DESIGN OF AN INFRARED MULTI-TOUCH SURFACE FOR USE AS A COMPUTER KEYBOARD

by

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ABSTRACT

A multi-touch surface was designed and constructed to detect a person's finger when pressed against the touch surface, with the objective of developing a prototype touch surface computer keyboard. The prototype developed was a nine-key multi-touch surface designed to utilize the FTIR touch screen method while also maintaining a low profile. To ensure a low profile, the final design utilizes infrared phototransistors to detect and interpret incoming infrared light reflected off a user's finger in contact with the touch screen. The device proved it was capable of accurately determining which key(s) a user wished to activate. The keyboard measures 0.92" high which was within a 1" maximum thickness functional requirement.

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Table of Contents

Table of Figures

Tables

Chapter 1: Background

Touch surface technology has become prevalent in a wide range of modern devices. It is utilized by a large number of mobile phones and tablets. Most laptops also provide a touch surface tracking pad rather than a conventional mouse, and some now also have a touch screen. Touch surface technology has not, however, been able to penetrate into the computer keyboard market as of yet. Using knowledge provided by previous research, this paper focuses on the creation of a computer keyboard that uses touch surface technology rather than mechanical keys.

While touch surfaces have existed since the late 1960s, they have only really become prevalent in the past decade. The original patent, filed by Eric Arthur Johnson and awarded in 1969, covered both capacitive and resistive touch surfaces,[1] which are two of the most common types seen today. The reasoning behind both being in the same patent is that both function in very similar ways. When the user makes contact with the touch surface, a change occurs in the state of the electrical system. If the touch surface is capacitive, the surface is designed to continuously conduct an electrical field. Touching the screen introduces the user's capacitance and thus disrupts the electrical field at that point. In the case of resistive touch surfaces, the touch surface is layered with conductive material. Touching the surface creates a short circuit between the layers at the point of contact. The original patent utilized embedded electrical wires, though modern touch screens like those in smart phones and tablets utilize thin conductive sheets.[2]

A more modern design for a touch surface uses infrared light as the method of touch detection. The use of infrared light, however, can be realized in several different ways. One method known as Laser Light Plane Illumination (LLP) is shown in Figure 1. This method utilizes infrared lasers projected just above the touch surface to create a plane of infrared light. When an object (finger, stylus, or otherwise) touches the screen, it breaks the laser plane and causes infrared light to scatter at that point.[3]

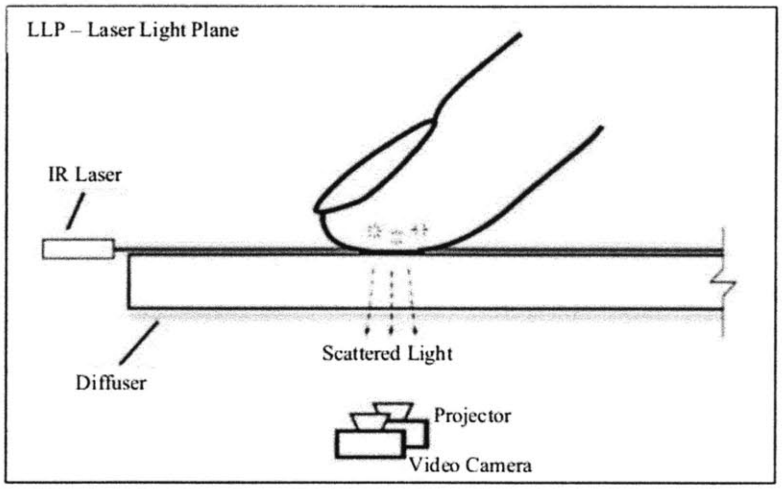

Figure 1 Illustration showing Laser Light Plane Illumination (LLP) Method. When the finger breaks the laser plane, infrared light is scattered and detected by a video camera below the touch surface.

