Project: N.A.S.A.S.

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1 Mission Statement:

For the past 50 years, innovations in display technology have been rapidly advancing at incredible pace. Large corporations such as Microsoft, Texas Instruments, and Phillips are rushing to develop cheaper, thinner, lighter, and more flexible displays. Ultimately however, the number of innovations that can be made using conventional 2D display methods will hit a peak. It is for this reason that many smaller research companies are investing in creating a new generation of displays that are no longer confined to the planar projections generated by current technologies. This new breed of displays will introduce a new dimension of depth into imaging, making the viewing experience more robust and realistic to the user. 3d display devices will soon take over the conventional display market, and is foreseeable to become a booming multi-billion dollar industry in the next few years.

Project N.A.S.A.S is an attempt at creating the world's first flat, cheap, and simple to use three-dimensional display. The goal is to create a product that looks nearly identical to a standard flat display device such as a plasma or LCD screen at first glance. However, when activated the images produced are no longer constrained to the two-dimensional plane of the screen, but posses a third spatial dimension of depth without the need for any external invasive equipment. The N.A.S.A.S will create a truly immersive visual experience. Unlike many 3D display technologies currently under research, the device we are proposing has several inherent advantages.

- **COST:** The majority of the technology use to create this device is relatively inexpensive and widely available. The elegance in the design is the ability to create something incredibly new by assembling bits and pieces of pre-existing technology and techniques.

- **SIZE:** Like the first generation of 2D displays, many of the existing 3D displays are fairly large. Some display devices such as "Depth cube" or "Swept volume" technologies require the display to be as large as the scene it is trying to represent. The N.A.S.A.S device removes this dependency by generating a scalable infinite volume for display that is confined to a flat thin surface nearly 1/3 the size of an LCD monitor.

- **Integration:** The N.A.S.A.S device is designed to be easily and seamlessly integrated with any common 2D display device. Instead of being a stand-alone system, the N.A.S.A.S is primarily designed as a modification to any pre-existing 2D display. Doing so allows the N.A.S.A.S to be cheaper and consequently increase its consumer base. The N.A.S.A.S is also easily de-activated so any 2D device it is attached to can return to is original state.

- **True Depth:** Unlike many 3D display devices that try and trick the human visual system into seeing depth, the N.A.S.A.S provides the user with a real depth experience. Its closest competitor, the auto-stereoscopic display, has been known to cause eye fatigue and headaches due to the conflicting visual cues provided by its false depth. The N.A.S.A.S takes into account all of the human visual systems sensitive responses, and triggers them correctly so there are no physical repercussion.

2 HOW IT WORKS:

The human visual system uses several mechanisms to determine the depth of an object based on the information provided to our brain through the eyes. One of the strongest cues we have is a phenomenon known as vergence.

When our eyes converge on a single object in the environment, the depth of the object can be determined by angle that our eyes must make to focus on the object. This can also be thought of backwards, by tracing the light rays from our eyes to the point of observation. The angle between the rays formed by each eye determines the distance. Figure 1 below demonstrates this idea.

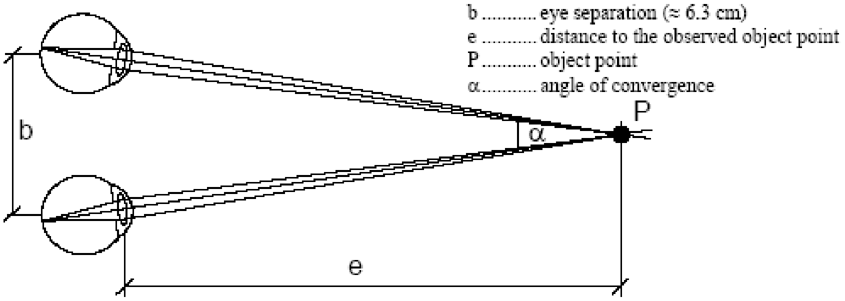

Figure 1. Human Visual System.

In the figure above, the angle α is proportional to the depth. The more acute this angle becomes, the lesser the eyes must pivot, and the further away the object is registered. This gives the brain information about depth.

