CONTRAST SENSITIVITY MEASUREMENT USING 10-BIT MONITORS

by

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STATEMENT BY AUTHOR

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______________________________________ *May 3, 2017*

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Table of Contents

LIST OF FIGURES

1 Method

1.1 Introduction

The eye is an important organ within the visual system; it allows for more than just simple sight. It is the organ that is responsible for seeing objects, reading, viewing photographs or film, etc. Visual acuity tests are regarded as the common standard for vision testing. It provides people with their eye glass or contact lens prescription, lens shapes, and eye issues. However, contrast sensitivity measurements are the best way to assess the acuity of the human visual system. They are the most complete and informative method for the assessment of the human visual system. Common diseases like glaucoma or cataracts could be detected much sooner if these kinds of contrasts tests were more readily available since they affect contrast faster than resolution. As vision tests are advancing to completely computerized or digital testing due to wear and tear or need for finer resolution on printed charts, standard visual acuity tests are no longer sensitive enough.

1.2 Goal

The motivation for this project was to establish a patient-interactive user interface using display technology that exhibits the high dynamic range to preserve all information needed to record contrast sensitivity measurements of eyes. Standard displays are 8-bit monitors that present only 256 shades of grey when the human eye can identify around 700 to 1000 shades. The need for 10-bit monitors is pertinent because it provides 1024 shades of color which provides patients the required information for testing their eyes.

2 Vision Testing

2.1 Visual Acuity

There are several vision tests currently available to assess the visual accuracy given the eye's variety of functions. Visual acuity, a measure of the eye's ability to see fine details, is commonly tested for at a standard visit to the optometrist's office. Measuring acuity can be done through a variety of methods like target detection, gap detection and target recognition, of which the latter is the most easily recognizable through the popularization of Snellan letters in eye charts. In the Snellan eye chart seen in Figure 2.1, each line of letters is scaled depending on the Snellan fraction, S:

$$S = \frac{20}{XX} = \frac{Smallest\ line\ subject\ can\ identify\ letters\ of\ a\ given\ line\ of\ chart\ at\ 20\ ft\ (6\ m)}{Smallest\ line\ standard\ observer\ can\ identify\ the\ same\ line\ at\ XX\ ft\ (XX\ m)} \tag{1}$$

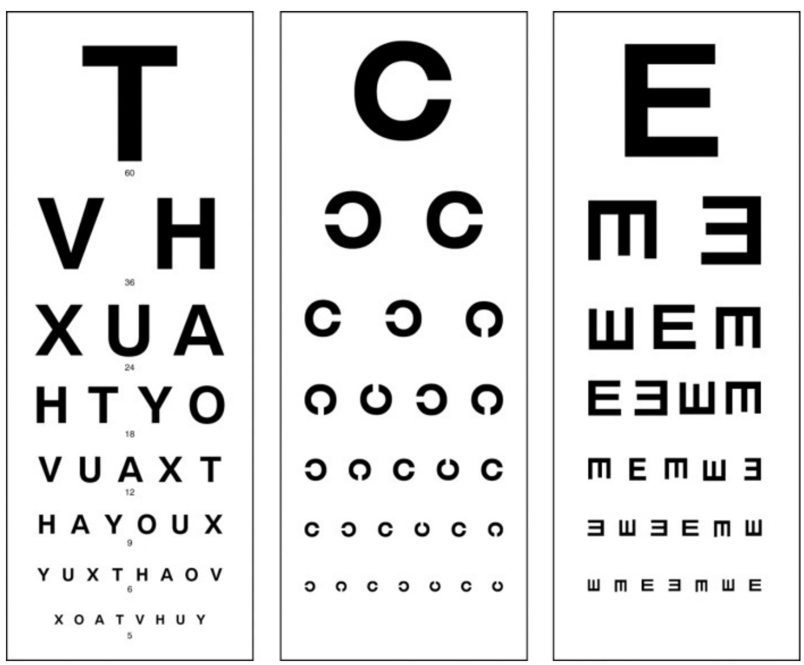


Figure 2.1)Example Snellen Eye Chart

For this visual acuity test, only a select variety of letters are used such that the thickness of the lines is equal to both the thickness of the white spaces between the lines and the thickness of the gaps between rows. The letter 'E' from the Snellen chart at the 20/20 line is referred to as the 'vision standard' as it helps determine the resolution of the eye and what is needed to test because it is the vision standard or normal. One arm of the 'E' subtends one arcminute on the retina when displayed at a 20-foot distance as shown in Figure 2.2, which equates to 100 cycles per millimeter. One line-pair, or one cycle, of one high contrast and one low contrast (one black and one white) is equal to two arms of the 'E' and subtends two arcminutes. Therefore, the two arcminutes can be related to the 30 cycles per degree (cpd) since one cycle is 2 arcminutes and 60 arcminutes is one degree (Figure 2.2).

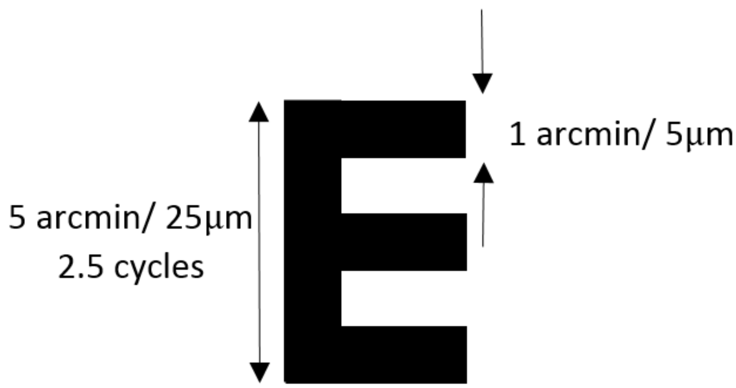


Figure 2.2) Letter 'E' on the 20/20 line of the Snellen Chart

Although this test is the most common used today, the amount of letters on each line and size vary and are not constant (Schwiegerling). As these tests measure visual acuity at high contrast, they do not adequately test the human visual system on their own and warrant contrast sensitivity testing for further follow-up.

2.2 Contrast Sensitivity

The importance of testing contrast sensitivity over visual acuity is its ability to detect early signs of a multitude of eye diseases like glaucoma, macular degeneration, and cataracts (Haymes). For example, while someone with glaucoma may achieve 20/20 vision on their acuity exams, they may struggle with activities of diminishing contrast (e.g. night driving) since not every moment in life can guarantee 100% contrast. Chronic diseases like diabetes and Alzheimer's can also be detected through contrast sensitivity testing. Besides disease detection, contrast sensitivity also provides doctors and clinicians with diagnoses for magnification, illumination needs, eye dominance, and quality of vision (Wilkinson).