Another method shown in Figure 2 is known as Rear Diffused Illumination (RDI). In this method, illuminators are placed below the touch surface and project infrared light upwards. When contact is made with the touch surface, infrared light at that point is scattered and reflected back down. In both cases a camera or sensor below the touch surface can register and locate the scattered light.[4]

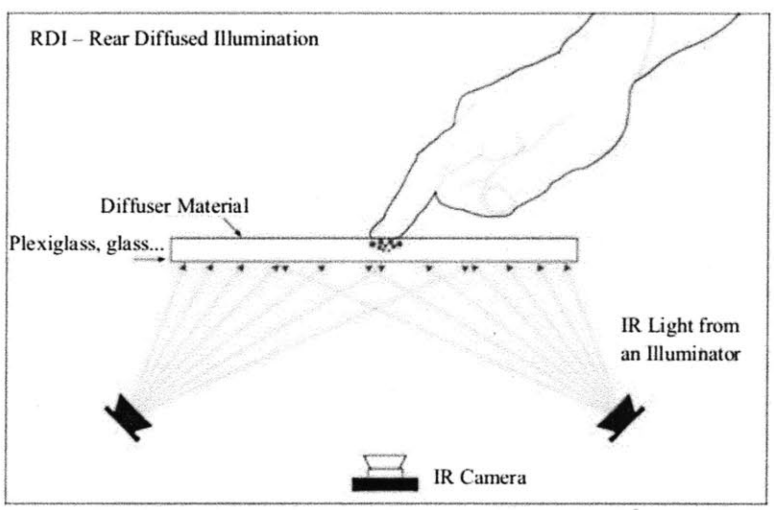

Figure 2: Illustration showing Rear Diffused Illumination (RDI) Method. The infrared light reflected off the finger is more intense than reflections from the other regions, and detectable by the infrared camera.

Another recent, popular method involves shining infrared light into the touch surface rather than above or below it. To achieve this effect, the device makes use of the optic phenomenon by which light is refracted when it enters a material with a different refractive index. Knowing what material the touch surface is made of, the material's refractive index, and the refractive index of the surrounding material, the critical angle can be mathematically calculated using Snell's Law. If light attempts to exit the material an angle greater than the critical angle, the light is instead reflected back into the material.[5] This phenomenon, known as total internal reflection, can be seen when infrared light is projected into an acrylic sheet. The infrared light is unable to pass from the acrylic into the surrounding air. If, however, the acrylic comes into contact with a material possessing a greater refraction index than air, the light becomes frustrated and is diffused at the point of contact as shown in Figure 3.[6]

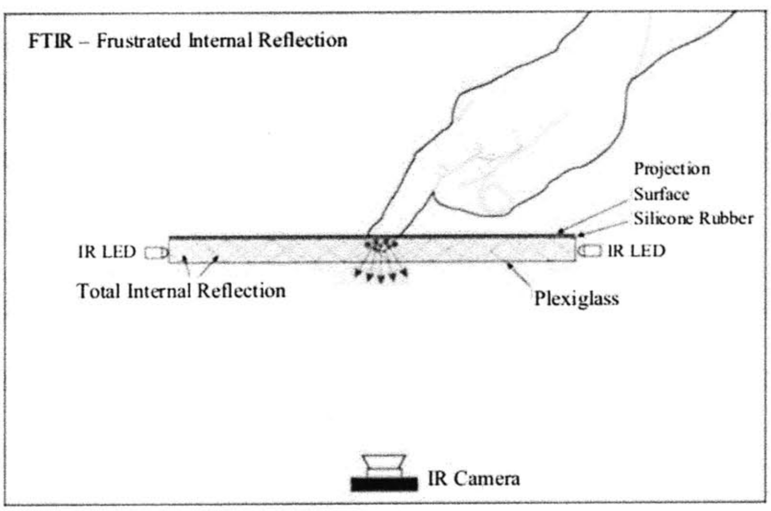

Figure 3: Illustration showing Frustrated Total Internal Reflection (FTIR) Method. The infrared LEDs shine directly into the side of the acrylic, causing total internal reflection of the light.

In 2005, Jefferson Han used this property to create a Frustrated Total Internal Reflection (FTIR) touch screen. By placing an infrared camera below the touch surface, Han was able to register and locate where users touched the screen based on where points of frustration occurred.[7]

Chapter 2: Introduction

While touch surface keyboards are not a new technology, there is a need for further development related to the use of touch surface technology in the design of a computer keyboard. Touch surface technology is already used in many modern devices such as track pads and tablets, and many touch screens incorporate software to enable typing with an on-screen keyboard. This technology has unfortunately overlooked desktop applications, namely switching out the mechanical keyboard with a touch surface keyboard. It is very likely possible to program an app that could make a tablet function as a desktop keyboard, however this idea can be costly if all the user wants is a computer keyboard. Thus the goal of this research is to find a method of building a functional touch surface computer keyboard for use at desktops or similar work stations.