All of this depth information is lost when a photograph or movie is displayed on a standard 2D display. The figure below shows the path the light rays must take to reach our eyes as they are projected from a standard LCD display.

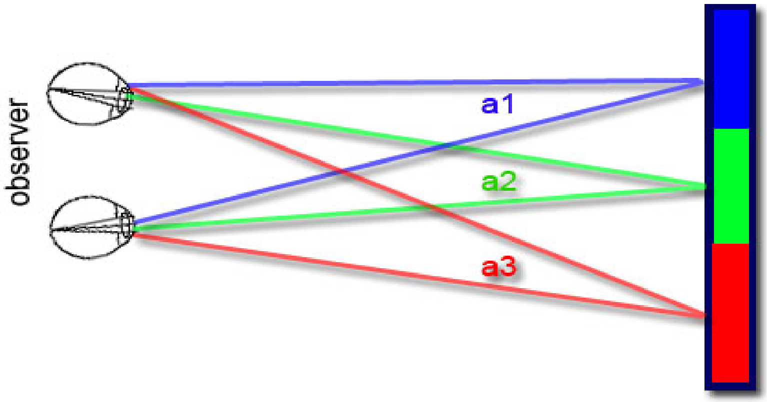

Figure 2. LCD display

The red, blue, and green rectangles represent different pixels (point sources) on the screen. The variables: a1, a2, and a3, represent the angle of divergence created by these point sources in respect to the observer's eyes. As you can see from the diagram a1 = a2 = a3 (there are small deviations but these are corrected by the curved surface of your eye). Therefore, since all the point sources in the display have the same divergence, every pixel is mapped to the same depth. This is what creates the flattened feel of a conventional 2D display, as opposed to the full depth feel of real life.

In order to recreate the realistic feel of varying vergance, the N.A.S.A.S device uses a tunable micro lens array added to the front of the display device. Each pixel has its own micro lens whose power and focal length can be individually manipulated. The result of doing so is the ability to push the vergence for each individual pixel to a desired location. When the user's eyes go to converge on a specific pixel's location, they now see the point of convergence that is produced by the lenses. Figure 2 below demonstrates what this system looks like to the user and showcases the effects of different lens powers.

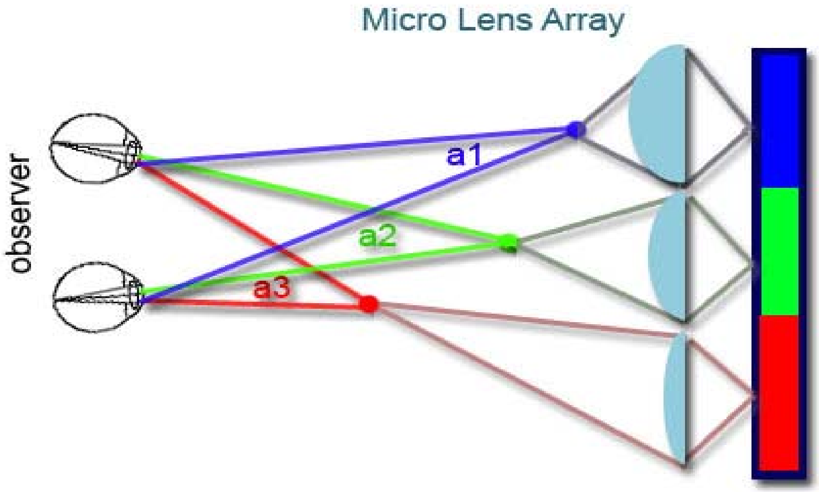

Figure 3. NASAS display using micro-lenses.

As you can see from the figure above, the angles a1, a2, and a3 are no longer the same due to the variable lenses placed in front of each point source. Thus, to the user all of these pixels appear to be spawning from different depths. When you consider and image to be composed of discreet point sources, you can see how mapping each pixel to a desired depth would produce a realistic 3 dimensional image.

3 TECHNICAL DETAILS:

3.1 Micro Lenses:

After reading the description of how this device works presented above, you may be wondering why this has never been implemented before. The main reason lies within the fabrication of the tunable micro lens array; which is the key to the entire device.

