the need of actual physical objects and would provide limitless applications in one table which would save space and money.

The origin of EducáTable is an improvement to the touch screen technology, in order to allow multiple users to apply multiple finger gestures for object manipulation.

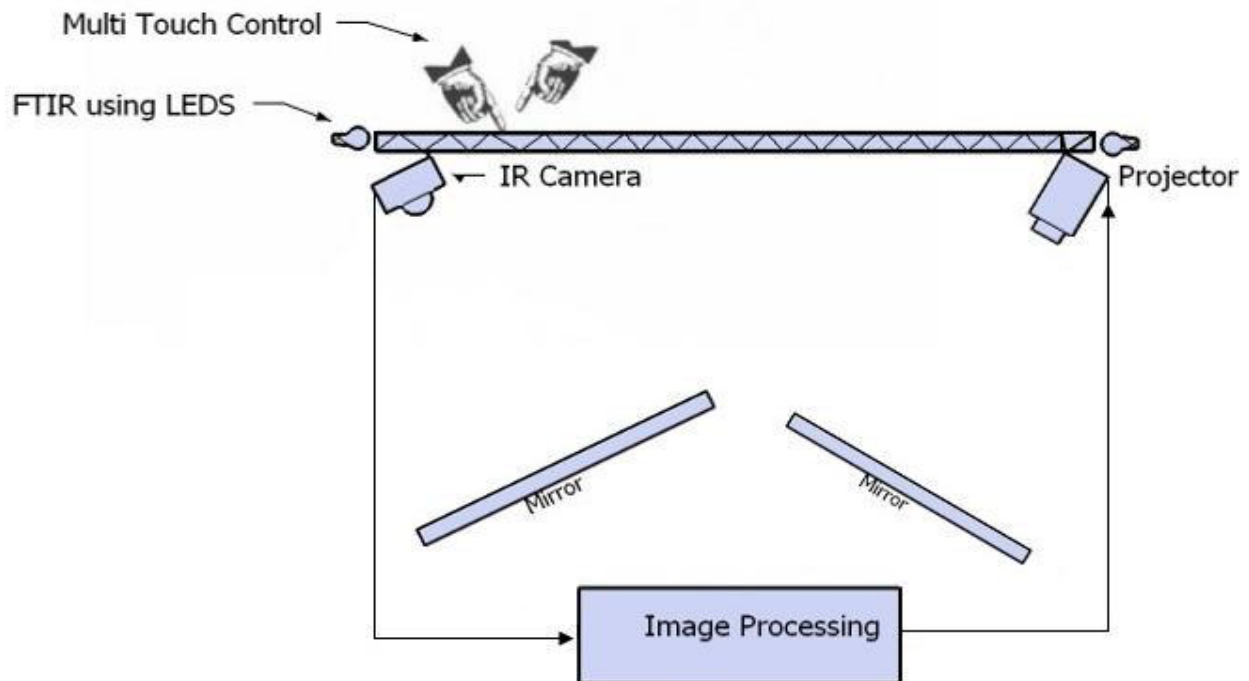# 2. Technical Section

2.1 Design

Figure 1: Design for EducáTable

Figure 1 shows the design of EducáTable. The input is given by touching or moving fingers on the table surface. IR LEDs are placed around the edge of the table surface using the FTIR technology (details in hardware section) so that when a finger is touching the surface, the light from the LEDs is reflected right below the finger and is captured by the camera. The image of the table is constantly captured by the camera and sent to the computer vision for processing. Output is generated by the computer based on the image received and sent to the projector which will display it back to the table surface. Two mirrors are placed inside the table, one each for the camera and the projector, so that the camera can capture the image of the entire table surface and the projector can project the output to the entire table surface.

2.2 Process Flow:
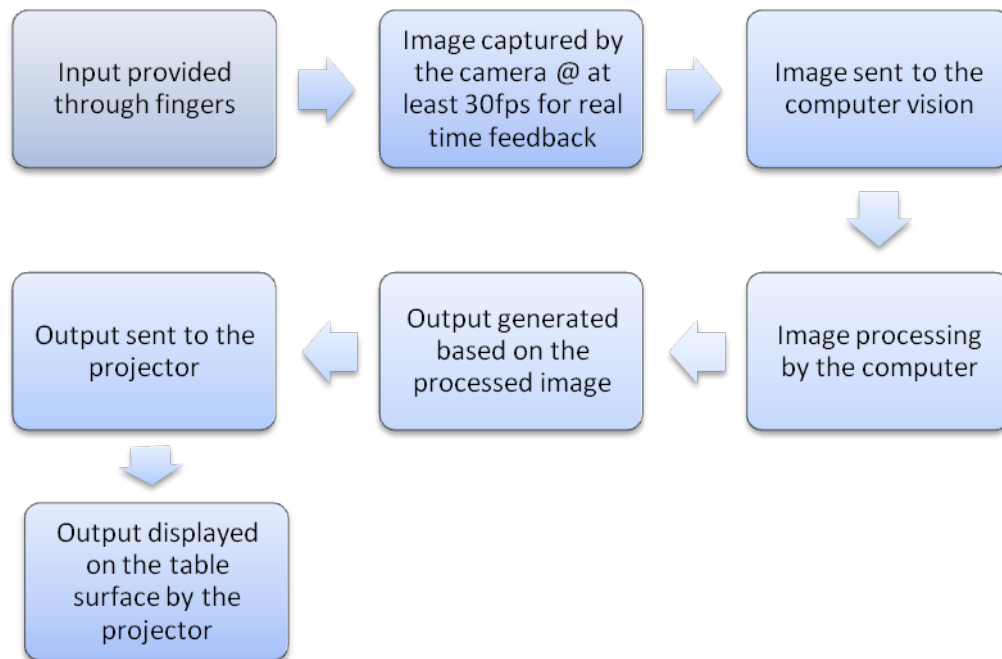
Figure 2: Process Flow for EducáTable

From the design and process flow as shown in figure 1 and figure 2 above, it is clear that the majority of the project depends on the image processing. For the image processing to be successful, proper selection and placement of the hardware is crucial. The quality of the image captured depends not only on the features of the camera and its distance from the table surface but also on the illumination provided by the IR LEDs as well as the transparency and material selection of the table surface. Similarly, the quality of the output and proper focus on the table surface depends on the focal length of the projector lens and the position of the projector compared to the table surface.

2.3 Hardware

The hardware part mainly consists of camera, projector, IR LEDs, touch surface, computer system and a table frame to hold and support all of these parts.

2.3.1 Table surface

Table surface is the primary hardware component which is also one of the most important parts that should be selected very carefully. It provides the input to the system, and also displays the output. Hence, it is essential to make the selection such that it works well for both input and output. It needs to be light-weight but sturdy enough as multiple users interact with the table at the same time. Acrylic sheet was chosen as the most appropriate table surface. An acrylic has stronger impact resistance than the glass, and unlike glass, it doesn't shatter when it breaks. Therefore it is a safer alternative to glass. Additionally, it is 17 times stronger than the glass but only 50% of its weight. These features of the acrylic sheet make it an ideal selection for our project.
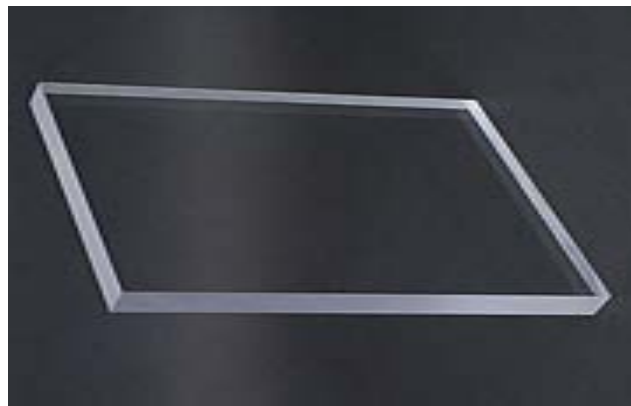
Figure 3: Acrylic sheet

Specifications for the acrylic sheet:

Dimension: 24 inches (length) by 18 inches (width) by 0.25 inches (thickness).

The dimension 24*18 gives a ratio 4:3 which matches the ratio of the image captured by the camera as well as the ratio of the image displayed by the projector. Additionally, the thickness (0.25 inches) allows the LEDs to be placed along its edges so that the light from the LEDs can enter and illuminate the inside of the acrylic.

2.3.2 Camera and IR LEDs

A camera is used in our project to capture the image of the table surface and to send the image to the computer vision for image processing. Since the computer vision generates an output based on this image, it is of greatest importance for the image to be clear enough so that the finger and object tracking is accurate. Thus the camera plays a pivotal role in the overall success of the design. Primarily, it needs to be able to capture the whole surface, so a high resolution camera (at least 640X480) with a wide-angle lens is preferred because the distance between the surface and the camera is very short. This problem is compensated because of utilization of mirror. Secondly, since a real-time feedback is absolutely necessary for the interaction, the camera needs to be able to capture images at a very fast rate. The desired rate is at least 30 frames per second so that the user can experience a smooth, real-time feedback.

Additionally, there is one more criterion that needs to be analyzed which is lighting conditions. It is important to realize the need of balance between the computer vision and human vision for accurate tracking and correct output. Computer vision is used for the input, i.e. for image capturing and processing, while the human vision is used to see the feedback that is projected by the projector. The human vision, which is the light coming from the projector, may easily interfere with lighting conditions required for the camera to be able to detect the finger touch on the surface. The light from the projector can result in a change in the illumination of the table surface, which will influence the quality of tracking. One solution to this problem is to use two different light spectra, one for tracking the movements of fingers, and the other for projecting the image. Since the output must be visible to the user, the light coming from the projector must be visible (wavelength ranging from 400 to 700 nm), and the table surface must be illuminated using invisible IR light (wavelength ranging from 700 to 1500 nm for near IR), so that an IR camera can be used to capture the image on table surface. The table surface can be illuminated using several IR LEDs placed around the edge of table (using FTIR technique). This would allow for the illumination for the camera and the illumination from the projector to be adjusted independently without interfering with each other. The camera that was chosen in order to meet all the criteria is PS3 eye-cam. In order to allow the camera to block visible lights and only receive IR light, IR filter in the camera was replaced by a magnetic tape from a floppy disk (which acts as a visible light filter).
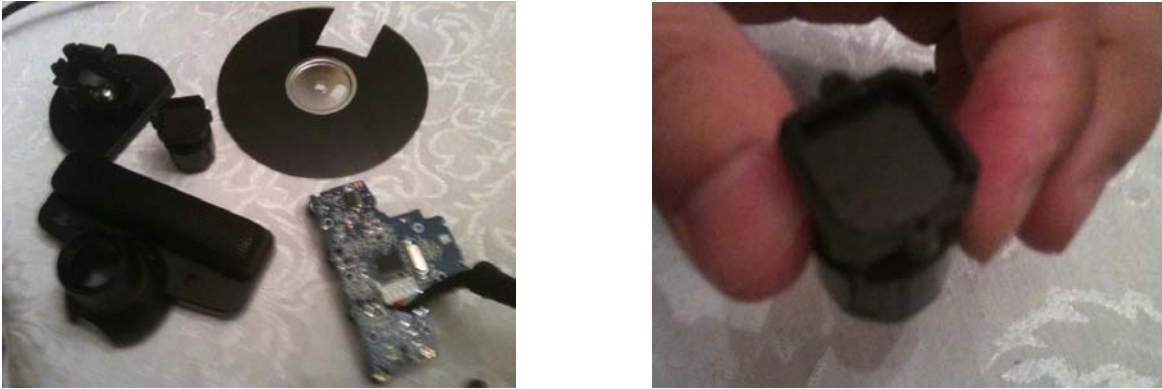

Figure 4: Sony PS3 Eye Cam

Figure 5: Replacing the IR filter in the camera with visible light filter

Specifications for PS3 Eye Cam:
- 640 * 480 at 60 frames/second
- 320 * 240 at 120 frames/second

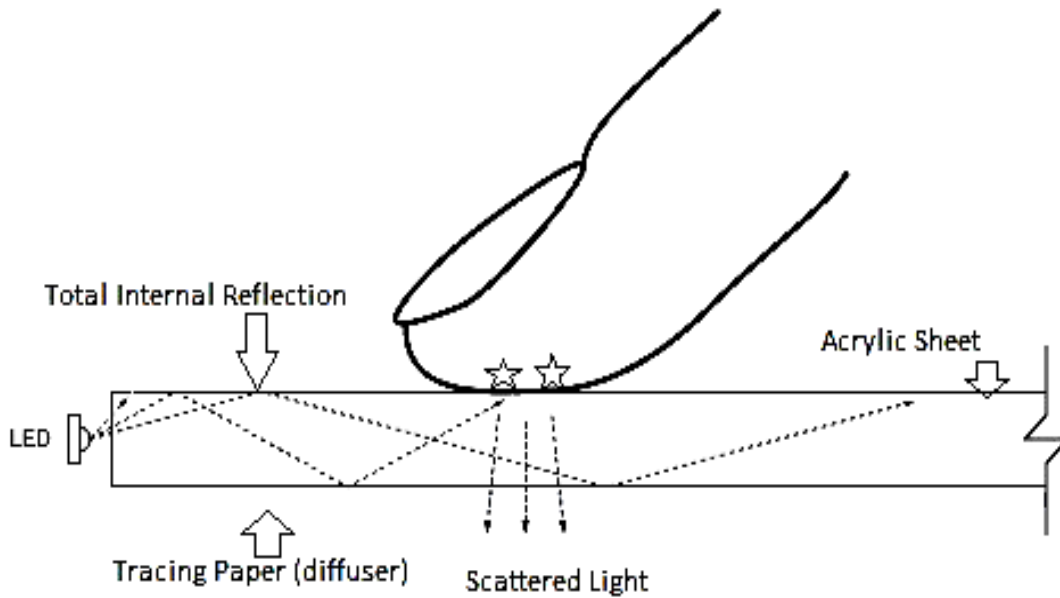## 2.3.2.1 Frustrated Total Internal Reflection

Figure 6: Frustrated Total Internal Reflection (FTIR)

As shown in the Figure 6, Frustrated Total Internal Reflection (commonly known as FTIR) method was implemented in order to get the best possible solution for image processing. In FTIR, when light enters into the acrylic sheet at an angle greater than or equal to its critical angle, the light will be reflected back internally and will be trapped within the acrylic illuminating the acrylic sheet. When a finger is pressed on the surface, the light rays reflected on the top surface of the acrylic underneath the finger get "frustrated", and some portion of the light no longer stays in the material. This means that the light leaves the acrylic directly under the point where a finger is pressed, optimally in a 90° angle to the surface. This allows the IR camera to capture all the touch points and send the data to the computer for image processing.