The following research pertains to the design of an infrared 9-key touch surface keyboard. The first step of this design was to outline functions that are necessary for the keyboard to successfully perform. This chapter discusses these functional requirements and the constraints that led to implementing infrared phototransistors in the prototype design. The functional requirements for a mechanical keyboard are described in Table 1. These requirements were created in order to ensure that the keyboard will be capable of detecting physical inputs (fingers pressing the keys) and translating those physical inputs into digital inputs for the computer to interpret. Additionally, most mechanical keyboards incorporate some form of physical feedback to tell the user that the physical input has been registered.

Table 1: Functional Requirements for mechanical keyboards

Functional Requirements for Mechanical Keyboards
Detect finger pressure on keys
Translate pressing keys into electrical signals
Low profile to allow for easy usage
Provide a form of haptic feedback to confirm the keystroke was made (optional)

The primary requirements for keyboards are the detection of haptic input, pressing the key(s), and translating that input into electrical signals. These signals can then be sent to a computer and translated in a variety of ways, such as making a letter appear on the screen or move an avatar inside of a videogame. Mechanical keyboards complete this task through the use of keys that, when pushed, complete a circuit. Pressing different keys changes which circuit or circuits are completed. These circuits act as an input signal (often to a computer) that can determine the desired input based on which circuits are completed.

Additional considerations for the functionality include the usability of a keyboard. Modern keyboards must be easy to use in a wide range of user settings. Typists place their keyboards in a wide range of locations ranging from on top of a desk to on the users lap. Many work stations have a sliding drawer where the keyboard is kept underneath the table. To ensure that the product is easy to use for the largest number of people, keyboards are designed to maintain a low profile. This ensures that the keyboard will be able to fit into most (if not all) locations where a user may wish to store the device.

The final functionality included in many mechanical keyboards is that a physical signal is returned to the user upon pressing a key and successfully completing the input circuit, known as "haptic feedback." This comes standard with most mechanical keyboards in the form of a slight "bump" during the pressing of the key. Such feedback gives users confirmation that the keystroke was completed. There are, however, a number of keyboards manufactured without the "bump" and instead rely on the key being stopped by hitting the bottom of the keyboard itself (aka "bottoming out") to provide the necessary physical feedback. For this project no haptic feedback was incorporated due to the added complexity. Future iterations of the keyboard may come equipped with a screen vibrator similar to those used in smartphones and tablets.

Chapter 3: Component Selection

3.1 Touch surface functional requirements

For the touch-surface keyboard prototype, the functional requirements are very similar to those required for mechanical keyboards. These requirements are shown in Table 2.

Table 2: Functional Requirements for the prototype keyboard

Functional Requirements for Prototype Touch Surface Keyboard
Detect haptic pressure on the touch surface and translate it into electrical signals
Determine the position of haptic input.
Low profile (max height of 1 inch)

The primary requirement for the keyboard prototype to meet is detecting haptic input. To complete this task, the prototype will utilize touch surface technology to detect finger position on the screen surface and translate that position into an electrical input. Table 3 outlines the different touch surface methods considered and ranks their strengths and weaknesses in the form of a Pugh Chart.

Table 3: Pugh Chart of possible touch surface methods. Upon weighing the pros and cons of each method (scores based on the scale "+" as 1, "=" 0, and "-" as -1), it was determined that the Diffused Surface Illumination (DSI) method was the best choice for this project.