Until very recently, the ability to make a lens whose focal length is easily and quickly modulated was nearly impossible. However, many research labs are currently working on such devices that utilize the unique properties of liquid crystals to achieve this incredible ability. One such institution is the Creole Optics and Photonics Research lab at the University of Central Florida, whose research has led to the majority of this device’s development. You can find their work and papers at the following website: http://lcd.creol.ucf.edu/

Liquid crystals contain some essential properties that make them a prime candidate for this application.

One such property is the ability of a liquid crystal to re-orient its direction when in the presence of an electric field. The molecules of a liquid crystal resemble a rod like structure with one long dimension and one short dimension. When an electric field is applied, the rod like crystals will experience a torque. Similar to how a bar magnet reacts in an magnetic field, the torque induced by the electric field on the crystals will cause them to rotate and align their long dimension with the electric field lines as demonstrated in the following figure.

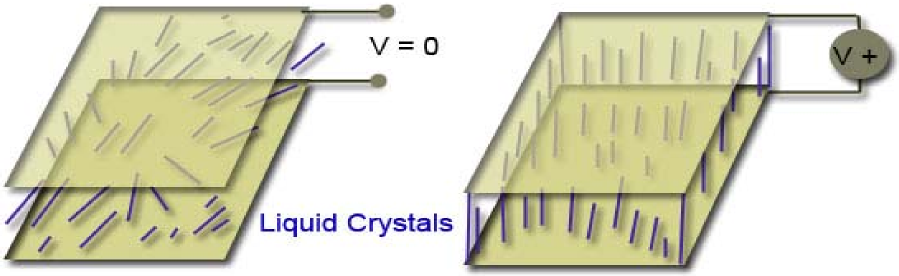

Figure 4. LC reorientation with electric field. Right image, liquid crystals randomly aligned under no field. Left: Applied electric field causes the crystals to orient with the field.

Another very important and unique property of a liquid crystal is that many of them possess a significant birefringence. Birefringence is a property of a material that has different refractive indices depending on how the light is oriented in respect to the crystal molecules. Assuming the incident light is held at a constant orientation, as the crystals are rotated in respect to the light the light will bend differently due to the changing refractive index as shown in the figure below.

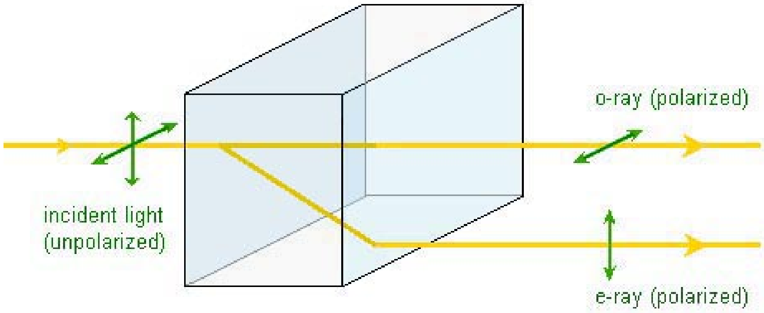

Figure 5. Birefringence of a liquid crystal [1]

As you can see, light oriented in different directions in respect to the crystal bend to different extremes. The o-ray represents light that is oriented along the axis of the crystal whose refractive index is smaller, and therefore does not deviate from its path. However, the e-ray represents light that is oriented along the crystals axis of high refractivity, causing it to bend drastically as it passes through the crystal.

It is a combination of these unique properties that makes tunable lenses possible. If you recall a lens is defined as a structure whose refractive index varies as a function of space. Typically this function is circularly symmetric. The result of this configuration causes light to bend at different amounts as the ray's distance from the center of the lens varies. This allows all of the light to converge to a point, because the incoming rays can no longer remain parallel. This focal point then becomes the location of the lights convergence and is therefore the new point source for that light.

Since liquid crystals can rotate their orientation with an electric field, and their orientation determines their refractive index, it then becomes possible to change the crystals refractive index with an electric field. Therefore by applying a circularly symmetric gradient electric field, you can create a circularly symmetric gradient of refractive index. This creates a lens. The power of the lens is determined by the contrast in the electric field gradient. The figure below demonstrates how the re-orientation of the crystals responds to a gradient electric field.