Figure 7: IR LED

Specifications for IR LED:
Wavelength: 880 nm
Forward Current: 100 mA
Forward Voltage: 1.5 V

Figure 8: FTIR setup

100 IR LEDs were used to illuminate the table surface as shown in Figure 8. The wiring diagram for the LED and the test results are explained in the Experimentation Section.

2.3.3 Projector

The projector gets the output from the computer vision and projects it on the table surface from underneath it. The projector must have a lamp that can provide the right illumination to the table surface. In our design, the projector projects to a small screen (table surface) and the ambient light present will be low, thus the projector needs to have very low lumens. Since the projector must project to the whole surface and the distance from the surface to the projector is very short, it needs to have a wide lens and a resolution of at least 640*480 (which is same as the resolution of the camera). This is compensated by using a mirror with the projector.

Figure 9: AAXA P2 Pico Projector

Specifications:

Native Resolution:	SVGA (800x600)
Brightness:	33 ANSI-Lumens
Contrast Ratio:	1000:1
Projection Lens:	Manual Focus
Aspect Ratio Control:	4:3
Dimension:	110*59*27mm
Weight:	260g
Power Consumption:	15w

This projector was chosen primarily because of its small size and light-weight features. Although the resolution is different from that of camera, it was fixed using the software by outputting the 640*480 pixels to the corresponding 800*600 pixels. The projector lens was not wide enough to display the output to the whole surface; hence it was positioned such that it projected to a mirror which reflected the projected light to cover the whole surface as shown in the above figure.

Tracing paper was placed under the acrylic sheet to project the image on the table surface and to reduce the brightness of the projection beam.

2.3.4 Table Frame

The table frame needs to be sturdy enough to hold all the hardware parts used in the project. It needs a tray to hold the camera, projector and a PC. The table frame is made up of metal and its dimensions are 33'x33' and allow the acrylic sheet and LEDs to completely fit within. The height is 29 inches which allows enough distance for the light reflected from the mirror to cover the whole table surface. This height also makes it suitable for the use by younger users.

2.4 Software

Software is equally crucial part of this project. The input going the computer is an image of the table surface, and based on that image, a sensible output must be generated that allows interaction with the users. Image processing allows for the interpretation of the input image so that the output can be produced.

From the software point of view, an image can be defined as a two-dimensional function, $f(x, y)$, where x and y are plane coordinates and the amplitude of f at any point of x and y coordinates is called the intensity level of an image at that point. In a digital image, x, y and the intensity level of f are finite value, and digital image processing means that those discrete quantities are processed by a digital computer. Components of digital image are known as pixels and they have to be finite value. Pixels can be thought of as small dots on the screen and image processing is used to color those pixels. In our project, time will also be taken into consideration since series of images must be processed to keep track of activity made by users on the surface of the table so that new function will be expressed as $f(x,y,t)$.

2.4.1 Image Processing for EducáTable

C# was used for image processing as well as for building applications. A library was generated to process multi-touch and this library acted as the core part of the software. It not only detects multiple fingers but also processes them so that the applications running on the table can process each finger to give an appropriate output. The library automatically starts the camera and processes each frame. For each frame, the number of fingers present on the table are detected after converting the input image from the camera to a grayscale image and applying appropriate threshold. Then by comparing the current frame with the previous frame and applying "Shortest Distance Algorithm," it is determined whether there is any finger gesture such as a new finger on the table, or a release of a finger from the table, or the movement of a finger. In "Shortest Distance Algorithm," the distance between each finger blob in the current frame and each finger blob in previous frame is calculated to determine which finger in the current frame corresponds to the finger in the previous frame. If there is any finger gesture detected, the program

automatically fires events such as fingerDown, fingerMoved or fingerUp to the applications that are running on the table. Each application must contain this library in order to receive notifications of any finger events. Then, depending on which event was fired, the application updates its contents such as position of a certain image on the table.
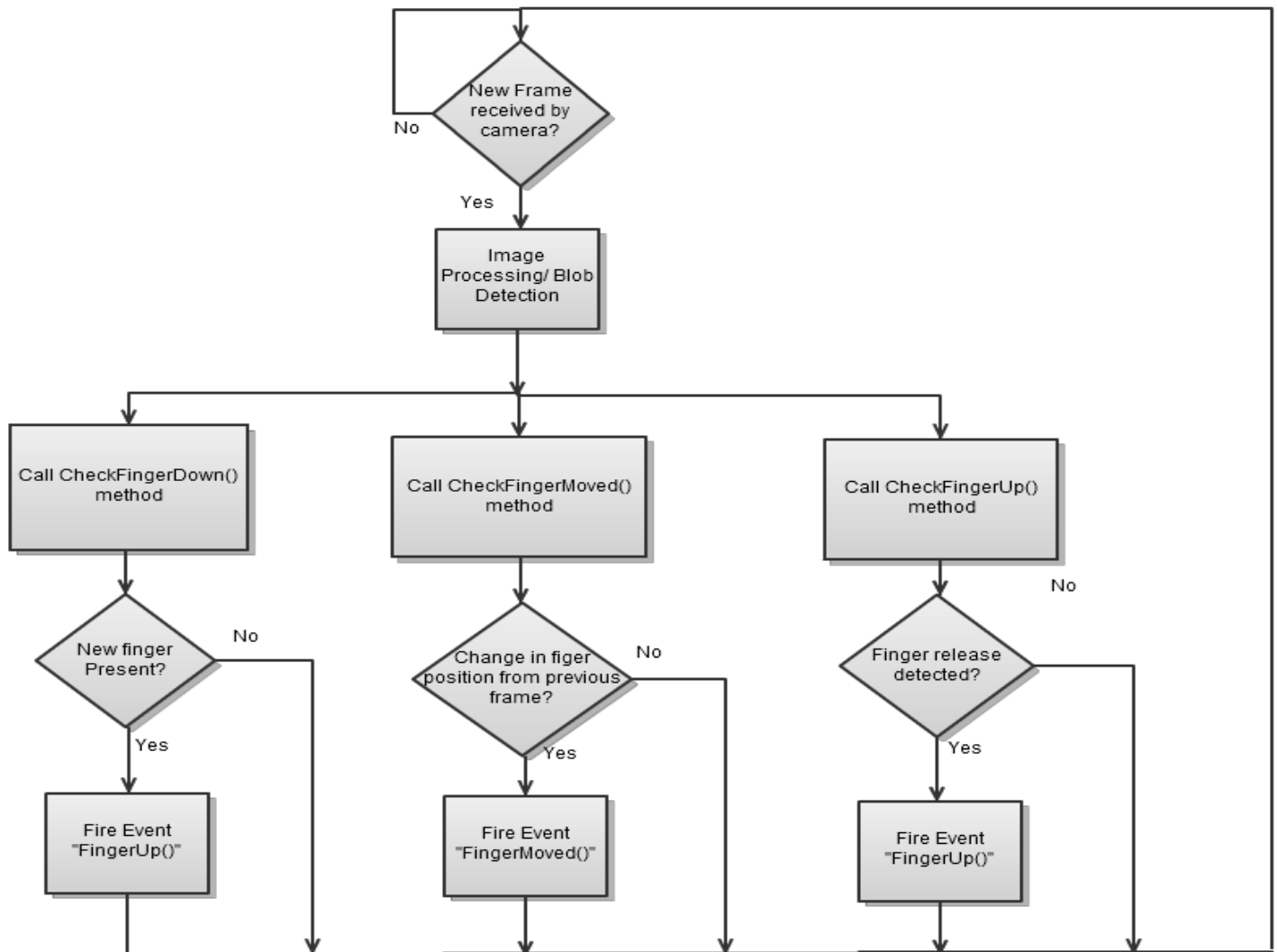

Figure 10: Top level flowchart for the library (finger gesture detection)
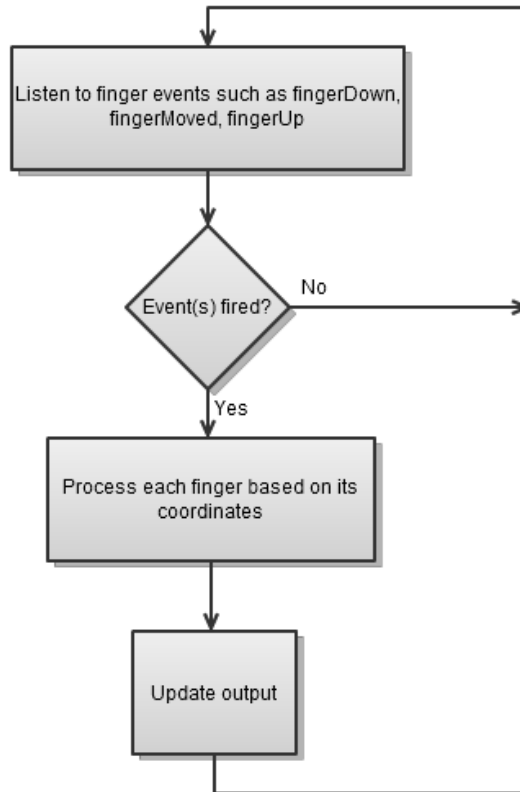
Figure 11: Top level flowchart for multitouch applications

3. Experimentation

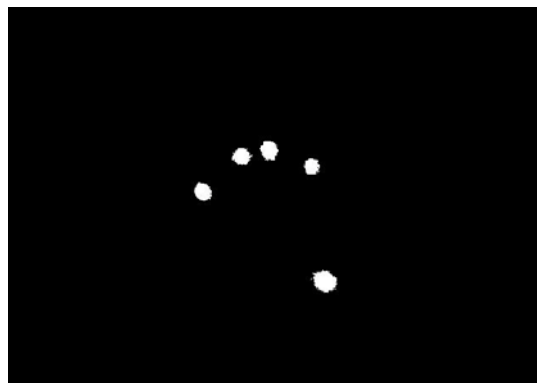## 3.1 Image Processing and output tests:

Raw image from the IR camera

Image after applying Grayscale filter and threshold

Figure 12: Image Processing results
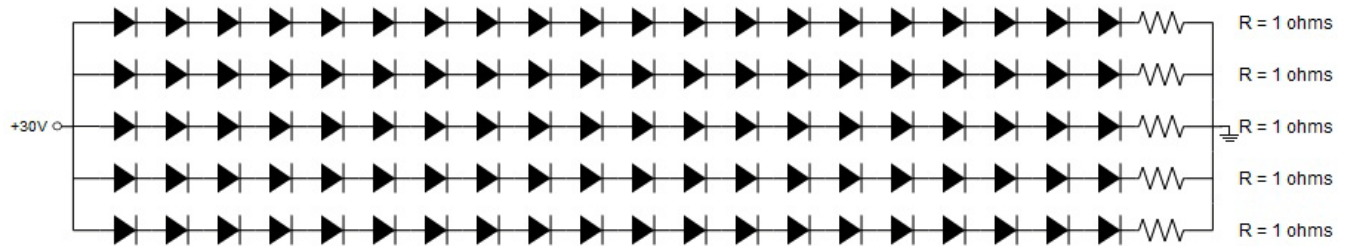
3.2 LED Schematic Test:

Figure 13: Schematic for LED setup

The figure above shows the wiring diagram for setting up the LEDs to cover the edges of the acrylic.

As expected from the circuit analysis, the measurements showed that the power dissipated by each resistor was 10mW and the current through each LED was 100mA. The above circuit is the best possible circuit for the project as it allows maximum brightness of the LEDs with low power dissipation in the resistor. Even with the resistors with the lowest power rating (1/4 Watt), maximum current flow was achieved without overheating the resistors.