Sensing Method	Cost	Construction	Profile	Sensitivity	Calibration	Net Score	Rank
Capacitive	-	-	+	-	=	-2	5
Resistive	-	-	+	-	=	-2	5
Rear Diffused Illumination (RDI)	=	=	-	+	-	-1	4
Diffused Surface Illumination (DSI)	=	+	=	+	=	2	1
Frustrated Total Internal Reflection (FTIR)	=	=	=	+	=	1	2
Laser Light Plane (LLP)	+	+	=	=	-	1	3

All six forms of detection are capable of detecting a single input, such as a stylus or single keystroke. For keyboards, however, multiple inputs may be present at any given time depending on the key setup. This obstacle is circumvented in most modern cellphones by the ability to change the value of a given key. For example, pressing one key can make all keys capitalize, while another can switch from a letter layout to numbers or symbols. This form of typing, while useful for one-handed applications, is less desirable in the case of computer keyboards. The first two methods of detection, capacitive and resistive, are useful for this one-handed application but are incapable of detecting multiple simultaneous inputs. Thus, despite benefiting from possessing naturally thinner profiles, both capacitive and resistive methods are inappropriate methods of detection. In a comparison between the remaining four methods, the LLP method falls short similar reasons. The LLP method has the advantages of being simple to assemble at a low cost and can detect multiple finger positions at once. Its main drawback is the possibility of occlusion with multiple inputs. Occlusion is where one input can potentially overshadow another input. When the laser plane is broken by an input, anything behind that point is not "visible" from that laser. If another input is placed in this "shadow," it will not be registered by the touch surface. The problem of occlusion can be reduced through the use of multiple laser emitters, which in turn makes assembly more complex and time consuming. Each emitter must also be aligned properly, or else the touch surface will not function properly. Due to these implications, the LLP method is not a valid choice for this prototype.

The three remaining methods all utilize infrared and, to ensure proper transmission of the infrared light, an acrylic touch surface. Both FTIR and DSI methods function by shining infrared light into the side of the acrylic layer, resulting in total internal reflection through the acrylic sheet. When contact is made with the surface of the acrylic sheet the infrared light becomes frustrated and diffuses. The main difference between the two methods is that DSI requires a particular type of acrylic for the touch surface known as EndLighten Acrylic. EndLighten acrylic contains embedded particles that reflect the infrared so that it remains near the surface. FTIR utilizes more generic acrylic but does require an additional compliant surface above the acrylic. The RDI method involves shining infrared light from below the top surface which is then reflected back down when contact is made with the touch surface. For RDI to function most effectively there must be some distance between the infrared emitters and the touch surface. This additional depth makes the RDI method impractical for use in this low-profile keyboard prototype. A comparison of the remaining two methods reveals that the DSI method is the optimal choice for the current prototype. While both DSI and FTIR benefit from having low profiles, the DSI method requires fewer steps in assembly in comparison to FTIR, which makes DSI a more reasonable choice.

3.2 Method of Detection

Since the touch surface technology chosen utilizes infrared light, the detection method must be compatible with infrared and able to accurately discern the location of haptic input. One method commonly implemented in the construction of large touch screen tables is to position an infrared camera below the touch surface. The camera captures any infrared light that has become frustrated and interprets where the frustration occurred. This method is capable of accurately detecting multiple points of frustration (and by extension points of haptic input) and can track them over time. While this feature is advantageous for touch-surface computers, such capabilities are excessive for a keyboard. Additionally, the camera must be distanced from the touch surface in order to function properly and the camera software must be calibrated for each touch surface to limit the probability of getting false readings, requirements that are too stringent for this prototype.

Given the constraints of this project, infrared cameras are an inappropriate choice. The required height would make the keyboard difficult to use, and the camera itself is complicated to install and calibrate. The alternative method chosen to detect infrared light was the use of phototransistors. A phototransistor is a type of variable resistor that, when exposed to the specific light wavelengths, the resistance across the component changes. These changes in resistance can be measured, and thus are usable as an input signal to the computer. Most phototransistors have very low profiles and can be placed very close to the touch surface, but do not have the same level of accuracy as an infrared camera. On their own phototransistors are only capable of detecting changes in the intensity of infrared light around the sensor. This limitation can be overcome by setting up a grid of phototransistors beneath the touch surface. The point(s) of frustration can then be located based on which phototransistors measure increased levels of infrared light.