Contrast sensitivity is necessary since visual acuity only measures of the visual system's spatial-resolving ability under high contrast conditions of 85% or more (Owsley). Although visual acuity has the capacity to test spatial frequency since it only requires the ability to separate periodic bar patterns or sine wave patterns in cycles or line pairs per degree, contrast sensitivity is recommended. This is due to the relationship between contrast modulation sensitivity and spatial frequency. The contrast sensitivity of the human visual system can be measured as the reciprocal of the minimum contrast or threshold contrast. The smaller the contrast needed to view the sinusoidal grating, the larger the sensitivity.

$$Contrast\ Sensitivity\ Function = \frac{1}{Contrast\ Threshold}$$

Though theorists in the field have proposed several contrast threshold models of varying importance, Peter G. J. Barten's warrants recognition despite the CSF model's complexity. His model considers image and internal noise, lateral inhibition, the optical MTF of the eye, and target size. Barten's approach considers a luminance signal or display image entering the eye to be filtered by the optical MTF of the eye and the lateral inhibition MTF. Lateral inhibition describes the filtration of lower spatial frequencies in the ganglion cells or ability to differentiate between a hard edge so the MTF of this is more on the neuroscience or psychometric effects. The image noise is considered external noise found from the source of the image such as grainy images or display noise from the display hardware. Internal noise may be caused by photons or fluctuations of photos that excite photo-receptors as well as neural noise from fluctuations when transporting signals to the brain (Barten). For this project, noise and lateral inhibition were considered as factors that affect CSF but ignored until 10-bit imagery was properly displayed. The focus was on optical MTF which is characterized by the eye lens and retina. The pupil diameter of the eye lens affects the optical MTF as it varies with scene luminance, but for this project the average pupil size of the eye is 4mm in diameter since the eye is about 2-4mm in bright light and 4-8mm in the dark.

For this purpose, frequency gratings are used since an image can be decomposed into an infinite series of sine waves as seen using the Fourier theory. Fourier analysis defines the luminance pattern of an image as the sum sinusoidal luminance variations (Barten).

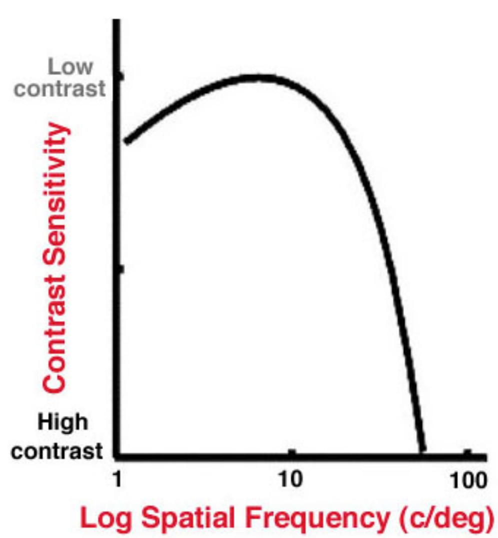


Figure 2.3) Contrast Sensitivity Curve

2.3 Current Tests

2.3.1 Pelli-Robson

The Pelli-Robson contrast chart has been used in many clinical research studies. The chart consists of letters grouped into triplets that fade by 0.08 log units as displayed in Figure 2.4. On average, a ‘normal’ patient may read up to 6-7 lines (2 triplets per line) whereas patients that can only read up to 4-5 lines experience moderate contrast loss (Wilkinson). Pelli-Robson tests letters at different contrast which raises the issue of only single spatial frequency testing. Low spatial frequency testing is insufficient since diseases like cataracts only affects high spatial frequencies.

Figure 2.4) Pelli-Robson Chart

2.3.2 Forced Choice

One common contrast sensitivity test used in clinical studies is the forced choice test. Under the design of this diagnostic tool, patients are presented with two images side by side. One of the images is a sinusoidal pattern and the other image is purely background, and patients must dictate where they see the pattern. Sinusoids are generally used but if it is desired to eliminate the hard edges from the displayed sinusoidal patches, then apodizing the patch with a Gaussian profile (Gabor patches) is suggested. Gabor patches are sinusoids enveloped by a Gaussian so that there is a fall off between the background and the patch. This method 'forces' the patients to respond to visual cues regardless if a target is not seen because at lower contrasts, some may not be able to distinguish the background from the pattern. As patients answer correctly, the grating contrast decreases in logarithmic steps of 0.1. If answered incorrectly, the grating contrast increases by four 0.1 logarithmic steps. Since guessing may occur, the false positives caused by errors can be 'backed out' to a distinguishable level of contrast so that the test can be repeated as described by Figure 2.5. Once ten incorrect responses are given, then the test is complete (Mihasi).

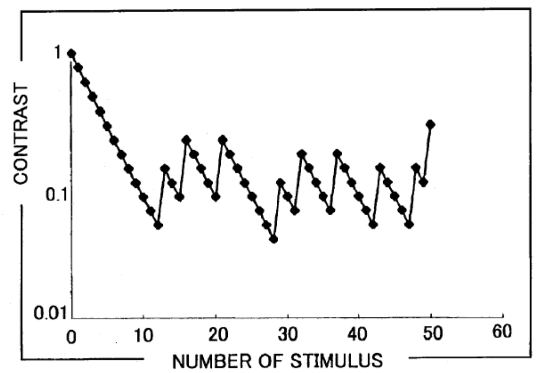


Figure 2.5) Spatial Frequency Results from Forced Choice Method (Mihasi 2005)

Due to the forced nature of the test and requirements for completion, this method becomes extensive and induces error due to eye fatigue. Patients may answer quickly and inaccurately to complete the test faster which leaves results inconclusive. Although most sinusoidal patterns are angled at 0 or 90 degrees, some tests incorporate a slight rotation. According to Campbell, visual capabilities are the greatest when the patterns are positioned at 0 or 90 degrees and weakest at 45 degrees.

2.3.3 Vector Vision

Standard contrast sensitivity tests have been completed with physical charts and clinical tools. There are two tests to measure contrast sensitivity: letter based and grating based. A commonly used grating test in clinical studies is the Vector Vision CSV-100. The Vector Vision CSV-1000E test is commercially used for Air Force vision tests as it aims to measure the contrast sensitivity function. For this specific chart, the test is conducted at a distance of 8 feet. The cart presents four different spatial frequencies of 3, 6, 12, and 18 cycles per degree at eight different contrast values as seen in Figure 2.6. Similarly, to the forced choice method, two images are presented vertically (on top or bottom); a black grey space in one and the vertical sinusoidal pattern in the other. The patient must decide whether the sinusoid is displayed on the top or bottom. An issue with this test is that it only covers a small amount of frequencies and contrasts. The hard edge of the sinusoids also acts as a visual cue for patients, but some believe that the Vector Vision tests aim to test at the peak of the CSF curve of 3-18 cpd. The responses are recorded on an ‘answer sheet’ to determine the given curve for the contrast sensitivity. Though this does seem to work, it does not grasp the entirety of the human visual system through contrast as it is restricting in resolution.