Testing results for LEDs:
V_F as shown in datasheet : 1.5V
Actual measured V_F: 1.495V

4. Experimentation Validation

The validation was done using a drawing application where the user can use fingers to select color and draw lines on the table surface. The lines were drawn exactly where the fingers touched on the table surface. Multiple users gave the input using the finger gestures and the application was able to track and display the result of those finger gestures in real time. This experiment validates the correct position of the camera and the projector; since for this experiment to be successful, the camera and the projector must cover exactly the same area on the table surface. This experiment also validates the entire design as it ensures that the position of hardware components is accurate and that the software is applicable to the design. New applications can be easily added by adding one line of code in each application to include the library for multitouch processing, and do not require any adjustment in the design. Therefore, the project is a success.
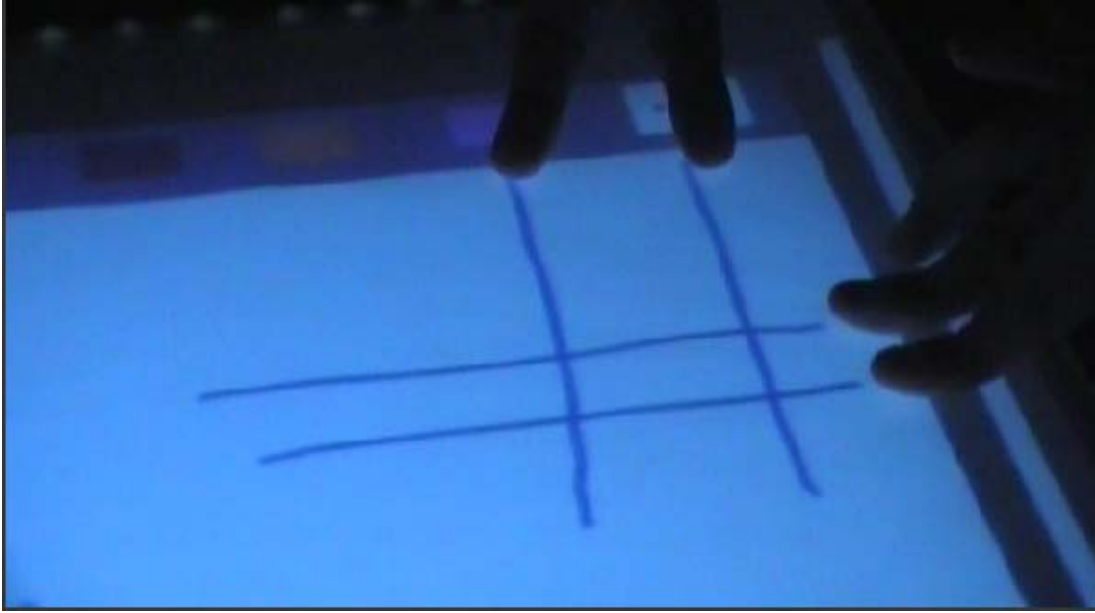
Figure 14: Validation of the multitouch and multiuser implementation

5. Financial Analysis

Manhours

NAME	HOURS (Approx.)
Sato	278 hrs * $20 = $5,560
Gopal	280 hrs * $20 = $5,600
Total	558 hrs * $20 = $11,160

Table 1: Labor Cost

Funds spent towards final product

# of items	Product	Price After Tax ($)
1	PS3 EYE CAMERA	41.99
1	13/30/AC-DC Adaper	31.49
1	Plexi (1/4) Polished Edge 18x24	47.75
1	Glass-top table	103.95
1	Tracing Paper roll(24 inches * 50yd) + Shipping	16.99
1	AAXA P2 Pico Projector + Shipping and Handling	377.50
2	Mirror	10.49
100	IR LEDs + Shipping and Handling	60.92
2	Plywood	14.56
1	Hinge	2.92
6	Nuts and washers	6.17
	Total($)	**714. 73**

Table 2: Parts Cost

Total Parts: $714.73   Total Labor: $11,160.00

Total Cost: $11,874.73

The total cost shown above includes the time for testing as well as developing the hardware. A lot of time was spent determining the exact setup of hardware components, writing the library and testing the software. If this product was to be built in large-scale, then the price of the labor and the hardware will go significantly down, and the price for the final product could go as low as $500. Thus, this product has the potential of being used in the future education system for younger children to provide them an opportunity to engage in interactive learning experience.

6. Administrative

6.1 Progress Summary

Task Name	Completion Rate	Weeks							
		8	9	10	11	12	13	14	15
1. Software									
1.1 Detecting Multiple Fingers	100%	▮							
1.2 Generating Libraries	100%		▮						
1.3 Coding multitouch applications	100%		▬▬▬▬▬▬▬▬▬▬						
2. Table Setup									
2.1 Table Frame	100%	▮							
2.2 Camera and Mirror Setup	100%			▬▬▬					
2.3 LED, Acrylic Sheet, Edges Polishing	100%			▬▬▬					
2.4 Projector and Mirror Setup	100%				▬▬▬				
3. Testing and Final Experimentation									
3.1 Initial Finger Testing	100%	▮							
3.2 Application Testing with Acrylic	100%			▬▬▬					
3.3 Application Testing with Projector	100%				▬▬▬				
3.4 Overall Testing	100%				▬▬▬▬▬				

Figure 15: Progress Summary

7. Documentation

The potential use of the project is not limited to school education; it can be used to work with a group collaboratively using existing applications. The project can be marketable as an affordable but a sophisticated toy for children against other toys such as play station. EducáTable has an advantage of being only one affordable multi touch product which differentiates itself from a normal touch screen technology or a game console. Users can use EducáTable intuitively and more simply by touching the table surface, thus it provides for an easy way to adapt to utilize the full potential of this technology. Instead of using a mouse, users can apply their finger gestures to manipulate such as move, scale, rotate or zoom in/out the objects displayed on the table surface. Therefore, the product is applicable to a broad range of users.

One of the alternatives to the implemented design was to use capacitive touch sensor instead of using an acrylic sheet with the combination of FTIR. With capacitive touch design, once the finger is touched, the touch disrupts the sensor's magnetic field, and this disruption is registered and sent to the software to dictate a response to the touch. Also the design with capacitive touch does not require a camera or a projector since we can purchase a capacitive touch-screen. We have chosen our design since the product's target is children; and we wanted to make it as safer as possible. Specifically, touch monitor could be harmful to children since if the screen breaks, fingers can be exposed to the electricity from the monitor. Hence, the chosen design has more safety and reliability. Since the design does not require a capacitive touch screen, the table surface can be easily replaced. Another alternative to the implemented design was to remove the mirror by using the projector that has a considerable short throw distance; however, the projectors that have this specification are more expensive than the one we used for the project, and would significantly increase the price.

7.1 Maintainability/maintenance of the final design solution

Maintainability	
Componets	Maintainance
Table Surface	1. Use a soft wet cloth or cotton to clean the table for better recognition of the finger gestures. DO NOT use a paper towel; it can easily scratch the surface. 2. Do not use any cleaner or anmonia to clean the table surface.
Software	Install the latest update for the software.
Hardware	1. Turn off the device when it is not used to avoid over-heating. 2. Avoid excessive shaking of the table

Table 3: Maintainability

7.2 Retirement, replacement, or disposal of the project

All electrical and electronic equipment used should be disposed in accordance with the regulations of state law. All the recyclable parts must be recycled accordingly.

8. Skills and Lessons Learned

We gained several skills such as the basics of image processing and real time video processing. We also learned the programming language C# which allowed us to expand our knowledge and skills in object-oriented programming. Before this project, multitouch technology was something we used to be amused at, and didn't really know much about how it was implemented. But this project allowed us to be able to implement the multitouch technology in our own multiuser interface and to write multitouch applications that could provide a greater interactive learning experience.

As for the lessons learned, a major conflict we had through the senior design project was the lack of participation from the two of the team members. We had to consult the faculty advisors to exclude two of our members since they became completely out of contact in the middle of the project. This caused us numerous problems, such as change in schedule, ordering the same parts that we were unable to get back from the missing members, and so forth. From this experience, we have learnt that there are several things that we should adopt to avoid similar situation. For instance, all project related resources must be accessible by each member at anytime. In other words, no project resource can be exclusively available to an individual. Having each team member provide emergency contact information would allow each other to maintain their access to the resources in case the person who possesses the resource goes missing.

As for the technical part, the most important lesson we learned was that we always need to think of the worst case scenario for any design or part of the design so that we are always prepared to overcome any obstacle that may be caused due to unexpected results from the design. This also taught us to allow enough time for testing because even if the system works for certain inputs, it may not work for all the cases, and the only way to realize this is by conducting as many tests as possible.

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Appendix A:

Proposal (ECE-492)

ECE 492

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The EducáTable

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Proposal

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FS: Dr. Jill Nelson & Dr. Jens-Peter Kaps

Date: Friday, October 30, 2009

Executive Summary:

Learning strong fundamental building blocks of mathematics creates the groundwork for future success in related studies and fields. As there are many educational systems implemented around the world today, there also exists a need for improvement. Research shows that children become familiar with blocks at an extremely early stage in their young lives. They are also able to quickly recognize the concept of computers and can learn to use them in a brief amount of time. One can benefit greatly from simply playing with blocks. Doing so can help build the basis for physical coordination, creativity, and sociolinguistic skills. Blocks have always shown a strong appeal to children even before they are given any formal education.

Physical interactivity with math concepts proves itself to be a strong teacher in mathematics for children. In conjunction with the strong appeal of blocks, an interactive table was considered. This table would combine the intuitive design and the playful attraction of basic toy blocks in order to interact with the surface of the table. The concept of this interface also allows more than one user to utilize the apparatus. The table itself would be able to present a wide range of mathematical concepts to its surface while the user or users are able to manipulate a solution on the same surface at the same time. The surface will be able to provide real-time feedback to the surface as an answer is being formulated.

The technology behind this interactive table is a combination of computer vision and video projection. The recognition and tracking of the blocks themselves against the surface of the table is done by means of the image processing with an industrial camera from the underside of the surface. This is done in the infrared light spectrum with the underside lit with infrared diodes. The data from the image processing is sent to a computer, which then delivers the appropriate information to be displayed to the projector. The projector delivers a given problem or feedback while providing light to the surface in the visible light spectrum in a real-time fashion.

Problem Statement:

The February, 2006, U.S. Department of Education study, "The Toolbox Revisited," tells us that 80% of the 1992 U.S. high school graduating class went on to college. Only about half of those students graduated with a bachelor's degree. The others dropped out. Inadequate preparation for college mathematics was a major contributor to the dropout rate. The foundation for K-12 mathematics is laid in the early years of elementary school. To succeed in college, this foundation must be solid.

According to the research done at Purdue University, early kindergarten motor skills, especially visual motor skills, contribute to achievement in reading and mathematics at the end of first grade even after controlling for initial skills and demographic information. Furthermore, the results suggest the importance of the role that motor skills can play in designing and implementing an early school achievement battery.

Table 1 displays correlations between reading and mathematics scores of fall kindergarten and spring first grade on the one hand and students' visual motor and gross motor skills of fall kindergarten on the other. Correlations revealed that visual motor skills had significantly higher correlations with cognitive achievement than did gross motor skills.

Table 1. Correlations of Motor Skills and Cognitive Skills

Subtests	Visual Motor Skills	Gross Motor Skills
Reading		
Fall kindergarten	.35	.15
Spring first grade	.40	.19
Mathematics		
Fall kindergarten	.44	.20
Spring first grade	.48	.22

Note: All significance levels are based on 2-tail tests using a normalized child weight.

All the coefficients were statistically significant at the level of $p < .001$.

As many government systems try to find ways to improve their education systems, there are still issues with standards of curricula for developing motor skills including basic mathematical skill in the preschool and elementary school settings. Children tend to develop their motor skills through common play more than reading books since they can ponder and reflect on experiences more easily through common play. Their perceptions are then represented by means of models, dramatizations, and art. Our goal is to provide a connection to children's natural interest in models and shape with their motor skills experience via an alternative interface.

To help children extend their everyday activities, from building blocks to art and stories to puzzles, the materials integrate three types of media: computers, manipulatives (and everyday objects), and print. Pedagogical foundations were similarly established; for example, we

reviewed research on making computer software problems for young children motivating and educationally effective (Clements, Nastasi, & Swaminathan, 1993; Clements & Swaminathan, 1995; Steffe & Wiegel, 1994).

The basics of early motor skill development can be organized into two areas: (a) spatial and geometric competencies and concepts and (b) numeric and quantitative concepts, based on the considerable research in that domain. Research shows that young children are endowed with intuitive and informal capabilities in both these areas (Baroody, 2004; Bransford, Brown, & Cocking, 1999; Clements, 1999a; Clements, Sarama et al., 2004).

For example, research shows that preschoolers know a considerable amount about shapes (Clements, Swaminathan, Hannibal, & Sarama, 1999; Lehrer, Jenkins, & Osana, 1998), and they can do more than we assume, especially working with computers (Sarama, Clements, & Vukelic, 1996). In the broad area of geometry and space, they can do the following: recognize, name, build, draw, describe, compare, and sort two- and three-dimensional shapes, investigate putting shapes together and taking them apart, recognize and use slides and turns, describe spatial locations such as "above" and "behind," and describe, and use ideas of direction and distance in getting around in their environment (Clements, 1999a). In the area of number, preschoolers can learn to count with understanding (Baroody, 2004; Baroody & Wilkins, 1999; Fuson, 1988; Gelman, 1994), recognize "how many" in small sets of objects (Clements, 1999b; Reich, Subrahmanyam, & Gelman, 1999), and compare numbers (Sharon Griffin et al., 1995). They can count higher and generally participate in a much more exciting and varied mathematics than usually considered (Ginsburg, Inoue, & Seo, 1999; Trafton & Hartman, 1997). Challenging number activities do not just develop children's number sense; they can also develop children's competencies in such logical competencies as sorting and ordering (Clements, 1984). Three mathematical themes based on the gained motor skills are woven through both these main areas: (a) patterns, (b) data, and (c) sorting and sequencing.

Approach:

There are many cognitive benefits that are attained from interactive games. Play can make for a more stimulating and rewarding learning process. Interactivity through games can help your child develop motor skills. Motor skills embraces:

- hand-eye coordination
- spatial skills
- creative problem-solving skills
- social skills, and
- language skills

The following is a list of criteria according to the identified problems by which each design was assessed:

- interactivity and feedback
- cost
- design stability/reliability
- appeal
- variety of math-related problems/concepts

Several approaches were considered in the attempt to fulfill the criteria well. The first design that was contemplated was a set of learning environment books. This idea was based on the improvement of the common elementary workbooks and the purchasable musical books found in many toy stores. As a child turns to a new page, he will be introduced to a new mathematical problem and/or concept. A number pad or a common button function that is attached to the outside perimeter of the book will be available to use for each page. A "talking" function may also be added to the book to provide a user details about each page as well as feedback when entering input to the book. This can be done by introducing a speaker that is always available to the user, much like the functional buttons.

The advantages of this interactive book would concentrate over the price and stability of the hardware design. Its components would be very inexpensive, seeing as there are only several necessary components: sheets of cardboard, ink, a speaker, a set of buttons, several basic circuit components, microcontrollers, etc. Many of the musical books available are made out of enough plastic and cardboard to endure much wear and tear as well as physical abuses. The variety of mathematical problems is limited to the number of pages held within one spine. The intractability and feedback are also limited to the input option, i.e. numbered buttons, and the output function, i.e. an automated voice from the speaker. The book aesthetics would reach a wide range of children, especially the younger readers if this type of book was created in more of that nature.

The next design was a video tutorial. This would use the advantage of graphical manipulation to gauge the user's interest while presenting problems in a fun and exciting way. This would allow the user to choose an answer when a question arises provide feedback as to why an answer is wrong or right.

Since this video tutorial would be made via digital media, its low cost and high durability is an advantage in its design. The shortcomings are present in the intractability, when the video would freeze a certain frame to let the user choose an answer to the given question. This may create a redundancy in the problems and concepts and in turn decrease the user's appeal to use the video, but the graphical advantage can be used strategically to minimize this issue. The digital space that media such as compact discs or DVDs provides is more than enough to provide a large variety of mathematical concepts as well as graphical, video, and musical aesthetics.