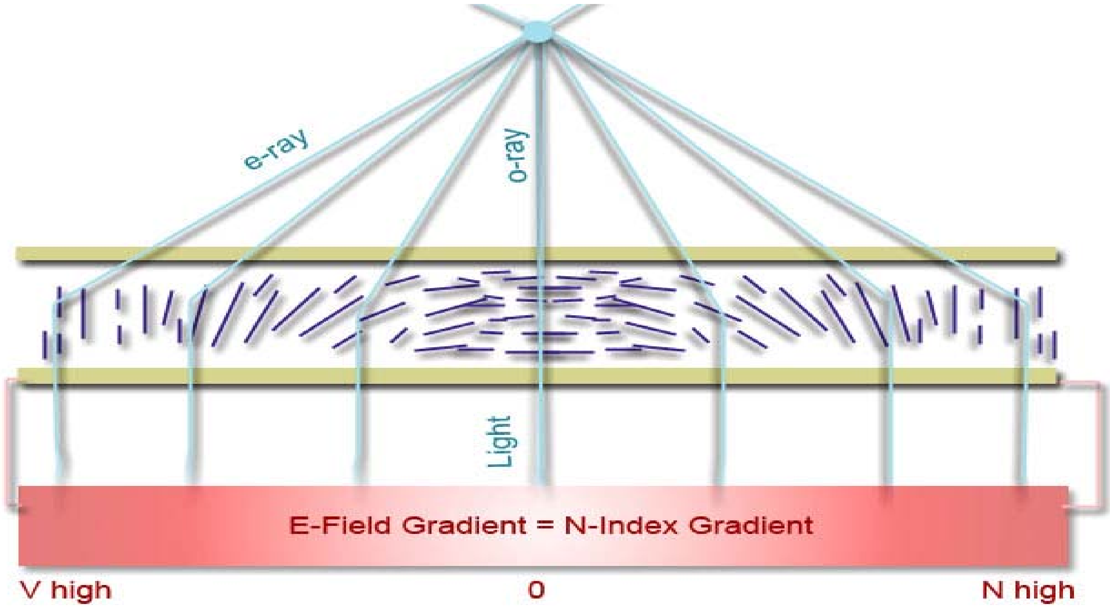

Figure 6. Creating a Micro-lens with a E-Field Gradient

3.2 Controller Hardware:

Now that the principles behind how this device functions have been explored, it is time to examine the practicality of constructing such a product. As mentioned earlier, to create a full 3D image would require a summation of discreet point sources whose vergences can be manipulated to generate depth. This means we would need a per-pixel control over the tunable micro-lens array. Fortunately, a common device already exists that can do exactly that.

A typical LCD monitor provides nearly all the essential hardware components to create the N.A.S.A.S and works as follows. The basis of a typical LCD display are two glass plates whose inner surfaces are coated with a clear conductive material known as Indium Tin Oxide (ITO) and whose outer surfaces are covered with polarizing filters whose primary axis's are crossed in respect to each other. An ITO electrode is printed for each pixel such that a different voltage can be applied between these plates at any pixel location. Sandwiched between these plates is a liquid crystal mixture. Similar to the mechanism described above, when a voltage is applied to a pixel electrode it causes the liquid crystals to rotate in respect to the field. As the crystals rotate, they allow varying amounts of light to pass between the polarized glasses depending on the amount of voltage applied. Below is a very oversimplified diagram of a typical LCD monitor. You can learn much more about LCD monitors and how they work at the following website:

http://www.plasma.com/classroom/what_is_tft_lcd.htm

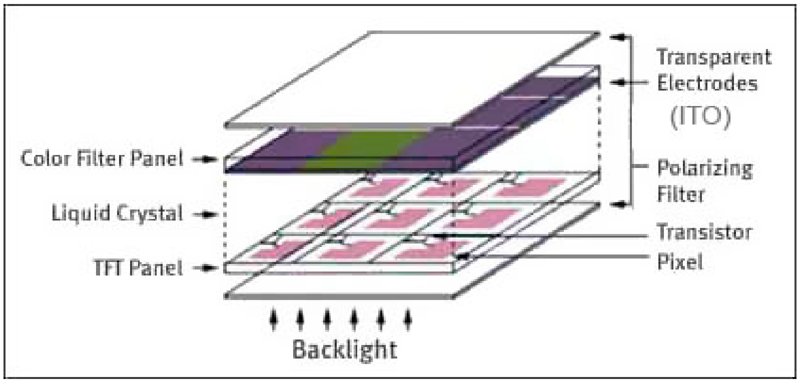

Figure 7. Basic components of an LCD monitor [2]