3.3 Method of Interpretation

Since multiple phototransistors are utilized in the prototype, an efficient method must be put in place to take the phototransistor readings and easily interpret them. One option is to create an even grid of sensors. This method is unfortunately inefficient since keyboard layouts rarely have keys aligned in perfect grids. Positioning one phototransistor at each key location and not a perfect grid is the easiest method for discerning which "key" the user is intending to press, alleviating the need to exactly locate where the user is pressing down on the touch surface. This also makes the circuitry paths less complex, allowing for a matrix form of interpretation. As seen in Figure 4, matrix circuitry conserves space on the circuit board and can easily be interpreted by a computer. For example, if a user presses down on the screen above phototransistor *A*, that phototransistor's resistor will trigger changes in the inputs *Upper 1* and *Lower 1*. The computer can then work backwards by looking up the matrix and determine that because *Upper 1* and *Lower 1* have been triggered, the user wishes to press the *A* key.

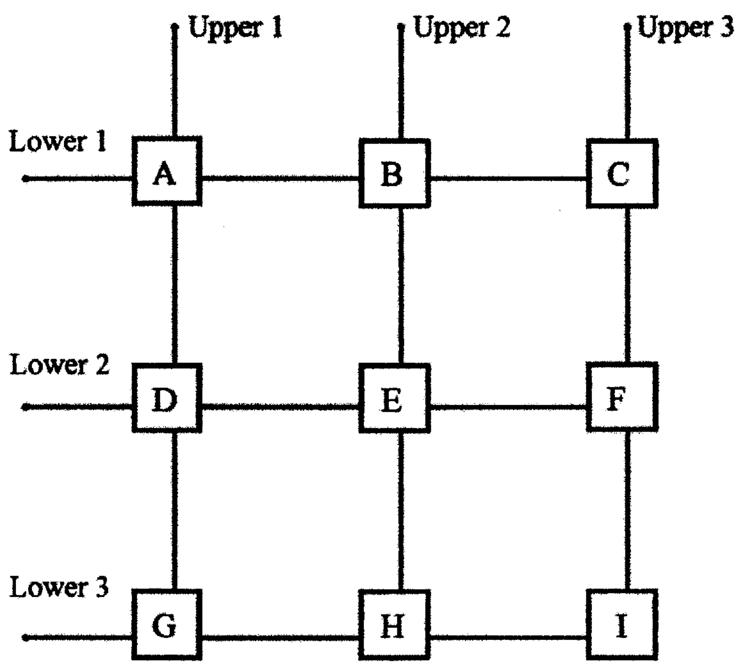

Figure 4: A circuit matrix for a 9-key keyboard. Using only 3 inputs (Upper) and 3 outputs (Lower), nine keys can be individually defined

Chapter 4: Final Touch Surface Design

Upon selecting the appropriate detection methods and components, the prototype design was finalized and construction could begin. The primary design goals were to create a simple device that was both low in cost and easy to assemble. Figure 5 shows the prototype CAD model and physical assembly; Figure 6 is an exploded view of the same assembly.

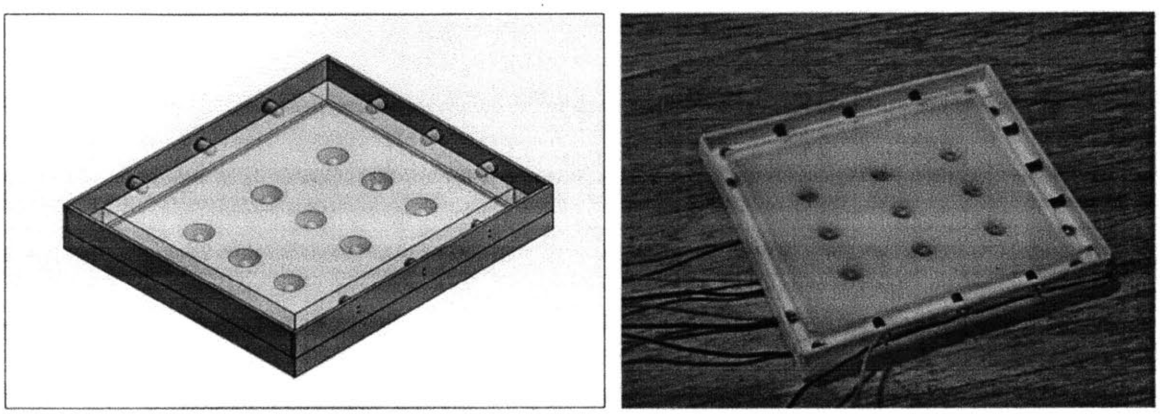

Figure 5: Final CAD design and physical assembly of prototype touch surface keyboard