The idea of a video tutorial lead to the approach of a mathematics tutorial software. This would also strategically use graphics to grab the attention of the user. Because the software's capabilities, besides graphics, are limited by the computer it is installed on and now that computer technology is quite advanced, this can do much more than a video tutorial could ever. Its intractability and variety of mathematical concepts are open to a wide range of possibilities. The software can span from the usage of virtual toy blocks for problems that involve geometrical problems to drag-and-drop grouping for word problem solving. The ability to present problems with many different creative approaches is where the software aspect shows much appeal to a user. The cost to develop this technology would not be very much. The stability would also come with testing and debugging to reach its final product. A great issue with this idea is the fact that intractability is also limited by the user's mouse and keyboard, which are the only input devices used to engage the software.

An approach towards an interactive table was also taken into account. This table would have a user manipulate blocks to solve given problems. The blocks would have markings on them that would distinguish themselves as number or mathematical symbols to both the user and a camera underneath the table surface. The camera would divide the table into units, recognize the markings, and track the blocks. This information would be sent to a connected computer which in turn would send information to a projector that would provide its feedback to the table surface, where the user would be able to read its display. When a problem or concept is projected, a user can take the available blocks to engage the table to find a solution.

The possibilities of intractability, appeal, and conceptual variety are almost limitless when considering an interactive table. This design uses the basic advantages of manipulating toy blocks with the graphical ability that computer technology allows today. The ability to project a variety of graphics permits a great range of concepts to be given to a user. The computer vision technology used against a surface allows multiple users to engage in the design, much like the software-based idea. The manipulation of blocks to children has always been a great appeal. Much study has put this notion of an interactive table to the test for feasibility to show this technology is strong in reliability. The downfall of this design may be the cost of the materials for the physical structure as well as the equipment to use computer vision. This design was found to be the most appropriate to satisfy the targeted problems in early education.

Preliminary Design:

In order to make the most efficient design, it is essential to first take a look at the process flow.
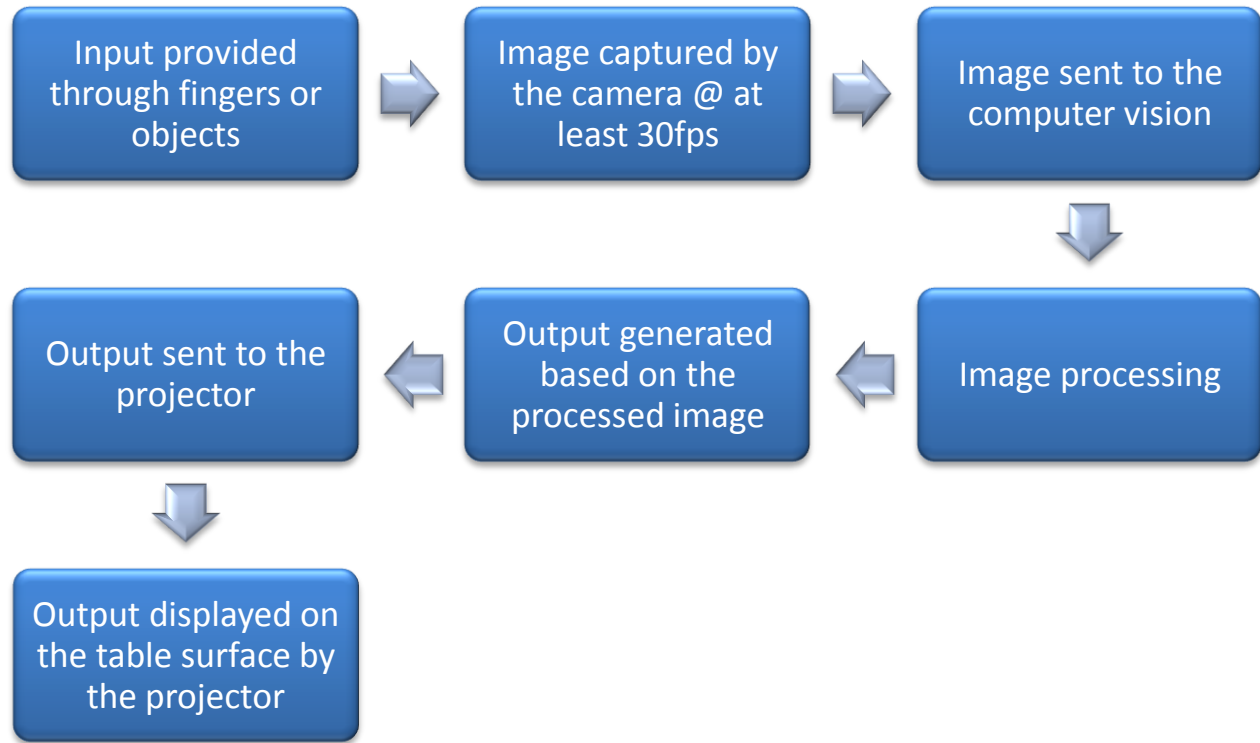
Figure1: *Process flow for the interactive touch table*

From the process flow as shown above, it is clear that the majority of the project depends on the image processing. For the image processing to be successful, proper selection and placement of the hardware is crucial. The quality of the image captured depends not only on the features of the camera and its distance from the table surface but also on the illumination provided by the IR LEDs as well as the transparency and material selection of the table surface. Similarly, the quality of the output and proper focus on the table surface depends on the focal length of the projector lens and the position of the projector compared to the table surface.

The hardware part mainly consists of camera, projector, IR LEDs, touch surface and a table frame to hold and support all of these parts.
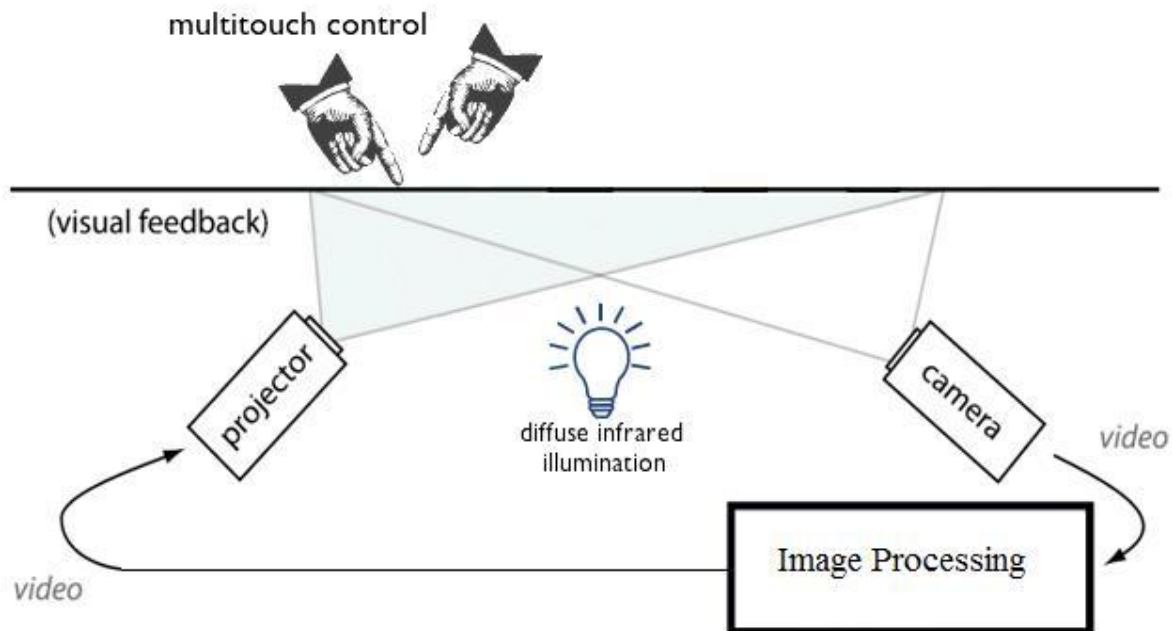
Figure2: *Preliminary design of the proposed interactive table.*

Credit: modification to the image available under Common Public License Version 1.0 (CPL)

Table surface:

Table surface is the primary hardware component which is also one of the most important parts that should be selected very carefully. It provides the input to the system, and also displays the output. Hence, it is essential to make the selection such that it works well for both input and output. After a great deal of research, it is decided that the table surface needs to be transparent enough to enable the darkened symbols to be detectable by the camera only when placed either directly in contact with the table or very close to it. Secondly, it must be opaque as to not allow a darkened figure or symbol to be detected when considerably displaced from the table. It needs to be light-weight but sturdy enough as multiple users interact with the table at the same time. Plexiglass is chosen for the table surface after some research. It is discovered that a plexiglass is 17 times stronger than the glass but only 50% of its weight, and has a huge selection of size, thickness and type such as clear, transparent, translucent, matte finish on one side, etc. These features of a plexiglass make it an ideal selection in our case. The plexiglass used in our project is 0.125 inches which is strong enough, and at the same time not too thick to distort the light. It is translucent with dimension of 22"x34" to allow enough room for multiple users.

Camera and IR LEDs:

A camera is used in our project to capture the image of the table surface and to send the image to the computer vision for image processing. The camera must be both programmable and able to detect in monochrome for computer vision reasons. Since the computer vision generates an output based on this image, it is of greatest importance for the image to be clear enough so that the finger and object tracking is accurate. Thus the camera plays a pivotal role in the overall success of the design. Primarily, it needs to be able to capture the whole surface, so a high resolution camera (at least 720X640, higher preferred) with a wide-angle lens is preferred because the distance between the surface and the camera is very short. Secondly, since a real-time feedback is absolutely necessary for the interaction, the camera needs to be able to capture images at a very fast rate. The desired rate is at least 30 frames per second so that the user can experience a smooth, real-time feedback. Also, to connect to the computer, an IEEE 1394 FireWire interface on the camera is considered to achieve the appropriate low latency real-time data transfer. Another requirement is CCD sensors. CCD sensors are created using a particular manufacturing process that allows current to run through its chips without distortion. This leads to very high-quality sensors that yield high fidelity and high sensitivity to lighting contrast over the CMOS technology. to the requirements is the availability of the interlaced mode. The interlace technique is usually used to improve picture quality of video signal. This method uses two fields, one containing the odd lines of an image and the other containing the evens, to display a frame. Problems arise under certain circumstances when an aliasing effect occurs. This generates "flickering" or "wiggling" frames that become a source of noise. This eliminates the choice of regular webcams used in the computer due to their low resolution and lower capture rate.

Additionally, before the selection of the camera, there is one more criterion that needs to be analyzed which is lighting conditions. It is important to realize the need of balance between the computer vision and human vision for accurate tracking and correct output. Computer vision is used for the input, i.e. for image capturing and processing, while the human vision is used to see the feedback that is projected by the projector. The human vision, which is the light coming from the projector, may easily interfere with lighting conditions required for the camera to be able to detect the objects. The light from the projector can result in a change in the illumination of the table surface, which will influence the quality of tracking. One solution to this problem is to use two different light spectra, one for tracking the movements of blocks and fingers, and the other for projecting the image. Since the output must be visible to the user, the light coming from the projector must be visible light (wavelength ranging from 400 to 700 nm), and the illumination of the table surface must be done be invisible IR light (wavelength ranging from 700 to 900 nm), so that an IR camera can be used to capture the image on table surface. The table surface can be illuminated using several IR LEDs placed below the surface. This would allow the illuminations for the camera and the projector to be independently adjusted without interfering with each other.

Possible camera models that fit the criteria are the AVT Guppy FireWire camera, the Unibrain Fire-I digital camera, the Prosilica line of cameras, and the Basler line of cameras. All other variables kept constant, the Unibrain Fire-I digital camera is chosen considering the cost factor. It is available for $100 - $150 which is a little expensive for our project but justified based on the features demanded by our design. The

Projector:

The projector gets the output from the computer vision and projects it on the table surface. The projector must have a lamp that can provide the right illumination to the table surface. In our design, the projector projects to a small screen (table surface) and the ambient light present will be low, thus the projector needs to have very low lumens. Since the projector must project to the whole surface and the distance from the surface to the projector is very short, it needs to have a wide lens and a resolution of at least 648*480 (or same as the resolution of the camera). In case the lens of the projector is not wide enough to display the output on the whole surface, the projector will project downward to a mirror which will reflect the projected light to cover the whole surface as shown in the figure below that displays the alternative design of the table.

Table Frame:

The table frame needs to be able to hold all the hardware parts used in the project. It will need a tray to hold the camera, projector and a PC. The dimension of the table is around 25'x37 so that it can fit the plexiglass, and that the height will be adjustable in order to make it appropriate for the use by kids. The table will have wheels for easy transport.
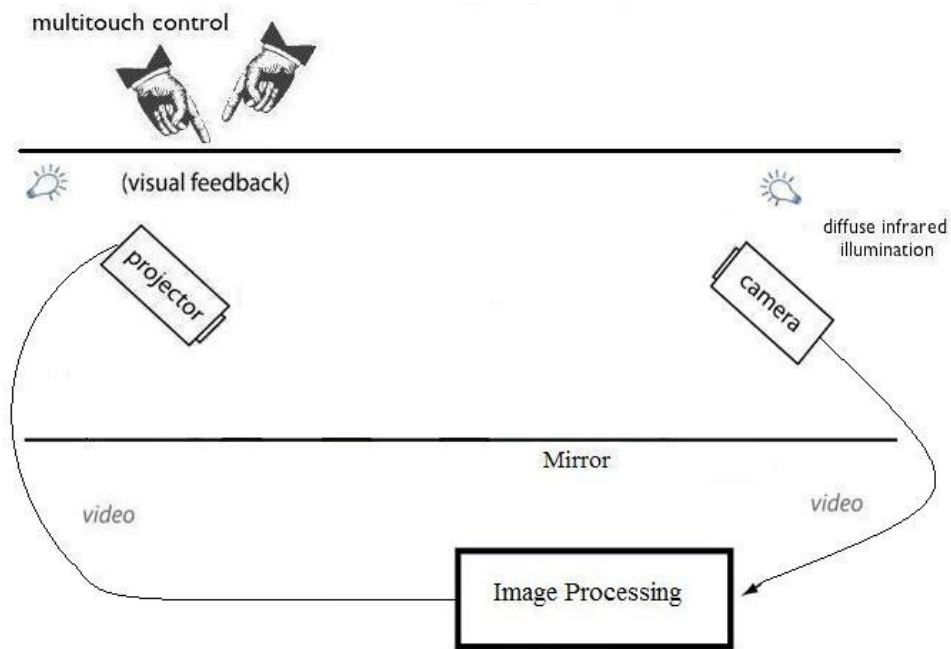

Figure3: *Alternative Design for the proposed Interactive Table in case the lens of the projector is not wide enough for projection onto the whole surface.*

Image Processing Fundamentals

An image can be defined as a two-dimensional function, f(x, y), where x and y are plane coordinates and the amplitude of f at any point of x and y coordinates is called the intensity level of an image at that point. In a digital image, x, y and the intensity level of f are finite value, and digital image processing means that those discrete quantities are processed by a digital computer. Components of digital image are known as pixels and they have to be finite value. Pixels can be thought of as small dots on the screen and image processing is used to color those pixels. In EducaTable project, time will also be taken into consideration since series of images must be processed to keep track of activity made by users on the surface of the table so that new function will be expressed as f(x,y,t).