Of course the explanation and diagram provide above are drastically oversimplified, however they demonstrate the key components of an LCD monitor that make it desirable for our application. The per-pixel voltage control is exactly what we need to create the micro-lens array.

4 PRODUCT DEVELOPMENT:

4.1 Theory and Hardware

To construct the N.A.S.A.S, it will be easiest to start out with a standard LCD monitor. The backlight will need to be removed, along with the polarizing filters on the glass. Then, the liquid crystals that currently reside between the glass plates will need to be extracted and replaced with the highly birefringent liquid crystals described in the micro-lens section. At this point, all of the necessary hardware components to individually create and control a per-pixel micro-lens array should be in place.

Once this has been accomplished, the task then becomes how to use the existing LCD controller to create a correct micro-lenses based upon the desired depth of each pixel. As mentioned earlier, in order to create a liquid crystal lens, a gradient electric field must be applied to each pixel. However, since each pixel only has a single electrode to control its field strength, it is impossible to easily create a gradient across a single pixel without having to redeposit the ITO. To solve this issue, we decided it would be easiest to group pixels together in 5 X 5 sections. This way, we can easily induce and control circularly symmetric gradient electric field across the pixel blocks as shown in the figure below.

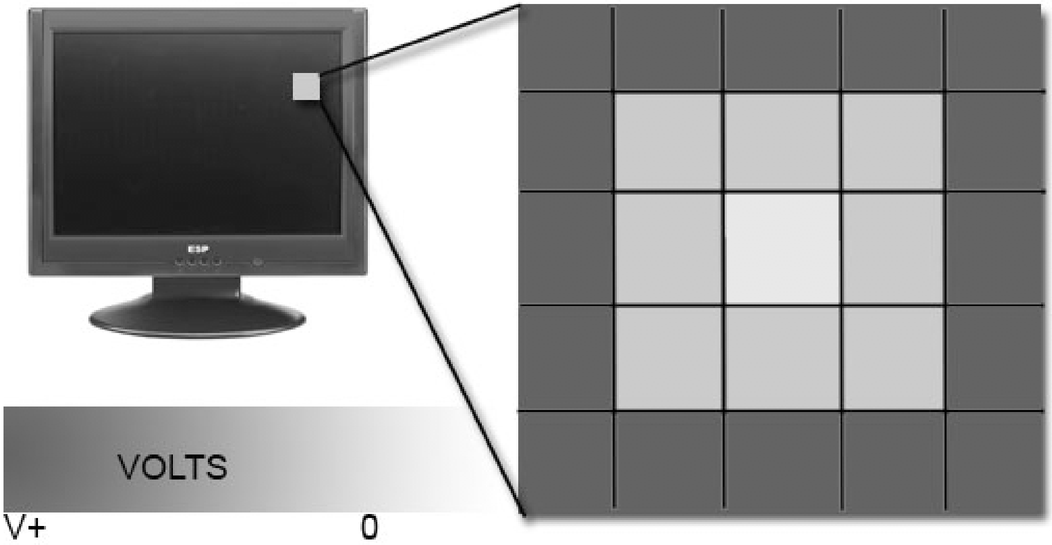

Figure 8. Grouped pixel micro lens structure

Since all of the lenses are the same size (5 X 5), the strength of the lens is dependant on how drastic the gradient refractive index is across a lens unit. Since each pixel’s voltage can be individually modulated through the LCD screen controller, we can apply different voltages to the concentric rings shown in the figure above. By doing so, we can create different circularly symmetric gradient profiles for each lens and therefore generate different focal lengths.

4.2 Software

Once the hardware is assembled, writing the software to drive this device is very simple. The most elegant and cost effective part of this system is that there is no need to create new drivers or proto-calls to interface with it. The N.A.S.A.S can be completely controlled through a standard VGA connector run from any standard video card.