As seen in Figure 6, the assembly can be separated into three layers. The upper layer is where the Diffused Surface Illumination (DSI) resides. The EndLighten acrylic is seated inside four L-brackets, each 1/16" thick, and in contact with the infrared emitters. By placing the

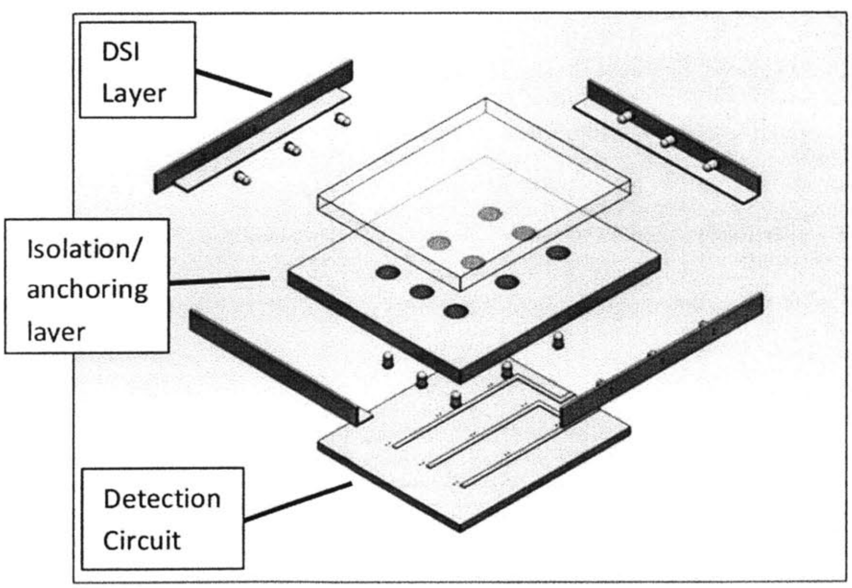

Figure 6: Exploded view of the final assembly. Three assembly layers can be seen: one layer for the DSI touch surface, the bottom layer for detection circuitry, and a middle layer to limit infrared scattering and simplify the assembly process.

acrylic on such a thin layer and in direct contact with the emitters, the assembly layer maintains a compact, low profile and ensures that the maximum amount of infrared light penetrates the EndLighten acrylic. Using the L-brackets as the contact surface of the acrylic also minimizes the contact area of the acrylic and thus also minimizes the amount of infrared light refracting out of the acrylic layer.

The infrared emitters that are in contact with the EndLighten acrylic are wired in parallel as shown in Figure 7. This ensures that if one emitter burns out the remaining emitters will continue to function. While the emitters would have to be replaced in a timely manner to keep the device running optimally, wiring in parallel gives the user some time to find and replace the burnt or broken emitter. A 1.5 Volt power source can be attached in the form of a single AA battery.

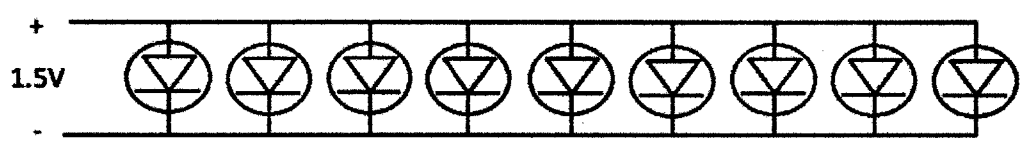

Figure 7: Electronic schematic of infrared LED emitters in which the emitters are wired in parallel.

The bottom layer of the keyboard assembly is the detection circuitry as shown in Figure 8. The copper pathways on the top and bottom of the circuit board form perpendicular rows. The anode of each infrared phototransistor is soldered to the lower side of the circuit board, while each cathode is soldered to the upper side. A wire is also soldered to each row on both sides of the circuit board to allow for easy measurement of voltage and for future attachment to an Arduino or similar processor.