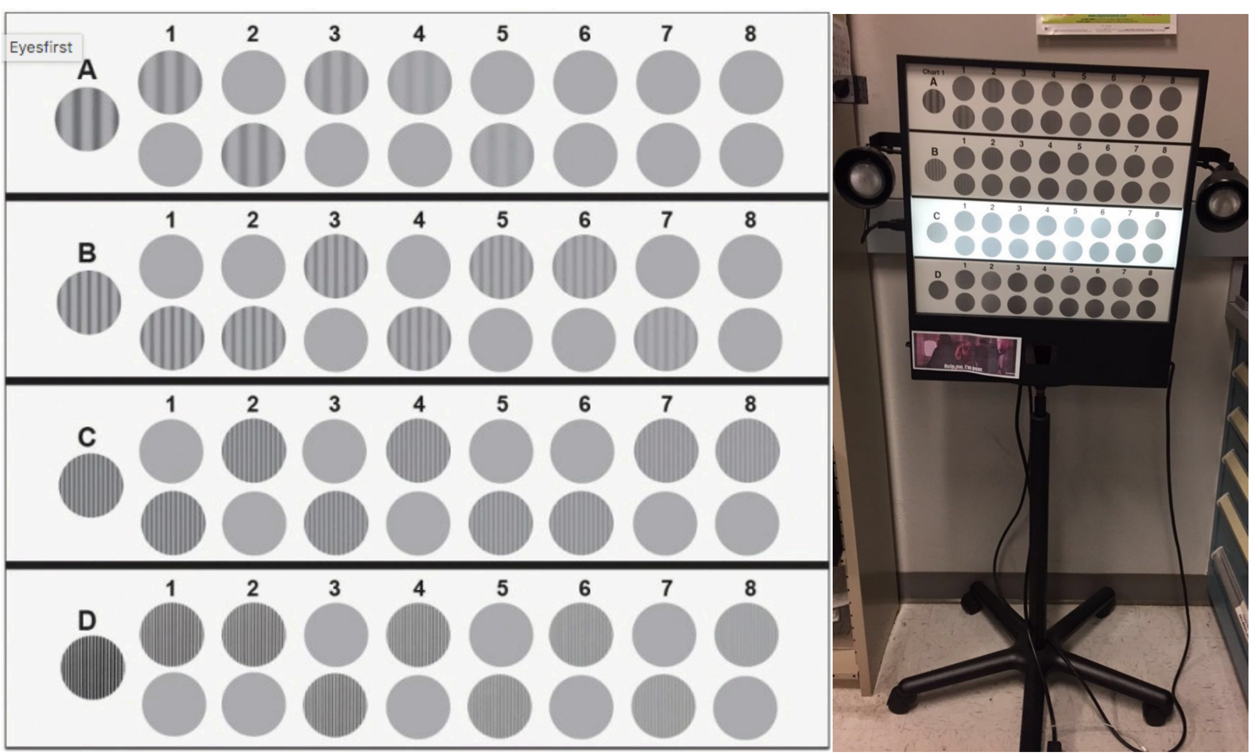


Figure 2.6) Vector Vision CSV-1000E Chart

2.3.4 Frequency Range

As discussed earlier, previous available tests only assess certain spatial frequencies. Most contrast sensitivity tests range from 3-18 cycles per degree as this range contains the estimated peak curve for the contrast sensitivity function. One qualitative measurement of the CSF can be determined from the Campbell-Robson CSF Chart in Figure 2.7. The chart changes in spatial frequency logarithmically in the horizontal direction as known as the “chirp” while it decreases in contrast vertically. The grating is scaled from 1-35 cycles per degree (cpd) from 0-100% contrast. The unique aspect of this chart is that the visibility of a range of spatial frequencies is displayed instantaneously in order to show the high dynamic range, whereas previous tests only focus on one specific spatial frequency at a time.

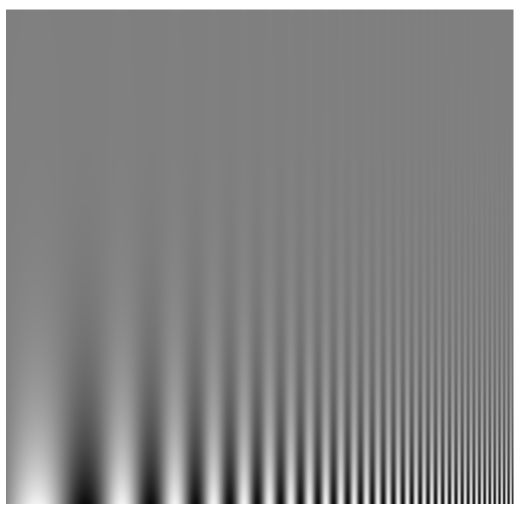


Figure 2.7) Campbell-Robson Grating

2.3.5 Mach Phenomenon

The Mach phenomenon is another factor to consider during examination. Mach discovered that there is a change in luminance gradient when viewing a diffuse luminous boundary such as the grating. This means that there is a white line visible with a decrease in gradient and a black line where there is a rapid increase in gradient also known as Mach banding (Lowry). Therefore, the difference in contrast between frequencies is large enough to notice where the vertical lines isolate different shades of color, and there is a distinct separation between visible greys as seen in Figure 2.8. The need for 10-bit monitors is apparent in Figure 2.9 with the comparison between 8-bit ramps and 10-bit ramps as the 10-bit ramp has a visibly smoother transition between shades of color.

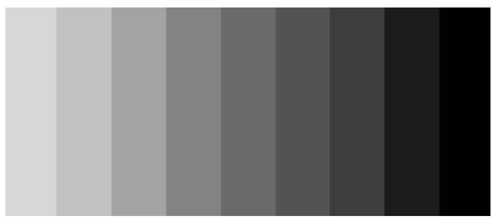


Figure 2.8) Example of Mach Banding

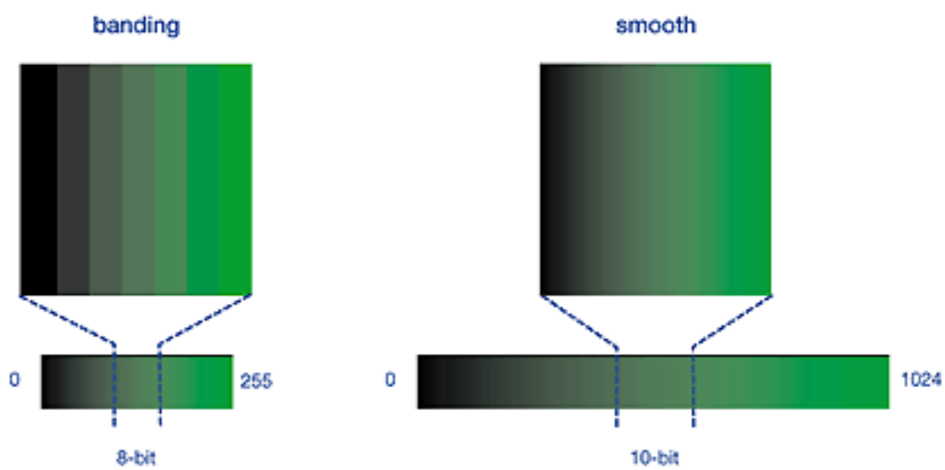


Figure 2.9) 8-bit Ramp versus 10-bit Ramp (from http:..imethane.blogspot.com/2013/01/10-bit-hi10p-vs-8-bit-video.html)