To make the software explanation simple, let us consider a grey-scale image output. Grey-scale simply means that the red, green, and blue sub-pixels that create a desired pixel color have all the same voltage applied to them, and can be considered one unit. A standard LCD monitor can output 255 different shades of grey, ranging anywhere from black to white. Each shade corresponds to a different voltage level applied across the pixel. Therefore, there are 255 distinct voltages we can use to create our system.

Almost every 3d graphics video card has an on board storage buffer known as the z-buffer. This buffer is used to store the per-pixel draw order of whatever is being displayed on the screen, and holds a grey-scale image of the frame. Each pixel’s depth from the screen is represented by a shade of grey. The image below shows a 3D rendered frame displayed on a standard screen and the corresponding contents of the z-buffer.

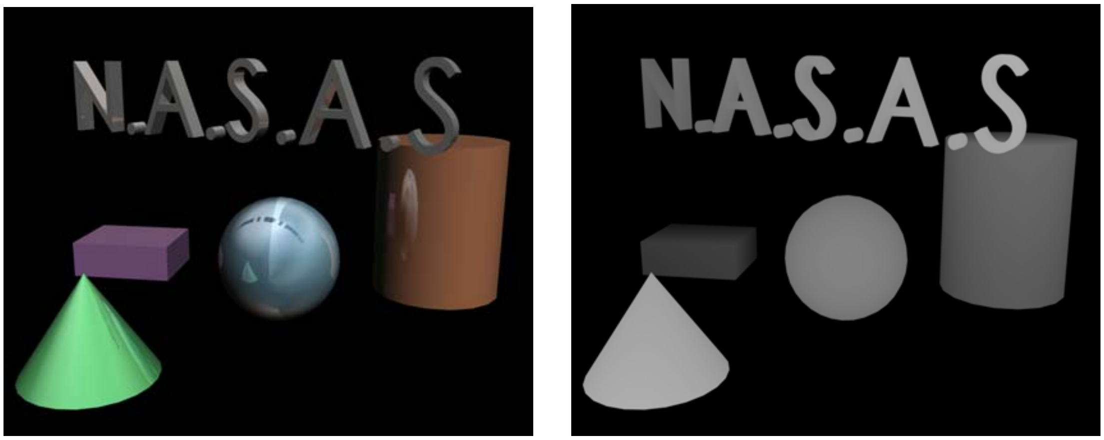

Figure 9. On the left, original render of a 3d scene on a 2d display. On the right is the corresponding z-buffer for this frame.

As you can see from the images above, the closer a pixel is to the viewer, the lighter the shade of black is. This is the exact correspondence we need to generate the output to the N.A.S.A.S. Using this frame buffer we can create an output signal that contains the correct pattern needed to create a micro-lens of an appropriate strength to be placed in front of each pixel block. The procedure to do so is as follows.

- **Grouping** - First, the z-buffer is rendered out to an image similar to the grey-scale image shown above. This is then broken up into groups of 5 X 5 pixels.

- **Averaging** - Since we do not have the capabilities to create a micro-lens for every pixel, the lens is made to display the average depth of all 25 pixels that make up a single micro-lens unit. To do this, each 5X5 pixel block is averaged to find the depth that will be mapped to this micro-lens.

- **Gradient formation -** The result of the averaging operation is used as the value for the center pixel in the pixel pattern shown in figure 8. For simplicity sake, the outer ring of every micro-lens is kept black. The middle ring is then filled in with a shade that is the median between the center pixel and black.

- **Assembly -** The previous three stages are repeated for every lens unit, and the results are concatenated into the final output image sent to the N.A.S.A.S device.

The figure below shows what the output signal to the N.A.S.A.S would look like given the same image as the input from the figures above.

Figure 10. Final output signal to the N.A.S.A.S for the given frames showed above

In theory, when this signal is outputted through the VGA cable to the N.A.S.A.S device described above, a micro-lens array should be generated that can correctly shift the vergences of the desired frame to create a 3D image.

5 SETUP:

The final product of the N.A.S.A.S should appear like the device shown in the following figure.