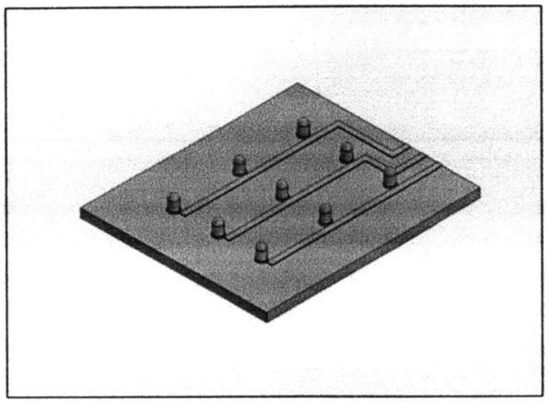 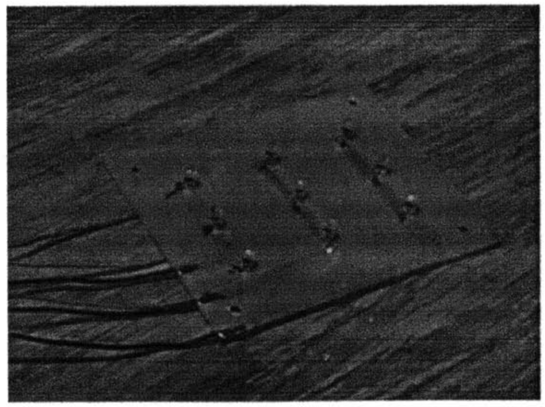

Figure 8: Final CAD and physical assembly of the detection circuitry. The circuit pathways create an electrical matrix as discussed in Chapter 3.3.

The middle layer is a sheet of 3/8" thick Delrin that acts as the anchoring layer for both the touch surface and the detection circuitry. Two 3/8" screws hold each of the L-brackets in place while an additional four screws keep the circuitry connected to the Delrin layer. Nine 1/2" holes drilled into the Delrin in the pattern of the phototransistors serves two functions. First, the holes allow the circuit board to be attached directly to the Delrin layer without the need for standoffs to compensate for the height of the phototransistors. Second, the Delrin surrounding each phototransistor act to isolate each sensor from one another. This helps to limit any false positives caused by infrared light diffusing at the wrong angle. When fully assembled the device measures 6.25" by 5.5" and has a profile of 0.92 inches, within the desired 1" functional requirement.

Chapter 5: Data Collection and Analysis

To ensure the prototype's functionality, a quality-of-detection test was conducted. The change in voltage across each phototransistor pathway was measured during various stages of use. Figure 9 shows the setup for these measurements. One AA battery was wired to the keyboard's infrared emitters while two sets of detection leads, one leading to the anode layer of the circuit board and the other to the cathode layer, were connected to a voltmeter. The remaining leads were left disconnected. For each anode/cathode setup, each "key" was tested by pressing down on the infrared layer above the phototransistor being tested and measuring the resulting voltage change. To ensure that the matrix circuitry was isolating the correct signal, phototransistors besides the one in question were also pressed at random while measuring the voltage change across the phototransistor in question. If the voltage change in both situations, pressing the desired key and pressing any other key, were found to be the same, then either the matrix circuitry or detection method would have to be modified.

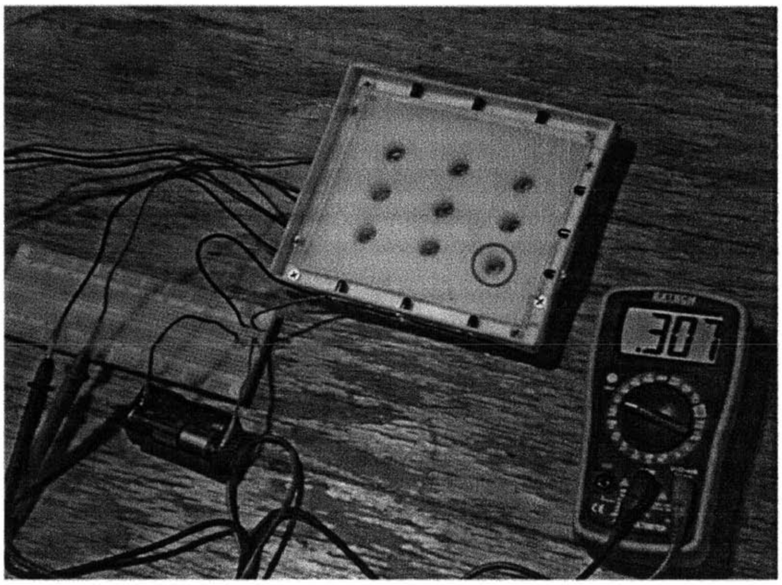

Figure 9: Experimental setup. Using one AA battery as power, the leads of one "top" circuit path and one "bottom" path are connected to a voltmeter. The phototransistor being tested in the photo has been circled in red.