3 Computer-based Testing

Computerized vision tests provide a modernized approach to existing eye exams with their own set of advantages and disadvantages. Converting from printed to computerized testing has become the new standard method since greater printer resolution is necessary to produce the entire range of contrasts or sizes of objects and it is much easier to use computers to do so. While printed charts are still utilized, computer testing is becoming more common because of its efficacy in adaptive measurements using a variety of stimuli, test settings, and other options (Pelli). Due to flexibility of programming, computerized-based tests can significantly speed up the testing by randomizing targets to eliminate the chance of memorization and altering contrast levels. Contrast calibration is important as the display luminance must be standardized before testing to guarantee precise contrast for measurements.

3.1 10-bit Monitors

The need for greater bit depth is becoming more prevalent for various applications such as medical imaging, photography, graphics design, movie production, and entertainment because of its wider color representation. Standard monitors are 8-bits per color channel of red, green, and blue or 24-bits per pixel. These 8-bit monitors can only display the colors that lie within their sRGB compliant triangle whereas the human eye is proficient enough to view all colors within the chromaticity diagram ("AMDs"). 10-bit imaging is significant because of the ability of this monitor to display 1024 colors per channel. Common monitors are only 8-bit monitors and display only 256 colors while human eyes can distinguish 720 to 1000 colors (Matthijs). This is displayed in Figure 3.1 through the chromaticity coordinates diagram. As seen, the sRGB represents the 8-bit color gamut, and the Adobe RGB represents the higher bit depth capacity to see more colors since the human eye can detect all colors within the chromaticity diagram. However, the higher the number is does not mean that there is better image quality.

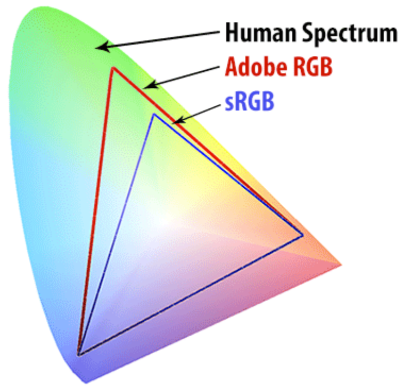


Figure 3.1) CIE-xy Chromaticity Coordinates for sRGB and Adobe RGB Color Gamu

In photographs, the correlation to image quality and image contrast can describe the system MTF at a particular spatial frequency or through the area under the MTF curve called the Subjective Quality Factor (SQF) (Granger). This can be used to compare aspects of CSF data to known image quality metrics between image quality and electronic displays.

The images used for contrast sensitivity testing are grayscale and monochrome, and a monochromatic monitor is used. To understand grayscale resolution, look-up tables are necessary to define the display capabilities. A look-up table (LUT) consists of a portion of memory that is inserted between the video memory which on the graphic board or display controller and the actual display. The address lines of the LUT are the input that connects to the memory. Here the pixel content is then stored in the memory to define where to point. Now the output is connected to the display such that in digital displays, like liquid crystal displays (LCDs), the digital output goes straight to the display. If the display is an analog system, then the digital output must first be converted to analog value. Therefore, 10-bit LUTs allow for better accuracy in rendering the images because there are 1024 colors and high color variety to blend and match the original image colors. This is especially important to contrast sensitivity because it explains "just noticeable differences" to the human eye based on luminance level and range. Contrast resolution describes the display’s capability in rendering the continuous gray tones and optimal perception of single contrast steps. Furthermore, higher image performance is a result of a balanced design from LUT input and output that is as high as 10-bits (Matthijs). Medical imaging examples of different 10-bit display devices include Barco Coronis 5MP Mammo and the Eizo GS510. Photography and graphics design examples include the HP DreamColor LP2480zx or the NEC LCD2180WG-LED (“AMDs”). The WIDE Corporation is known to use 10-bit monitors for medical imaging due to their models’ success in precision.

3.2 Graphics Card

10-bit imaging performance is successful if the monitor can connect to a video graphics card that will display properly. In order to avoid Mach Banding this graphics card must communicate with applications that successfully depict the 10-bit images. For instance, Advanced Micro Devices (AMD) is a technology company that develops computer processors and other drivers that fully support 10-bit displays. The interface for communication can be through a single or dual link DVI or DisplayPort. Unfortunately, with the WIDE 10-bit monitor, the AMD card was unable to effectively display 10-bit images.

Therefore, the nVidia is a better choice as it has the more stable software to support the 30-bit output. The hardware and software must be compatible to display the 30-bit output successfully. While the card is capable of full 10-bit color (30-bit), only the luminous channel is used with the monochrome display at 10-bits. The nVidia graphics cards are used for a variety of applications ranging from business workstations to computer gaming. They exhibit high performance for a less expensive price.

4 Verification

4.1 System

Computerized vision testing should be standardized especially with 10-bit monitors, but the challenge again is displaying the images suitably with so few programs being able to do so and without banding in regular 8-bit screens. For this Master's Project, the images created are displayed on a 21" Model 106-1600X2 10-bit monitor developed by WIDE Corporation. WIDE developed this display to generate the highest quality images and most comprehensive tools. Using the nVidia Quadro 500 video graphics card in conjunction with the monochromatic 10-bit WIDE monitor, 10-bits was successfully displayed by ensuring the 30-bit display option was on and supported. For the goal of the project, the test frequency range is over 0-35 cpd to cover just past the average cut-off frequency of the eye's resolution of 30 cpd. A sample chirp image was created in MatLab and opened using Adobe PhotoShop CS6 since the two programs do support and display the 10-bits properly. This grating is suitable for contrast variation and interactive compatibility. Other supporting programs include C++ with OpenGL since the OpenGL driver enables the 10-bits. Hardware to pair with these programs such as left and right buttons, dials, and joysticks, etc. may also aid in making these tests user friendly and more rapid. Recreating this test in programs should expedite the test process, opening doors to many opportunities in vision testing from speeding up the process to retrieving more consistent results. Other display parameters and system information can be found in the Appendix. Some interesting key points include that the monitor is monochromatic, so colors are displayed in gray scale. Contrast ratio is important to compare since it is so high at 700:1 while LCD screens are 209:1 and CRTs are 16:1 in contrast. The resolution of the monitor is important in determining whether the full dynamic range will be able to be displayed. Therefore, the resolution in cycles per degree of visual angular subtense can be calculated:

$$Pixel\ Pitch = \frac{0.165mm}{pixel} \Longrightarrow Pixel\ Density = \frac{25.4mm}{0.165mm/pixel} = 153.94\ pixels$$