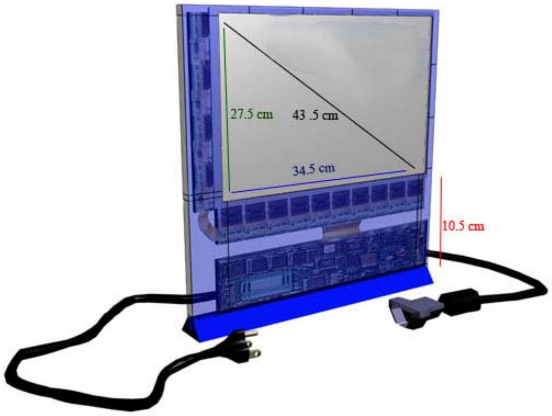

Figure 11. Concept design of the N.A.S.A.S

The N.A.S.A.S. is designed to be a freestanding device that is placed in front of any standard 2D display. The 2D display will be run normally, displaying its typical 2D projection. The N.A.S.A.S will be fed with the output signal generated by the steps outlined above, corresponding to the same input signal going to the 2D display. When the viewer looks through the N.A.S.A.S and at the 2D display, he should experience a full 3D effect unlike any other provided by a product currently on the market. The figure below demonstrates this configuration.

Figure 12. N.A.S.A.S system setup diagram

6 PROJECT STATUS:

6.1 Progress:

Because of the simplicity in its design, it was originally thought that one or two people who understood the concepts behind it could assemble this device. However, initial attempts at its construction have been unsuccessful thus far, but have produced small accomplishments along the way toward the ultimate goal. Our progress includes the following.

A standard LCD monitor was purchased and disassembled. The backlight was removed and the circuits were properly preserved. Auxiliary FFC connectors were purchased and installed so that the glass could be easily access and controlled without being obstructed by the circuits. A PVC frame was constructed to hold the glass and driver circuitry upright to make the device free standing and portable as shown in the figure below. At this point, the LCD could still be activated and functioned correctly as shown below as well.

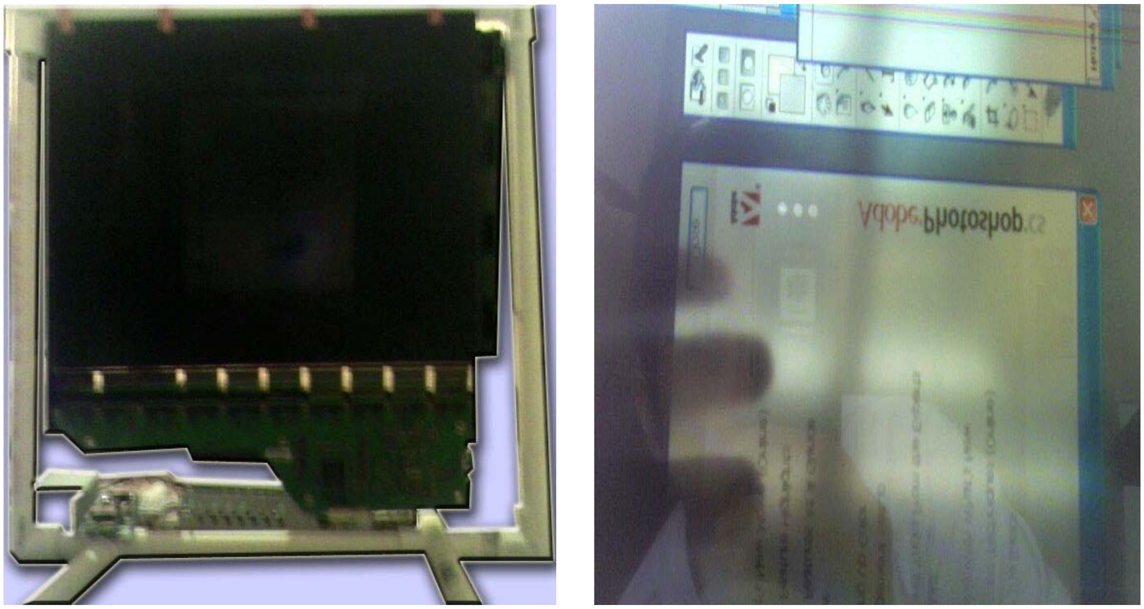

Figure 13. Right: The temporary rig constructed to hold all of the N.A.S.A.S components and make them upright. Left: The LCD monitor activated once the backlight had been removed and cables replaced.