Image Processing for EducaTable

Camera is used as a sensing device to obtain digitized quantity of an image based on the light intensity. In EducaTable project, camera will sense an image in Infrared (IR) bands that has the wavelength ranging from 760mm to 900mm. IR is used so that it can be distinguished from the visible light emitted from projector. By using computer, both the coordinates (sampling) and amplitude (quantization) will be digitized to convert sensed data (sinusoidal wave with amplitude as a voltage) to digital form.

Matlab Fundamental

MATLAB stores most images as two-dimensional arrays (i.e., matrices), in which each element of the matrix corresponds to a single *pixel* in the displayed image. For example, an image composed of 300 rows and 300 columns of different colored dots would be stored in MATLAB as a 300-by-300 matrix. In Matlab, there are a few types of images. Black & White images are called binary images, containing 1 for white and 0 for black. Grey scale images are called intensity images, containing numbers in the range of 0 to 255 or 0 to 1. Colored images may be represented as RGB Image or Indexed Image. For faster processing speed and saving storage purposes, binary images are used in the project.

Matlab Format

Binary image Processing

In MATLAB, a binary image is of class logical. Binary images contain only 0's and 1's. Pixels with the value 0 are displayed as black; pixels with the value 1 are displayed as white. This saves memory when processing an image (that is performing mathematical operations on an image) compare to other formats such as grey scale image (unit8 which ranges from 0 to 255).

Pixel Values in a Binary Image
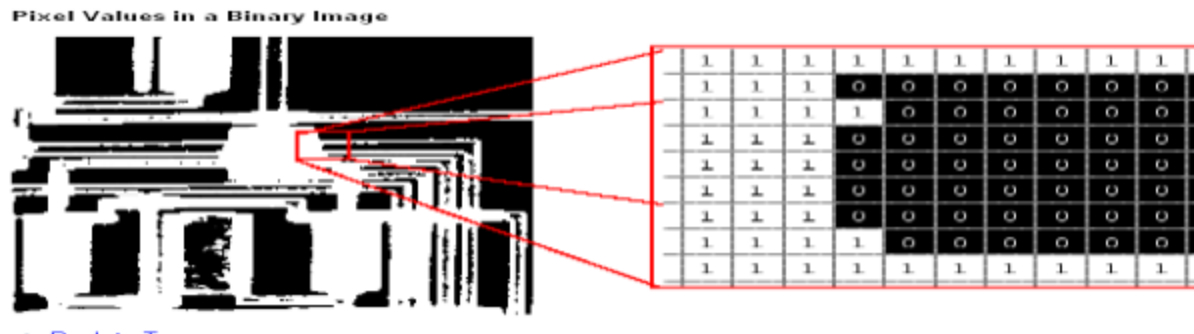
Matlab vs. C++

Matlab is very helpful for start designing any application, because it can be used to verify designs with minimum amount of coding since MATLAB provides many functions for image processing and other tasks. Also all the source codes of functions are accessible by any users, they can be modified for testing. However, for real-time application or for video/image processing, the processing delay is a critical issue. In this case we should switch over to C++ after some initial testing of algorithm in Matlab. By means of Matlab Compiler toolbox, conversion of .m files to C++ and vice versa is possible so that switching from Matlab to C++ should not be a problem during the course of the project.

Applications to Enhance Motor Skills

There are a number of applications that can be used through image processing to help kids develop their motor skills. Some of those applications are as follows:

- Race track
- matching images of animal with their names
- Adding multiple shapes to make a new shape
- Simple arithmetic operations
- Color snack

For instance, a projector can put an image of a race track in various difficulties on the surface of a table and a user will be asked to move a miniature car to complete the course. A computer will keep track of the movement of the car and give feedback in a real time. In Color snack, a table has images of various foods of one color. At the top are the symbols, "I tasted ___". At the bottom are the symbols for "I like ____". User can color the foods with the appropriate color and a computer will ask them to answer which foods they like by allowing them to selecting an image of food on the table. This will help them identifying a color, answering yes/no (ex. "Do you like carrots?") and naming different foods. All of the applications listed above can contribute to increase children's motor skills. These applications can be completed through image processing by capturing movements of blocks or fingers on a surface table.

Preliminary Experimentation Plan and Evaluation Criteria:

The design process includes a great deal of testing and experimentation. Experimental plan is as follows:

Design:

What is already known: Parts that are required for the design of the table.

Parts used: Table surface, camera, projector, computer, image processing software, visible light filters, IR LEDs, blocks with unique marks for input, and table frame and support.

What will change: Input (block type and position) and finger tracking.

What needs to be measured: For building of the hardware, the distance that the camera and projector must be placed in relation with the table surface must be measured. During the design, the capture rate of camera (fps), lumens and power usage of the projector, dimensions of the surface and the table frame for stability, and the sturdiness of the table surface itself will be measured as well.

What will be kept the same: The position of camera, projector, and table surface on the table frame will be fixed in relation with each other. For the selection of the camera, same surface will be used for each camera to determine the best camera. Similarly, for the selection of the surface, the camera used will be same for all surfaces.

Step-by-step procedure:

Tests and experiments in each step of building will be conducted for the selection of the best components.

Basic hardware (Selection of and experimentation with different surface material and cameras):
Several samples of plastic and acrylic sheets and two different cameras will be used initially. Eventually, there is a plan in place to buy a high quality webcam ranging from $50-$80 and a Fire-I camera ranging from $100-$150. The webcam is chosen to keep the cost low, and the Fire-I camera is chosen for better quality and capture rate (predicted in comparison to webcam). Several tests will be conducted including capture rate (frames per second) and video capture quality based on the evaluation criteria (table shown in the next page) to determine if the webcam can function as well as the Fire-I camera, and to determine the best choice for the surface.

Image Processing and Projection:
Simple test codes will be written at the beginning to process the video captured by the camera in real-time. The image processing will track the block position and movement on the table surface. Since image processing is the main part of the project and will determine the speed and performance of the end unit, lot of time will be invested on testing the code and continuously

improving on it by making it faster and better. For the image processing to be successful, the system needs to be able to identify the unique marks on the blocks and be able to track the movement of the blocks and finger touch in real time. Since the system is going to be interactive and the users get immediate feedback as they manipulate, it is very important that the system provides uncompromisable speed and accuracy when it comes to tracking the blocks and processing the information. At first, Matlab will be used for the image processing because it is simpler compared to C and also because of ample access to research on Image Processing in Matlab. If successful in completing the coding earlier than scheduled deadline, there is a plan in place to implement the Image Processing in C language since it is much faster than Matlab.

Projector setup and experimentation:
        Codes need to be tested with a projector. After the image processing, the computer sends the output to a projector which will display readable information such as words, symbols and images on the table surface. The projector needs to have lower lumens and needs to project to the whole surface from the bottom. It will also need to have lower focal length, since the table will not be very high. Distance need to be measured that the projector needs to be placed from the surface for best focus. Similarly, the camera position and its distance from the surface will also be determined on a trial and error basis in order to get the correct focus on the surface for tracking the objects.

Analysis of Data:
        After experimenting with the cameras and the surface sheets, the data collected from the experiments will be analyzed to select the best camera and the surface for the project. Similarly, the measurements recorded for the set up of camera and projector will be analyzed in order to build the table frame and support. The table below lists the evaluation criteria that will be used to make the best selection of the components for the design.

Evaluation Criteria:

Components	Criteria
Table surface	Translucent, leveled, round, and sturdy, light-weight, made up of plastic or acrylic material.
Camera	Programmable, able to detect in monochrome, at least 30 fps frame rate, video resolution of at least 640*480, higher preferred, IEEE 1394 FireWire interface, addition of visible filter and removal of IR filer.
Projector	Low lumens, low focal length.
IR LEDs	700 to 900 nm wavelength, enough to brighten the whole table sufficiently for the camera to be able to properly identify the objects.
Code	Able to track the blocks and movement in real-time with greater accuracy and speed.
Table Frame and support	Round frame to support the table surface. Table- strong and sturdy enough to hold all the components used.

<u>Preliminary list and brief description of tasks and allocation of responsibilities</u>

The **Project Manager** is responsible for ensuring that the Project Team completes the project. Alan Chong is the project manager for the team. He is responsible for developing the Project Plan with the team and managing the team's performance of project tasks. He is also responsible for communication, including status reporting, risk management, escalation of issues that cannot be resolved in the team, and, in general, making sure the project is delivered in budget, on schedule, and within scope.

The **Project Team Members** are responsible for executing tasks and producing deliverables as outlined in the Project Plan, at whatever level of effort or participation has been defined for them. The Team Members are Gopal Paudel, Kousaku Sato, and Pragyan Mainali. Everyone has a vital role in successfully completing this project.

More specifically, Gopal will be focusing on preliminary experimentation plan and evaluation criteria. He will be responsible for gathering data and experimenting as to the satisfactory of the expected results. He will also review evaluation criteria to see if it matches our specification.

Sato's primary function will be to test the design specification of the hardware. He will research on the materials needed for the optimum operation of the EducaTable. He will also help keep track of the progress report.

Pragyan will work with Sato in preparation of the hardware. He will research on image processing and help write the code for the software needed for the project.

Alan, the project manager, will make sure the project is being completed on timely fashion. On top of that, he will be actively involved in the coding of the software to help facilitate proper working of the camera and the projector.

Preliminary Schedule and Milestones

	ⓘ	Task Name	Duration	Start	Finish	Predecessors
1		⊟ 1. Building the Hardware	6 days?	Mon 10/19/09	Mon 10/26/09	
2	▦	1.1 Construction of Table	6 days?	Mon 10/19/09	Mon 10/26/09	
3	▦	1.2 Constrution of Glass Top	6 days?	Mon 10/19/09	Mon 10/26/09	
4		⊟ 2. Image Processing	49 days?	Mon 10/26/09	Thu 12/31/09	
5	▦	2.1 Test Coding	44 days?	Mon 10/26/09	Thu 12/24/09	
6	▦	2.2 Tracking	44 days?	Mon 11/2/09	Thu 12/31/09	
7		⊟ 3. Projection	20 days?	Mon 1/4/10	Fri 1/29/10	
8	▦	3.1 Test coding	20 days?	Mon 1/4/10	Fri 1/29/10	
9	▦	3.2 Tracking	20 days?	Mon 1/4/10	Fri 1/29/10	
10		⊟ 4. Hardware finishing	5 days?	Mon 2/1/10	Fri 2/5/10	
11	▦	4.1 Compilation of Projector and filtrati	5 days?	Mon 2/1/10	Fri 2/5/10	
12		⊟ 5. Aplication Analysis	15 days?	Mon 2/8/10	Fri 2/26/10	
13	▦	5.1 Math Concepts	10 days?	Mon 2/8/10	Fri 2/19/10	
14	▦	5.2 Math Problem Demonstration	5 days?	Mon 2/22/10	Fri 2/26/10	
15	▦	5.3 Commercial problem anylysis	5 days?	Mon 2/22/10	Fri 2/26/10	
16		⊟ 6. Improvements	22 days?	Mon 3/1/10	Tue 3/30/10	
17	▦	6.1 Any room for improvements??	22 days?	Mon 3/1/10	Tue 3/30/10	
18	▦	7. Demonstration	1 day?	Wed 3/31/10	Wed 3/31/10	
19	▦	8. Reporting	1 day?	Mon 5/3/10	Mon 5/3/10	

Gantt Chart

Ready

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W.S. Wilson. Elementary School Mathematics Priorities. AASA Journal of Scholarship & Practice, 6(1):40-49, Spring 2009. This comes complete with a rebuttal to precision.

Appendix B:

Design Document (ECE-492)

EducáTable
Design Document
ECE 492 Senior Design

Team Members: Alan Chong
Kousaku Sato
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Problem Statement

The February, 2006, U.S. Department of Education study, "The Toolbox Revisited," tells us that 80% of the 1992 U.S. high school graduating class went on to college. Only about half of those students graduated with a bachelor's degree. The others dropped out. Inadequate preparation for college mathematics was a major contributor to the dropout rate. The foundation for K-12 mathematics is laid in the early years of elementary school. To succeed in college, this foundation must be solid.

According to the research done at Purdue University, early kindergarten motor skills, especially visual motor skills, contribute to achievement in reading and mathematics at the end of first grade even after controlling for initial skills and demographic information. Furthermore, the results suggest the importance of the role that motor skills can play in designing and implementing an early school achievement battery. Table 1 displays correlations between reading and mathematics scores of fall kindergarten and spring first grade on the one hand and students' visual motor and gross motor skills of fall kindergarten on the other. Correlations revealed that visual motor skills had significantly higher correlations with cognitive achievement than did gross motor skills.

Table 1. Correlations of Motor Skills and Cognitive Skills

Subtests	Visual Motor Skills	Gross Motor Skills
Reading		
Fall kindergarten	.35	.15
Spring first grade	.40	.19
Mathematics		
Fall kindergarten	.44	.20
Spring first grade	.48	.22

Note: All significance levels are based on 2-tail tests using a normalized child weight.