For 1°, there are two pixels necessary to view one line-pair or 0.5".

$$\frac{153.94pixels}{1} \cdot \frac{0.5inch}{1degree} \cdot \frac{1cycle}{2pixels} \Longrightarrow Resolution = \frac{38.485cycles}{degree}$$

4.1.1 Calibration

VeriLUM external calibration was used to conduct a luminance uniformity test that provided the exponential trend. For this test, different levels of contrast within grey background images were created and displayed in MatLab. Using the external calibrator, the luminance values were recorded from different areas of the display screen and plotted as seen in Figure 4.1. An exponential trend is present which accounts for the gamma correction seen in display luminance.

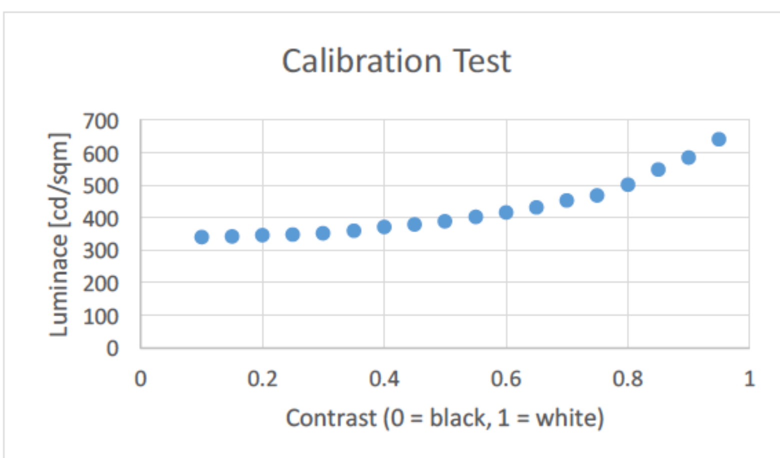


Figure 4.1) Calibration Test for WIDE 10-bit Monitor

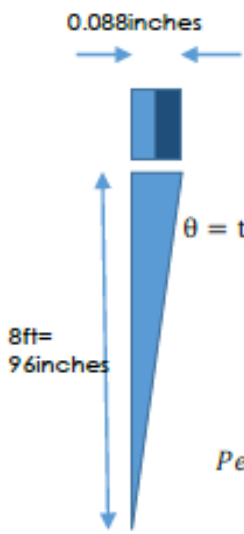
4.2 Test Methods

4.2.1 Computerized Vector Vision

To demonstrate how important the 10-bit monitors versus 8-bit monitors differential is, a computerized version of the Vector Vision CSV-1000E Chart Test was created and under development. Using the two-button designed Graphical User Interface (GUI) stating “LEFT” or “RIGHT”, this test randomizes if the sinusoid is on the Left or Right of the screen at four different frequencies and eight contrasts. It also asks for user response and tracks the correct or wrong answers at those points. This provides a faster method of testing than the actual chart test because the refresh time is instant, and responses are instantly recorded. An advantage to these computerized tests are that the gratings can be altered to various viewing distances. For example, the test can be taken at arm’s length or at the standard eight feet just by changing the calculations for the generated sinusoids. The computerized test example is shown below in Figure 4.2.

Figure 4.2) Computerized Vector Vision CSV-1000E Version Prototype

To assure that the spatial frequency matches, a simple trigonometric calculation was made. The 18 cpd sinusoid was measured such that one line-pair was 0.088 inches so that at 8 feet the angular subtense is 0.0525 degrees. By taking the inverse, 19.03 cpd were produced for a 5.41% error of accuracy. Though this test only goes through few frequencies and contrasts, the computerized version is quicker due to the instantaneous image refresh rate. Plotting of the contrast sensitivity still needs improvement in this software.



$$\left(\frac{18cycles}{degree}\right)^{-1} = \frac{0.0555degrees}{cycle}$$

$$\theta = \tan^{-1}\left(\frac{0.088inches}{96inches}\right) = 0.0525degrees \Longrightarrow (0.0525degress)^{-1}$$

$$\frac{1cycle}{0.0525degrees} = \frac{19.03cycles}{degree}$$

$$Percent\ Error = \frac{|18cpd - 19.03cpd|}{19.03cpd} \times 100\% = 5.41\%\ error$$

However, it is useful for the evaluation of ocular disease, particularly cataracts, glaucoma, optic neuritis, diabetes and macular degeneration, or for better assessment for contact lenses and refractive surgery.

4.2.2 Free Hand Draw

The objective of this test is to use the subject’s responses to characterize the contrast sensitivity function. The Campbell Robson CSF chart is displayed with an array of options to vary as the test was conduction. Options include altering grating orientation, spatial frequency, which tests were completed, and which files to open or save, etc. as seen in the GUI of Figure 4.3.