Next, the two chemicals LC E48 and RM 257 described in the following article were purchased from Merck.

http://lcd.creol.ucf.edu/publication/2006/Opt%20Comm%20Ren.pdf

The procedure outlined in the above article is the basis for this project. The glass plates were then separated and the LC mixture between them was removed by gently whipping off the inner surface of each glass plate. The figure below shows the two separated plates of glass. At this point, when the glass plates were temporarily put back together the display surface was no longer clear. This indicates that no LC remained between the glass plates to allow light to pass between the crossed polarizers.

Figure 14. The two glass plates separated before replacing the liquid crystals between them .

The glass plates were then separated again, and the new LC mixture was brushed on to the inner glass surfaces. This was done two times using different LC mixtures. The first time the mixture was composed of 100% LC E48 and the second time it was composed of ~65% LC E48 and ~35% RM 257. The plates were then sandwiched together and mounted on the rig. This time the display surface was clear, proving the liquid crystals had adhered and aligned with the glass. The controller circuits were then connected and powered up. The VGA chord was run from a laptop to the N.A.S.A.S, and an output signal duplicate of the laptop screen was sent.

If everything worked as designed, the result of this connection would have looked very similar to powering on an LCD without the backlight as shown in figure 13. Some sections of the glass would appear clear where there is no voltage being applied and others opaque where there is. This would indicate that the crystals were re-orienting with the electric field. The next step would be to remove the polarizers and color filter from the outer LCD glass, drive the device with the special micro-lens output signal, and the N.A.S.A.S would have sprung to life!

6.2 Problems:

Unfortunately this was not the case, and upon powering up the N.A.S.A.S, nothing happened. The clear display glass never turned opaque even when a purely black signal was sent to it. This means that the crystals for some reason were not re-aligning with the electric field.

One strong possibility could be that the driving voltage to the LCD may not have been strong enough to cause the crystals to rotate. In reference 3, it states that given a mixture of 70% LC to 30% RM 257, the crystals rotated (before the UV curing) at a voltage of 15 V. It was also stated that the threshold voltage is decreased as the percentage of LC increases. Consequently, it was believed that using a 100% LC mixture would result in a low operating voltage, and one that can be generated by the LCD controller. Referring to reference 2, a typical LCD controller can output a signal range from -5V to 8V depending on the shade of the pixel. Outputting an all black signal and attempting to use a voltmeter between the glass plates yielded only a voltage of about 4V from positive connection to a grounded metal fixture, and only about 0.5V from plate to plate. However, taking a measurement between the two plates of glass is very difficult when trying to maintain their connectivity to the driver circuit, so those results may not be valid. Either way, this a probable suspect for the reason the system does not function currently.

Another likely problem could be that the LCD controller system may have been damaged during its reconstruction. When trying to re-assemble the glass plates, a long crack formed diagonally along the length of the ground glass surface. This may have an effect on the voltage across the liquid crystals. However, this seems unlikely since the system was tested one time before the crack formed and it still failed to power on, but it remains a possibility.

6.3 Future work and help needed:

At this stage in our development, it is becoming more evident that we do not posses the correct equipment to construct such a device and diagnose the problems with it. From here the next steps would be either to create a new highly birefringent liquid crystal mixture with a much lower operating voltage and attempt to use this mixture in a standard LCD module, or to create a newer LCD controller with a much higher signal voltage.

Either route would require specialized knowledge of chemistry and electronics that we do not currently have.

This document was written in hopes to persuade people who have this knowledge to step forward and help create what could potentially be revolutionary, and change the way we view and interact with our world.

7 REFERENCES:

[1] http://plc.cwru.edu/tutorial/enhanced/files/lc/biref/biref.htm
[2] http://www.plasma.com/classroom/what_is_tft_lcd.htm

[3] http://lcd.creol.ucf.edu/publication/2006/Opt%20Comm%20Ren.pdf

[4] http://lcd.creol.ucf.edu/