All the coefficients were statistically significant at the level of $p < .001$.

As many government systems try to find ways to improve their education systems, there are still issues with standards of curricula for developing motor skills including basic mathematical skill in the preschool and elementary school settings. Children tend to develop their motor skills through common play more than reading books since they can ponder and reflect on experiences more easily through common play. Their perceptions are then represented by means of models, dramatizations, and art. Our goal is to provide a connection to children's natural interest in models and shape with their motor skills experience via an alternative interface.

To help children extend their everyday activities, from building blocks to art and stories to puzzles, the materials integrate three types of media: computers, manipulative (and everyday objects), and print. Pedagogical foundations were similarly established; for example, we reviewed research on making computer software problems for young children motivating and educationally effective (Clements, Nastasi, & Swaminathan, 1993; Clements & Swaminathan, 1995; Steffe & Wiegel, 1994).

In order to assist children develop their motor skills through play, EducáTable providers an interactive table for multiple users to solve given problems. This design uses the basic advantages of manipulating objects projected on the table surface and toy blocks with the graphical ability that computer technology allows today. The ability to project a variety of graphics permits a great range of concepts to be given to a user. The computer vision technology used against a surface allows multiple users to engage in the design, much like the software-based idea. The manipulation of blocks to children has always been a great appeal. Much study has put this notion of an interactive table to the test for feasibility to show this technology is strong in reliability. Therefore, EducáTable can be used as an appropriate teaching tool to satisfy the targeted problems in early education.

The EducáTable can be used in diverse fields. Not only it is beneficial to the education system, but also can be used as an interactive tool, a sophisticated gaming console, and an easy to use multimedia device. It is easily marketable to general public at an affordable price. If marketed properly, this device has a potential to grow globally.

1. Functional Design/Architecture

There are two basic levels in the functional design: level0 and level1.

Level0 is shown below, which is very basic and simple diagram of the design with two inputs to the system and the output from the system. The table below the figure describes each input, output and the functionality of the functional design of this level.
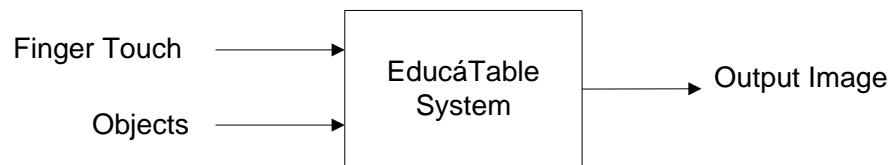
Fig: Level 0 EducáTable System functionality

Module	EducáTable System
Inputs	- Finger Touch input: can be multi-touch. - Objects: unique marking for each object to distinguish other input objects.
Output	- Image projected on the table.
Functionality	Produce an image based on the markings on the objects or the position of the finger touch, and display the image.

The figure below shows level 1 of the functional design. This design shows the main components of the system linked in order from input to output. The table below the figure describes each input, output and the functionality of the functional design of this level.
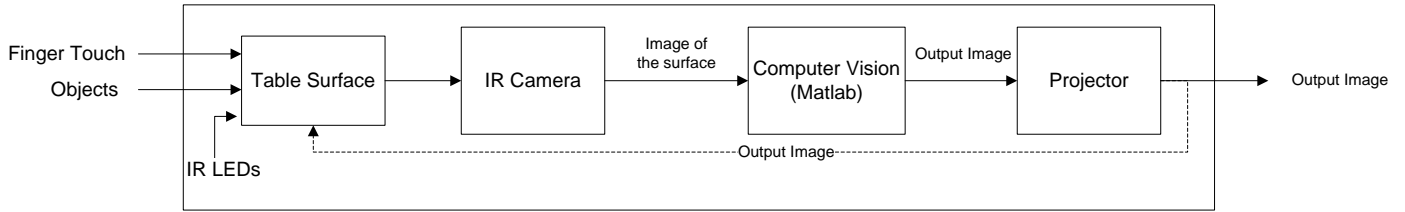
Fig: Level 1 EducáTable design

Module	Table Surface
Inputs	- Finger Touch input: can be multiple fingers. - Objects: unique marking for each object to distinguish other input objects/ can have multiple objects on the table. - IR LEDs: illuminate the table surface
Output	There is no output from the table surface. The table surface itself acts as the input to the camera
Functionality	Produce an image based on the markings on the objects or the position of the finger touch, and display the image.

Module	IR Camera
Inputs	- The table surface
Output	- IR image of the table surface @ at least 30fps
Functionality	Capture the image of the table surface @ at least 30fps and output it to the computer.

Module	Computer Vision/ Matlab
Inputs	- IR image of the table surface
Output	- Output image to be displayed on the table surface.
Functionality	Process the input image and produce an output image based on the input.

Module	Projector
Inputs	- Image: to be displayed on the table surface.
Output	- Image: same as the input.
Functionality	Project the input image to the table surface.

2. System Design/Architecture
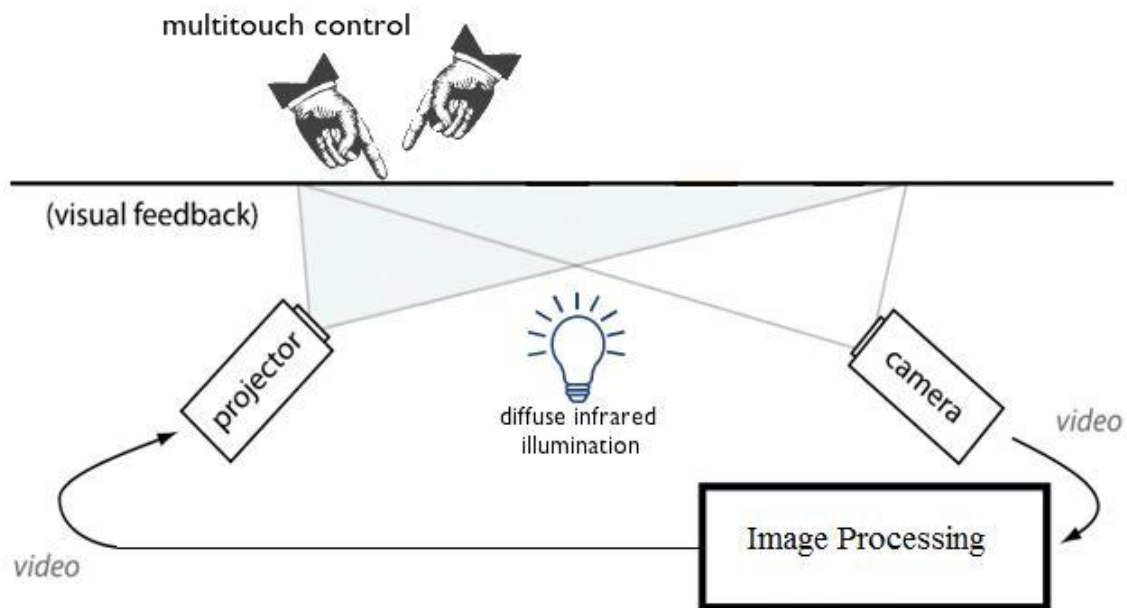
The EducáTable design is comprised of several system components in order to fulfill the desired requirements.

The following main components are used in the system design:

1. Table surface
2. Diffused IR lights
3. IR Camera
4. Computer
5. Projector

These components will be discussed in detail in the Detailed Design section of the report.

Fig: Top Level System Design for EducáTable

3. Detailed Design

3.1 Table surface:

Fig: Polycarbonate Sheet

Table surface is the primary hardware component which is also one of the most important parts that should be selected very carefully. It provides the input to the system, and also displays the output. Hence, it is essential to make the selection such that it works well for both input and output. The table surface needs to be transparent enough to enable the darkened symbols to be detectable by the camera only when placed either directly in contact with the table or very close to it. Secondly, it must be opaque as to not allow a darkened figure or symbol to be detected when considerably displaced from the table. It needs to be light-weight but sturdy enough as multiple users interact with the table at the same time. Plexiglass or Polycarbonate sheets are the best selection for the design. The dimension of the surface is desired to be around 2ft by 3ft.

3.2 Camera and IR LEDs:

A camera is used in the project to capture the image of the table surface and to send the image to the computer vision for image processing. The camera must be both programmable and able to detect in monochrome for computer vision reasons. Since the computer vision generates an output based on this image, it is of the greatest importance for the image to be clear enough so that the finger and object tracking is accurate. Thus the camera plays a pivotal role in the overall success of the design. Primarily, it needs to be able to capture the whole surface, so a high resolution camera (at least 640X480, higher preferred) with a wide-angle lens is preferred

because the distance between the surface and the camera is very short. Secondly, since a real-time feedback is necessary for the interaction, the camera needs to be able to capture images at a very fast rate. The desired rate is at least 30 frames per second so that the user can experience a smooth, real-time feedback. Also, to connect to the computer, an IEEE 1394 FireWire interface on the camera is considered to achieve the appropriate low latency real-time data transfer. Another requirement is CCD sensors. CCD sensors are created using a particular manufacturing process that allows current to run through its chips without distortion. This leads to very high-quality sensors that yield high fidelity and high sensitivity to lighting contrast over the CMOS technology to the requirements is the availability of the interlaced mode. The interlace technique is usually used to improve picture quality of video signal. This method uses two fields, one containing the odd lines of an image and the other containing the evens, to display a frame. Problems arise under certain circumstances when an aliasing effect occurs. This generates "flickering" or "wiggling" frames that become a source of noise. Possible camera models that fit the criteria are the AVT Guppy FireWire camera, the Unibrain Fire-I digital camera, the Prosilica line of cameras, and the Basler line of cameras. However, for the testing purpose, a mid-range USB Webcam is chosen.

Fig: Microsoft LifeCam VX-5000
Camera used for the testing purpose.

Additionally, before the selection of the camera, there is one more criterion that needs to be analyzed which is lighting conditions. It is important to realize the need of balance between the computer vision and human vision for accurate tracking and correct output. Computer vision is used for the input, i.e. for image capturing and processing, while the human vision is used to see

the feedback that is projected by the projector. The human vision, which is the light coming from the projector, may easily interfere with lighting conditions required for the camera to be able to detect the objects. The light from the projector can result in a change in the illumination of the table surface, which will influence the quality of tracking. One solution to this problem is to use two different light spectra, one for tracking the movements of blocks and fingers, and the other for projecting the image. Since the output must be visible to the user, the light coming from the projector must be visible light (wavelength ranging from 400 to 700 nm), and the illumination of the table surface must be done be invisible IR light, so that an IR camera can be used to capture the image on table surface. The table surface can be illuminated using several IR LEDs placed below the surface. This would allow the illuminations for the camera and the projector to be independently adjusted without interfering with each other.

Fig: IR LED

3.3 Projector:

The projector gets the output from the computer vision and projects it on the table surface. The projector must have a lamp that can provide the right illumination to the table surface. In our design, the projector projects to a small screen (table surface) and the ambient light present will be low, thus the projector needs to have very low lumens. Since the projector must project to the whole surface and the distance from the surface to the projector is very short, it needs to have a wide lens and a resolution of at least 640*480 (or same as the resolution of the camera). In case the lens of the projector is not wide enough to display the output on the whole surface, the projector will project downward to a mirror which will reflect the projected light to cover the whole surface.

3.4 Table Frame:

The table frame needs to be able to hold all the hardware parts used in the project. It will need a tray to hold the camera, projector and a PC. The dimension of the table needs to be around 2.2ft by 3.2ft so that it can fit the table surface, and the height needs to be no more than 3 ft in order to make it appropriate for the use by kids.

4. Prototyping progress report

4.1 Current Activity Report:

Several tests have been performed in concurrent with the project's requirement. Research has been done in image processing to adapt best possible solution to be implemented. Here are the lists of activities performed in the project.

1.   **Hardware**

Choosing the table surface is the crucial part of hardware design. The surface needs to be matte finished on one side and clear on the other side. This allows for tracking of finger(s) or object(s) on the surface easier to process. Several samples of the table surface have been collected. Mainly, three surfaces were tested on for the tracking: clear glass, Polycarbonate, and acrylic sheet. The following picture shows the test done with an acrylic sheet and an USB webcam:
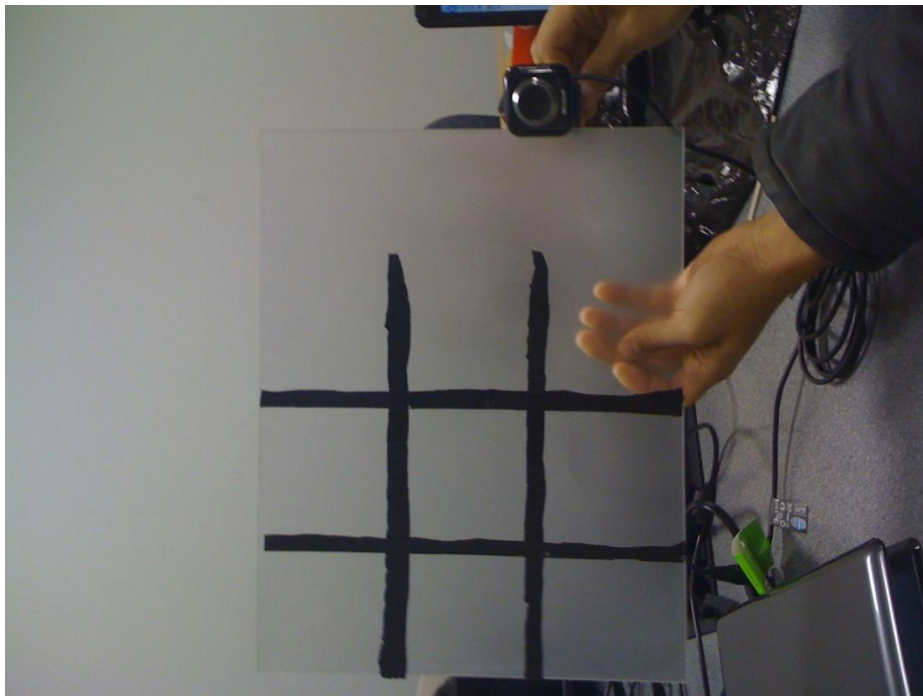
Fig: Acrylic Sheet with grid lines defined to track images to be processed.