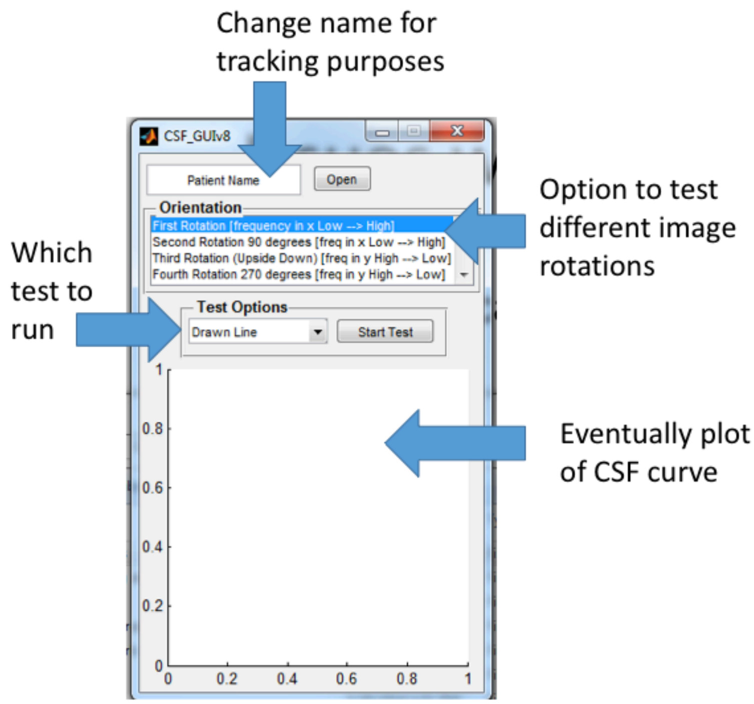


Figure 4.3) Free Hand Draw Test GUI Controls

Subjects will be asked to draw a line at their contrast threshold where the differences between white and black are no longer distinguishable. Once the chosen test parameters are set and the "Start Test" button is clicked, a pop-up box will appear on the screen to begin the test. This program then begins a timer that tracks the traced mouse position until the "OK" button at the end is clicked or the time limit is exceeded. At the completion of this test, the traced mouse position points are calibrated in order to remove unwanted data such as the points traced outside of the actual image. The traced mouse position where the pixel and position points are calibrated and converted to spatial frequency and contrast space. The data points are extracted from MatLab into Excel where the data can be manually graphed. Figure 4.4 displays the results from an initial test done where the top figure represents the traced line using the mouse during the Free Hand Draw test whereas the bottom figure is the log plot of the converted points averaged out. The mouse feedback produces a lot of noise since it does not account for any other factors. However, it is a starting point in reproducing the contrast sensitivity curve.

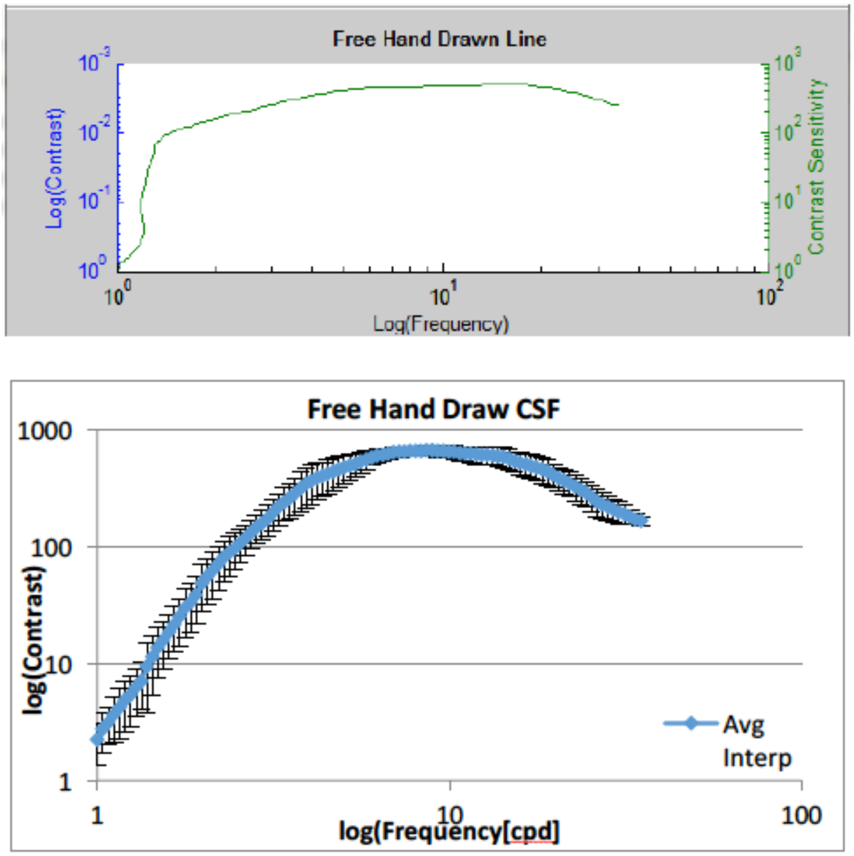


Figure 4.4) Preliminary Free Hand Draw Results

4.2.3 Growing Boxes

The full Campbell-Robson Chart grating is presented in this test as well. This test consists of bars which grow at set speeds and stop at their estimated contrast threshold that the observer can control. The final product should represent a bar graph with the combination of bars to show the contrast sensitivity curve. The bars can come from the top or from the bottom of the image to make sure that subjects are consistent in measurements. These versions are aimed to be more user friendly, accurate, and repeatable since the bar width and growth rate can be modified. Initially, this test was supposed to be portrayed in the same GUI as the Free Hand Draw test as one of the options. However, MatLab did not allow the overlay of a transparent window with the displayed Campbell-Robson Chart. Consequently, C++ with OpenGL is another program that can exhibit 10-

bit output with the transparent growing boxes and subjects control over the speed and response to their thresholds. Since the images are generated electronically, the number of frequencies or frequency width can also be changed.

An example for subject interaction was to have a moving bar system that the subject stops at the appropriate time Figure 4.5. Once the test is run, the initial results of the contrast threshold should be as in Figure 4.6 where the white dots represent the user's input when stopping the box at the threshold.