When the infrared emitters were turned on, the phototransistor readings showed an increase in voltage, meaning some infrared light was leaking out of the EndLighten. The presence of ambient light was found to vary the level of light in the initial condition, and is responsible for small variations in the voltage measured. When the battery was disconnected and ambient light present, the voltage across each phototransistor pathway was measured to be 0.240 ± 0.005 V. When the battery was connected the voltage increased to 0.306 ± 0.005V. Similarly, it was found that "pressing" on any key (aka phototransistor) besides the desired key resulted in a voltage increase of approximately 7 mV.

When the proper key was pressed, the voltage across the phototransistor increased by approximately 20 mV, nearly three times the voltage change in comparison to pressing the incorrect key. This comparison can be seen in Figure 10. This means that, while some false positives are present, the desired key can still be distinguished, especially with the proper software. The false increase in voltage was likely due to some degree of infrared light being diffused at a sharper angle rather than directly down through the acrylic.

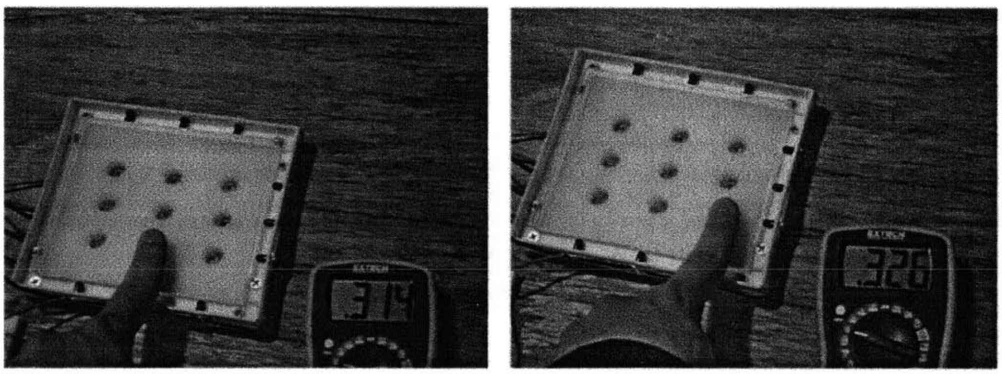

Figure 10: (Left) "Incorrect" key being pressed. (Right) Desired key being pressed. The voltage change was consistently 12 mV greater when the desired key was pressed.

Chapter 6: Conclusions

This design project presented details the development of a touch surface computer keyboard and shows how the design process fulfilled its purpose to create a device that has a low profile and can detect finger positions on a touch surface. Using the DSI method of detection allows for easy assembly. The infrared phototransistors located below the acrylic surface measure incoming infrared light, detecting when and where a user might be touching the surface of the device. By placing the infrared phototransistors close to the acrylic, the profile necessary for the device to function is kept to a minimum. The matrix circuitry provides a practical method for determining which phototransistor(s) detect a key being "pressed." Additionally, matrix circuitry can easily be scaled up as more keys are introduced beyond the nine present in the prototype.

The importance of this research will become more apparent when the market demands for further integration of touch screens into modern devices. This research provides a new potential method of producing a low-profile, multi-touch keyboard. Additionally, the research may become a guide in developing new touch surface technologies as many of the challenges discussed here will likely continue to be applicable.

Next steps in the development of this new keyboard technology would likely be to integrate circuits to interpret the phototransistor readings and in turn send signals to a computer or similar device. Design of an outer casing and covering for the touch surface will also greatly improve the device's aesthetics. Additionally a coating over the touch surface may help to limit the amount of noise and variance caused by unpredictable light conditions.

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