Another hardware that was used in the test was a webcam. Microsoft LifeCam VX-5000 USB Camera was chosen for the testing purpose. It has a video resolution of 640 x 480 and capture

rate of 30 frames per second. This is not the optimum image capturing device for the project, but definitely a best and economical alternative to run tests.
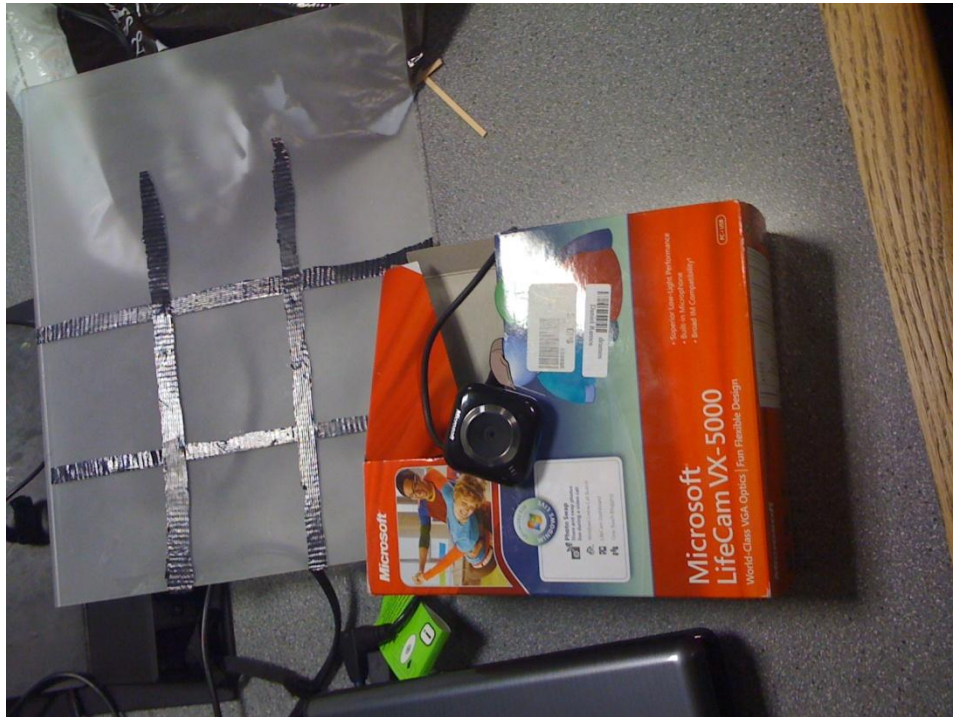
Fig: Microsoft LifeCam VX-5000

2.   **Software**

Image processing is the fundamental of this project. MATLAB has been the primary software to process images captured from the webcam. Tests on reacTIVision, the open source software provided by the reactable.com, were done to complement the results from MATLAB. Here are the screenshots of images captured using reacTIVision:
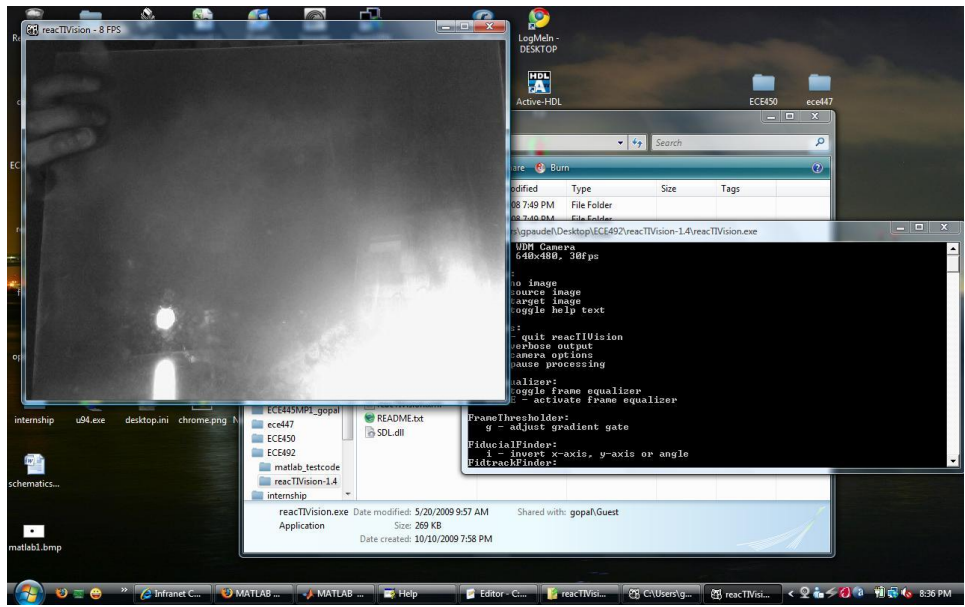
Fig: Clear side of the surface facing the camera with light source pointing at the surface.
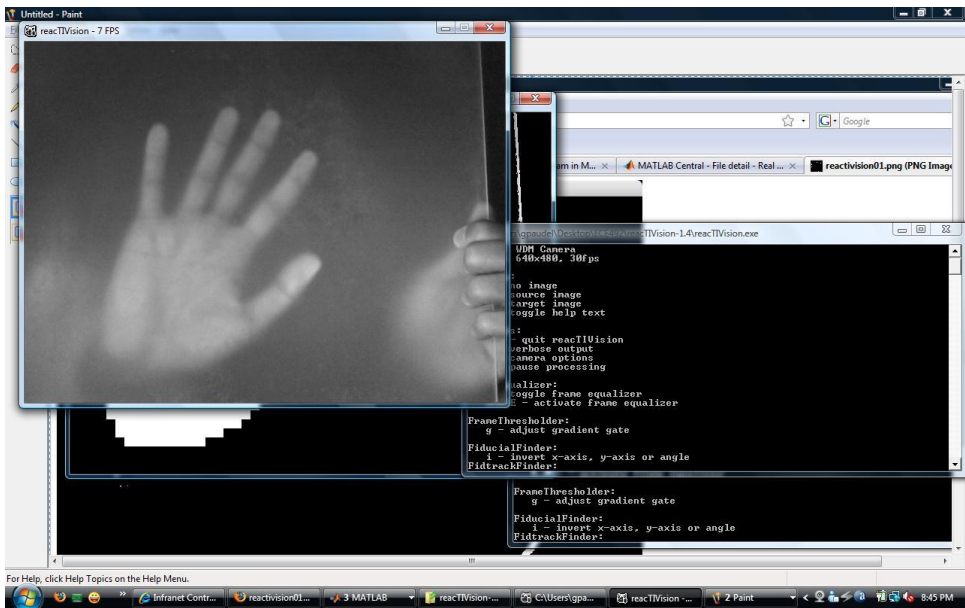
Fig: Flashlight bouncing off the table.
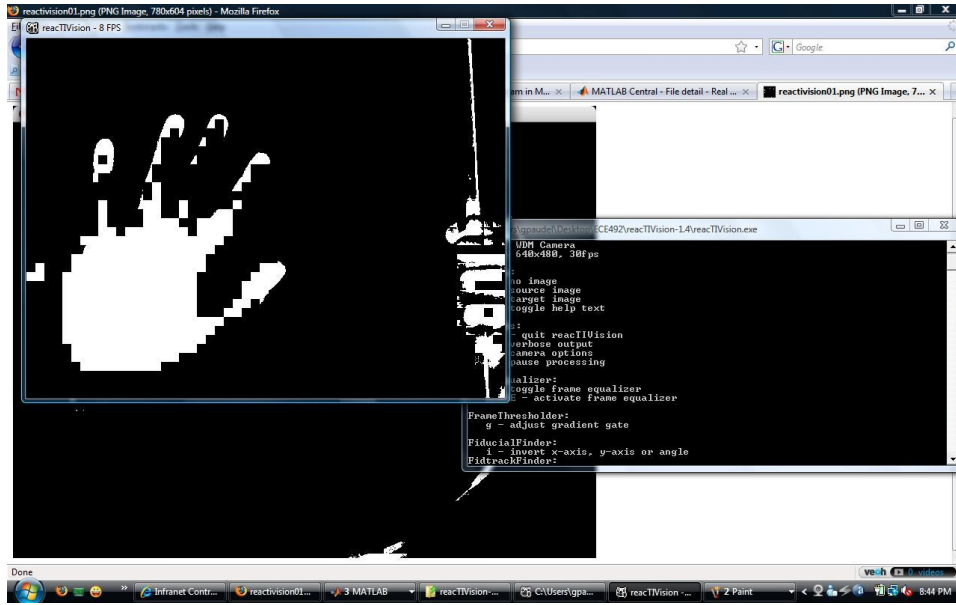
Fig: Binary image of the previous image
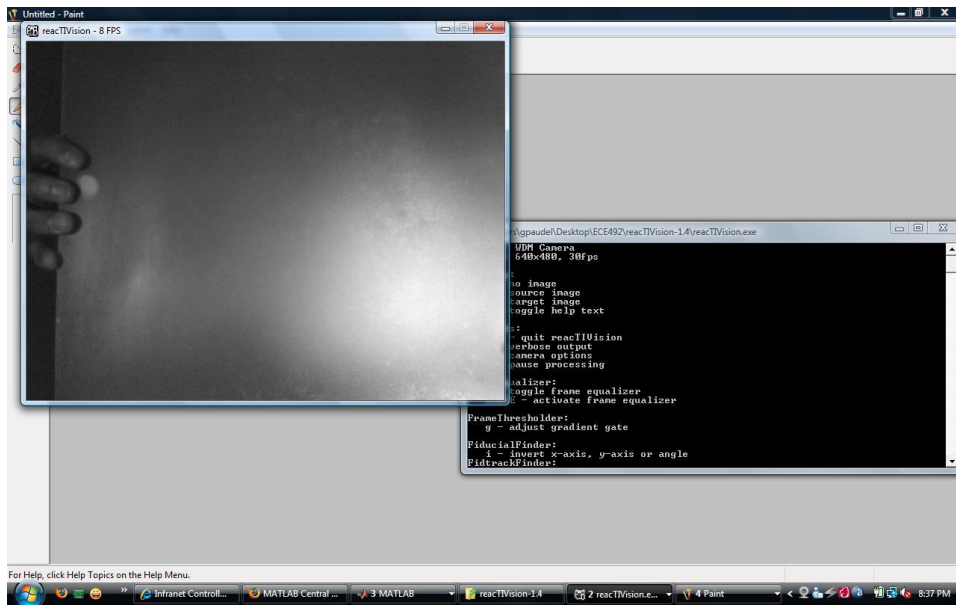
Fig: Matte side facing the camera
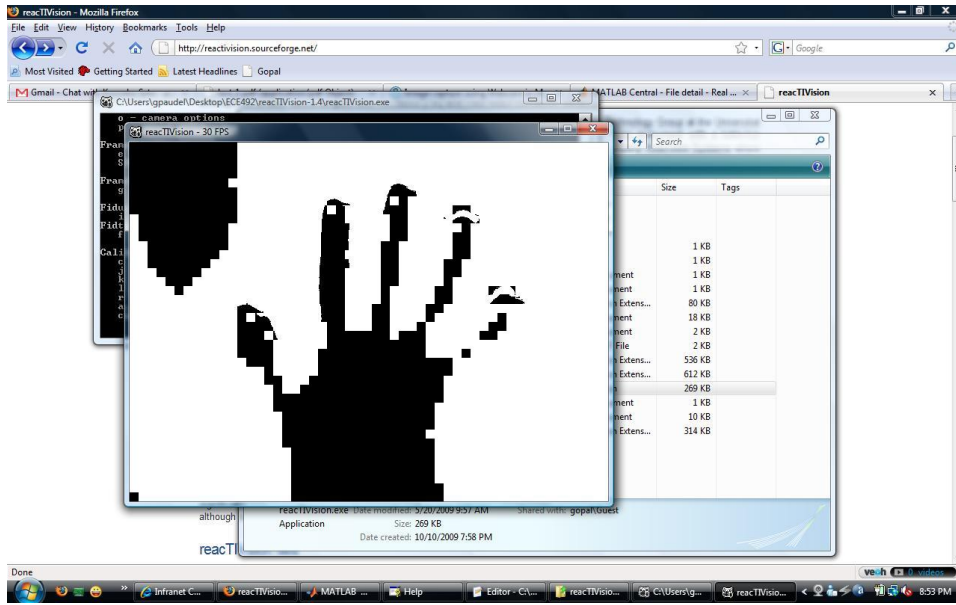
Fig: Binary image (ambient light, no flashlight source on surface)

4.2 List of prototyping activities for the next 2 weeks:

Nov/Dec 2009

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
22	23 Group Meeting : Task Breakdown; Progress Report	24 Matlab Simulation	25	26 Thanksgiving Day; Enjoy Holiday :)	28 Matlab Simulation	28
29	30	1 Order surface glass online	2	3 Pre-Construction of surface table	4	5

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4.3 Problems/Surprises:

First, Matlab code was implemented for reading and displaying the image from the camera. The processing time was calculated for each frame. The biggest surprise was the time lag. It took 1.038315 seconds to process a single frame. The following MATLAB code was used for primary testing:

```matlab
%this function creates a video input object and then reads an image frame from
the webcam, then displays it on the computer.

function compute()
vid = videoinput('winvideo');
start(vid);
data = getdata(vid,1);
imshow(data);
stop(vid)
```

Using the tic toc commands, time taken for each line was found to be as follows:

```
vid = videoinput('winvideo');        0.041082 seconds
start(vid);                          0.150030 seconds
data = getdata(vid,1);              0.635185 seconds
imshow(data);                        0.046512 seconds
stop(vid)                            0.165506 seconds
Total time:                          1.038315 seconds
```

The processing time was found to be 1.038315 seconds for each frame which means less than 1fps was achieved using the above code. Our design requires at least 30 fps for real-time output. So, research was done on alternative ways on MATLAB to achieve faster processing time on images from camera. One of the alternatives was found to be Simulink. The above code was implemented in Simulink and the total time required to process each frame was calculated.