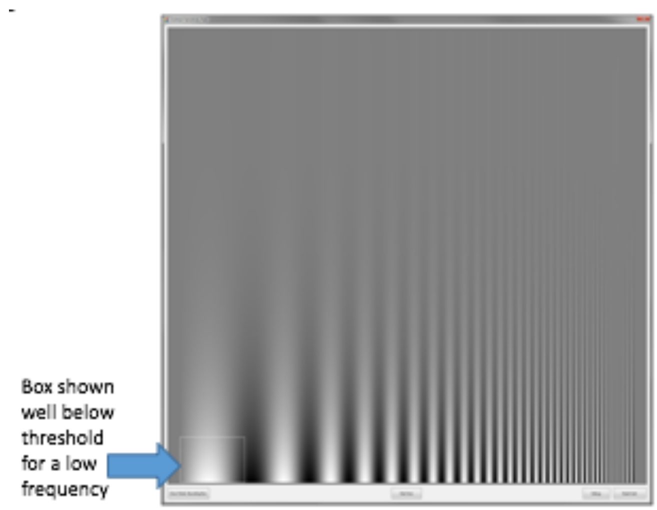


Figure 4.5) Growing Boxes Test Example

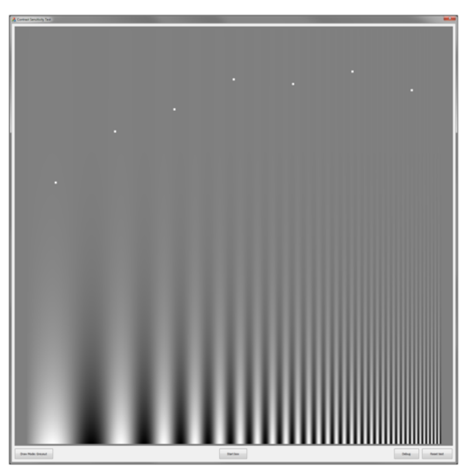
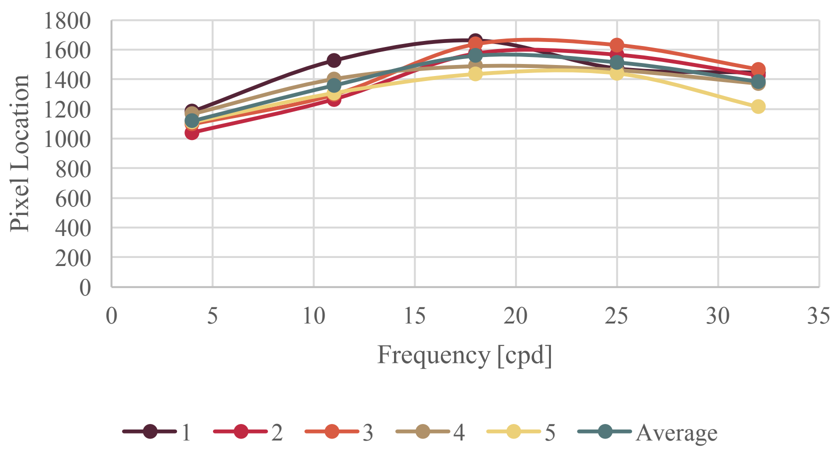


Figure 4.6) Preliminary Growing Boxes Test Results

This test is aimed to be more user friendly, accurate, and repeatable. It provides another alternative to the Free Hand Draw test since there is less bias, error, and/or noise from the mouse feedback. Another benefit includes the option to change bar width and box growth rate for greater data. A preliminary was completed to show consistency in drawing the contrast sensitivity curve (Figure 4.7). These results proved that the measured points follow a similar CSF u-shape. The shape can be fine-tuned depending on frequency spacing or width between growing boxes to increase sample points.



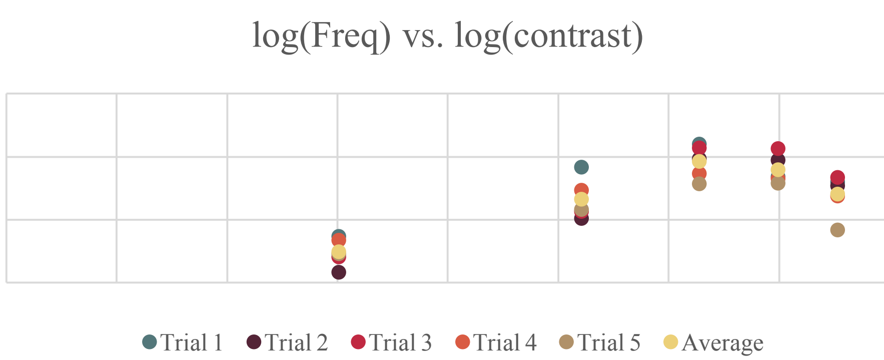


Figure 4.7) Preliminary Growing Boxes Results

4.2.3.1 Grey-out Option

Similarly, there can be a grey-out option to account for any residual images subjects might see from exposure to the full chart (Figure 4.8). In addition, in the grey-out option, the edges of the box can be softened to prevent edge clues for the subject. It is possible that each box would contain only a single spatial frequency to allow the CSF to be measured or sampled at series of pre-chosen frequencies. The contrast between the grey background and growing box containing a certain part of the Campbell-Robson chart create less luminance change since it is less harsh than the contrast between full black and white just like the Vector Vision and Forced Choice tests display the Gabor patch against the grey background. This option greys out the Campbell-Robson grating and only displays the grating in a small box that grows at this rate and stops the same way.

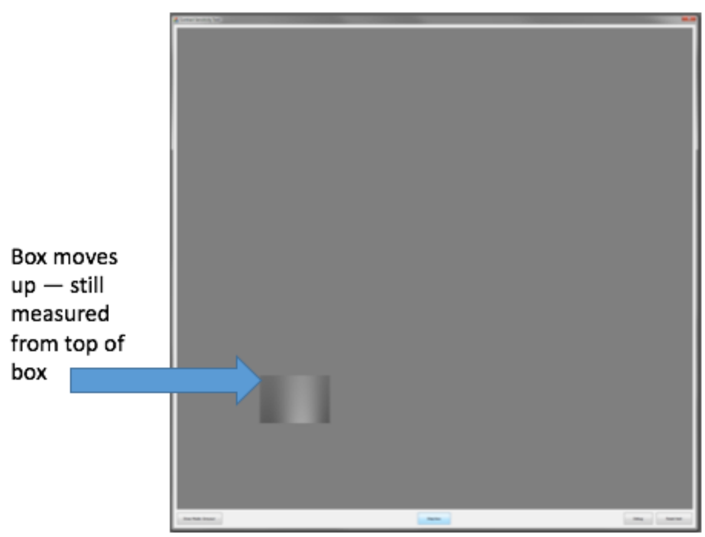


Figure 4.8) Growing Boxes – Grey-out Option

5 Tests Under Development

Unfortunately, the progress of this project was discontinued due to sponsor management changes and lack of funding. However, there were several tests to be completed for future work and research. 10-bits is necessary for vision testing so these tests should be used as routine methods to determine contrast sensitivity functions.

5.1 Manual Increasing Contrast

The goal for this test would be to display single frequency sinusoids at low contrast and to manually increase the contrast with a type of knob adjustment until the contrast between line pairs is visible. This noticeable contrast is measured and recorded and then the next frequency is tested until all frequencies are successfully completed. An example of this test is displayed in Figure 5.1.

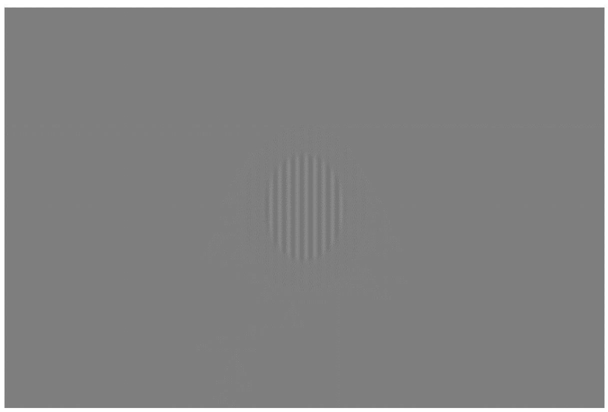


Figure 5.1) Manual Increasing Contrast Prototype

5.2 Single Frequency Growing Boxes

Another approach is to reproduce the growing boxes test with single frequency steps instead of with the Campbell-Robson chart. This might provide a more accurate result while still achieving that high dynamic range. Instead of the full grating of 1-35cpd, only single frequency gratings are displayed at a time with decreasing contrast within the box.