The following shows the schematic and the output in Simulink:

Fig: Schematic for taking input from USB Webcam and displaying on the computer screen.

By using Simulink, almost real time video processing was achieved.

In any multitouch application, output is a real-time feedback of the input.

For testing Simulink with the camera and the input image obtained by the camera, the following Simulink schematics was used, in which the output is based on the input and is determined by the function in Embedded Matlab Function block. The input image is analyzed in the *Embedded Matlab Function* block and the image to be projected is chosen based on the analysis.
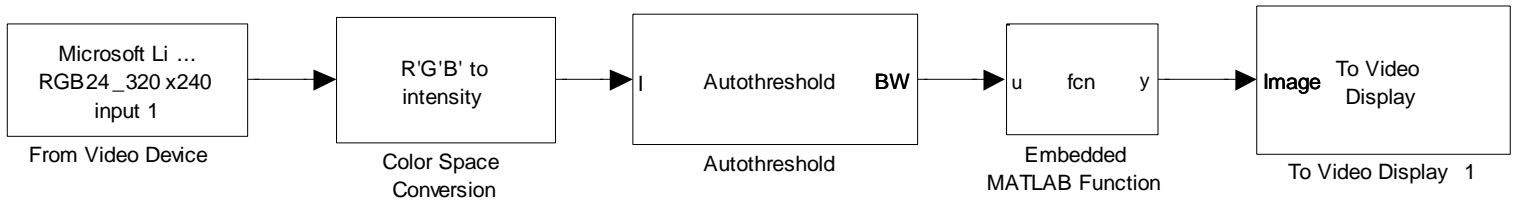
Fig: Schematic for displaying the output based on the input image from the camera

5. Experimentation Plan and Evaluation Criteria

The bulk of experimentation plan will encompass software component of the project. A program written in Matlab/Simulink will be tested by the following order.

5.1 Template Matching

In order to identify objects, image processing technique, known as template matching, will be used to accomplish the job. Template matching is a technique in image processing for finding sub regions of an image which match a template image. The matching process moves the template image to all possible positions in a larger source image. So when an object is placed on the surface of the table, a camera will capture the image and send its information to a computer and the image will be compared with pre-programmed templates in Matlab which contain the matrices of pixel values for each unique shape. Then, it computes a numerical metric that indicates how well the template matches the image in that position. There are certain techniques to obtain numerical values during matching process, such as Sum of Absolute Differences (SAD), Sum of Squared Differences (SSD), Maximum Absolute Difference (MaxAD). The size of the valid region can be calculated by the difference between the sizes of the input and template images plus one.

$$\text{size}_{valid} = \text{size}_{input} - \text{size}_{template} + 1$$

In order to achieve a real-time video processing, the project requires a fast search method to choose the best match between templates and captured image. The most exhaustive method will be to compare each pixel of the image. Even though result of this searching method will probably produce very precise result, it will take relatively considerable amount of time and might slow down the process. Therefore, it is important that we explore other search methods to solve this problem. Some of the alternatives for searching methods are as follows:

1. The search starts with a step size equal to or slightly greater than half of the maximum search range.

2. The block compares nine search points in each step. They comprise the central point of the search square, and eight search points located on the search area boundaries.

3. The block decrements the step size by one, after each step, ending the search with a step size of 1 pixel.

4. At each new step, the block moves the search center to the best matching point resulting from the previous step.

The speed of matching process for each alternative is top-down, the fastest to the slowest. The best method will be chosen in terms of criteria, such as precision and speed.

5.2 Box Recognition on Table Surface

In order to detect a block placed by user on a table surface, four black marks of the equal size are painted on edges of the block. If the camera detects the marked edges, it can be said that the box is placed on the table and there is a shape to be identified by template matching technique that was discussed earlier. The following is the drawing of the box that has marks on the edges and a shape to be identified.
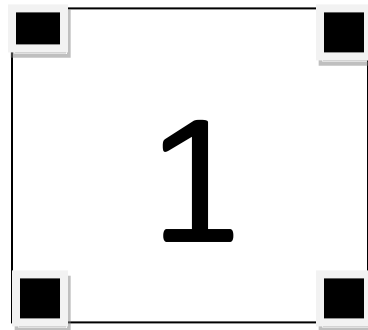
By locating the black marks on the edges of the block prior to identifying an object, one can make sure that a recognized shape will match with one of templates, but not the other sources of image (ex. a hand). This will allow a camera to detect multiple boxes anywhere on a table surface easily and possibly reduce errors during searching process. The most important evaluation criteria for this experiment will be precision in locating boxes on a table surface.

5.3 Identifying a Shape in Any Orientation Angle

A general template matching method can be prone to error when a shape is rotated in some degrees of angles since the order of pixel vales in matrices of the obtained image will differ according to orientation angle. One way to identify the shape in any orientation by means of template matching is to compare images in terms of ratio of white and black, which is equivalent to binary values '0' and '1'. Regardless of a change in orientation of an image, numbers of '0' and '1' will remain almost unchanged(if not exact the same, set the range for matching) for the same image shape, and therefore, by comparing the ratio of black and white of image with another, we can identify a shape in any orientation angle. Evaluation criteria is the consistency of the ratio of white and black of an image in multiple experiments since the result will directly contribute to how precisely we can identify the shape.

5.4 Fiducial Location and Orientation

Another alternative is to use something similar to a method that the program reacTIVision uses to identify location and orientation of an object and it is to use fiducials that are identified purely by their topological structure. Each fiducial in a set has a unique topology. In addition to expressing the correct topology, the geometry of each fiducial is constrained by the method used to compute its location and orientation. One way to compute fiducial location and orientation is to design a segmentation algorithm, which might only retain axis aligned bounding boxes for each region. The center of a region's axis aligned bounding box can provide a good approximation for the center of the region if the region is square, circular, and/or relatively small. As leaf regions will always be the smallest regions in a rendering of a tree, their centers are likely to be the most accurate spatial information we have about a fiducial. Consequently, computation can be implemented on a fiducial's location and orientation as a combination of the bounding box centers of its leaf nodes.

As illustrated in the following, the center point of the fiducial by taking a weighted average of all leaf centers. The vector from this centroid to a point given by the weighted average of all black (or white) leaf centers is used to compute the orientation of the fiducial. Each leaf is weighted by a function of its depth in the tree to account for the total area it consumes. This method can be effective because it can be applied to any fiducial with at least one black and one white leaf region.
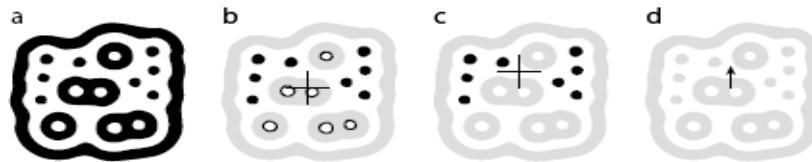
Figure 5: (a) a reacTIVision fiducial (b) black and white leafs and their average centroid (c) black leafs and their average centroid, and (d) the vector used to compute the orientation of the fiducial.

This experiment can be evaluated in terms of precision and speed in identifying a shape and its location as well as its orientation and the result will be compared to the method of using ratio of white and black that was discussed previously.

5.5 Finger Detection & Tracking

In real-time, the system can track the position and motion of the finger. The first phase of the tracking system involves separating potential hand pixels from non-hand pixels. Since the web camera is mounted under a non-moving workspace (a table), a simple background subtraction scheme is used to segment any potential foreground finger information from the non-changing background scene. At system startup, a background image x is captured to represent the static workspace from a camera. Subsequent frames then use the appropriate background image to segment out moving foreground data. In other words, for each pixel in frame i, the foreground mask image IF (for a camera) is computed as: $IF = 0$ $|Ii - x| > \sigma_x$ or $IF = 255$ otherwise, where σ_x is a fixed threshold to differentiate foreground data from background data. It is to be noted that background subtraction is performed in Grey scale color space with 8-bits per color channel. The

resulting *IF* is a binary image with a single 8-bit channel. One of the goals in this experiment is to find good/working value for σ_x and evaluation criteria is how well σ_x can differentiate static background and foreground image. For tracking, change in background and foreground image will be updated on previously captured image in each frame cycle so that path of finger movement on a table surface can be observed. The evaluation criterion for this experiment is how fast a finger can move without losing track of its motion during video processing.

6. Allocation of Tasks and Responsibilities:

The tasks for this project have been divided among the team members as provided below:

Hardware Design:

- Table construction using purchased surface materials
    - Pragyan Mainali and Alan Chong
- Researching and Purchasing a projector and a camera
    - Kousaku Sato and Gopal Paudel

Programming:

- Image/Video Processing using Simulink
    - Kousaku Sato, Gopal Paudel, Pragyan Mainali, and Alan Chong
- Writing Code for Application
    - Kousaku Sato, Gopal Paudel, and Pragyan Mainali

Research on Hardware:

- Kousaku Sato, Gopal Paudel, Pragyan Mainali and Alan Chong

Research on Image/Video Processing

- Kousaku Sato, Gopal Paudel, Pragyan Mainali and Alan Chong

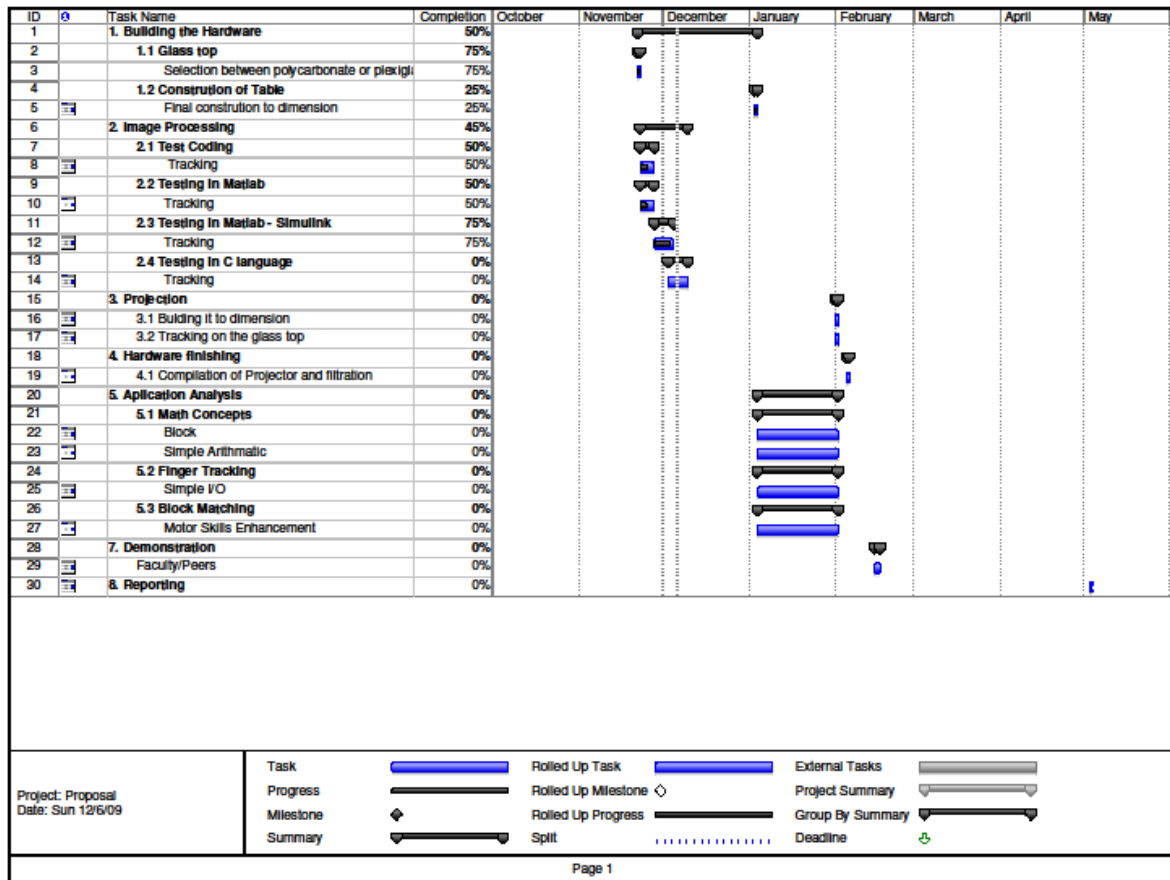**Program Troubleshooting for Hardware**

- Pragyan Mainali and Alan Chong

Program Troubleshooting for Programming

- Kousaku Sato and Gopal Paudel

Technical Writing

- Kousaku Sato, Gopal Paudel, Pragyan Mainali

7. Final Schedule and Milestones:

ID		Task Name	Completion	October	November	December	January	February	March	April	May
1		1. Building the Hardware	50%								
2		1.1 Glass top	75%								
3		Selection between polycarbonate or plexigl	75%								
4		1.2 Constrution of Table	25%								
5		Final constrution to dimension	25%								
6		2. Image Processing	45%								
7		2.1 Test Coding	50%								
8		Tracking	50%								
9		2.2 Testing in Matlab	50%								
10		Tracking	50%								
11		2.3 Testing in Matlab - Simulink	75%								
12		Tracking	75%								
13		2.4 Testing in C language	0%								
14		Tracking	0%								
15		3. Projection	0%								
16		3.1 Bulding it to dimension	0%								
17		3.2 Tracking on the glass top	0%								
18		4. Hardware finishing	0%								
19		4.1 Compilation of Projector and filtration	0%								
20		5. Aplication Analysis	0%								
21		5.1 Math Concepts	0%								
22		Block	0%								
23		Simple Arithmatic	0%								
24		5.2 Finger Tracking	0%								
25		Simple I/O	0%								
26		5.3 Block Matching	0%								
27		Motor Skills Enhancement	0%								
28		7. Demonstration	0%								
29		Faculty/Peers	0%								
30		8. Reporting	0%								

Project: Proposal
Date: Sun 12/6/09

Task		Rolled Up Task		External Tasks	
Progress		Rolled Up Milestone ◇		Project Summary	
Milestone ◆		Rolled Up Progress		Group By Summary	
Summary		Split		Deadline ⇩	

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