5.3 Computerized Force Choice

Similar to the method used to computerize the Vector Vision, the same methods should be able to be applied to the forced choice test. This will help decrease testing time and increase accuracy by mitigating eye fatigue. Here the sinusoids may be tilted about 10 degrees to the left of right. Just like the forced choice test mentioned before, the user must decide which way the sinusoid is tilted when randomly displayed at different frequencies and contrasts. With quick results, the data can be analyzed to determine the contrast limit. The progress of this test was cut short so only a 10-bit forced choice prototype was rendered. An example of the tilted sinusoids can be seen in Figure 5.2.

Figure 5.2) Computerized Force Choice Prototype

To speed up and simplify the testing process, the addition of video game style buttons was suggested. Instead of utilizing the right and left buttons on the GUIs for the Vector Vision and Forced Choice tests, the new system will have these arcade buttons of different colors to record their responses; for example, green is left and blue is right. The buttons would sit on top of an encasing like the plastic black box seen in Figure 5.3 (top) for easier patient use. Inside of the box contains the microcontroller Arduino IDE that the buttons are connected to run the code that records responses. The idea was to make the test more intriguing to patients by creating this game style atmosphere for faster responses with the two buttons instead of using a keyboard or the GUI so it is also less confusing. However, this was still under improvement and this analysis was not completed.

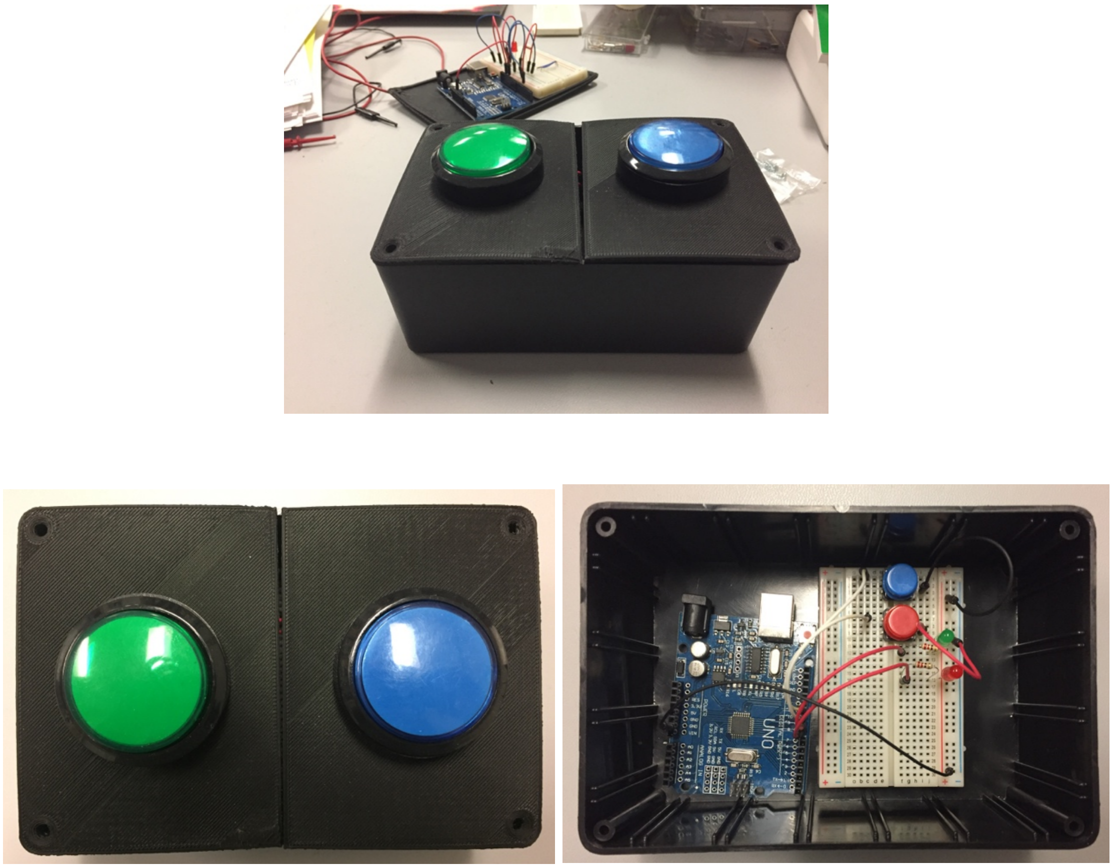


Figure 5.3) Video Game Style Buttons for Computerized Vision Tests

5.4 Test Status

Several potential methods were in development until this project was discontinued due to lack of interest. The computerized Vector Vision test is running, but only records users' responses and does not produce the contrast sensitivity curve. The Free Hand Draw test is repeatable but does not appear to be as good as growing boxes method. The Growing Boxes test explores various background contrasts, frequency widths, and gratings. The test was still under development as more code was being written to extract the data points into Excel or other files for further test analysis like the Free Hand Draw test. The test analysis can be conducted to complete these simple contrast sensitivity tests before considering ignored factors such as psychometric functions that affect the bias, neural noise, and patient responses.

6 Conclusion

Regular computers, televisions, cell phones, and other display screens make up 8-bit monitors which only has 256 shades per RGB color. While the average person can view 720 shades, if not as much as 1000 shades for artists and radiologists, Mach Banding happens due to the over shoot in viewable shades. This skews results as there is a fringe wash out which confuses patients since they can see the horizontal line between line-pairs within the grating. This optical effect can be reduced by applying the use of 10-bit monitors that provide the necessary 1024 shades per color channel when viewing images.

One early conclusion is that computerization of tests can speed up vision testing significantly. By conducting computerized vision tests, the responses prompt more accurate results with less patient eye exhaustion. There are also many options for the methodology of these vision tests with user interfaces, vertical or horizontal tests, different surroundings or backgrounds, or single frequency versus continuous frequency displays. Still, these tests use valid approaches to determining contrast sensitivity before funding was pulled. Further studies need to be done with 10-bit monitors in medical application to quantify how well it works or potential errors. The increased research will provide more practical use than current CSF tests, deliver error reduction, and contribute to better CSF testing and analysis. Hopefully, these faster and practical methods for CSF testing set contrast sensitivity as an essential marker during clinical vision tests. The tests can provide early detection for eye diseases. CSF tests can also offer quality testing for different contact brands and fits to weed out patient preference over another. As contrast sensitivity becomes more routine, the metrics between image contrast and image quality can be determined.

7 Appendix

7.1 Display Parameters

Screen Dimension: 10-bit WIDE monitor Model IF2105MP (PN21IQS)

Pixel Counts (H x V): 2560 x 2048

Pixel Pitch: 0.165mm x 0.165mm

Brightness: 1000 cd/m^2 <MAX>

Contrast Ratio: 700:1

Year: August 2008

Bit Depth: 8 or 10-bit

Mode: Monochromatic

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