

# Observer Calibrator for Color Vision Research

Zhen Zhou, Ben Grotton, Kevin Kruse, Alex Skinner, Antonio DoVale, Susan Farnand, Mark Fairchild;  
Rochester Institute of Technology (RIT), Program of Color Science, Rochester, NY

## Abstract

*The variability of human observers and differences in the cone photoreceptor sensitivities are important to understand and quantify in the context of Color Science research. Differences in human cone sensitivity may cause two observers to see different colors on the same display. Technicolor SA built a prototype instrument that allows classification of an observer with normal color vision into a small number of color vision categories. The instrument is used in color critical applications for displaying colors to human observers.*

*To facilitate Color Science research, an Observer Calibrator is being designed and built. This instrument is modeled on one developed at Technicolor, but with improvements including providing higher luminance levels to the observers, a more robust MATLAB computer interface, two sets of individually controlled LED primaries, and the potential for interchangeable optical front ends to present the color stimuli to observers. The new prototype is lightweight, inexpensive, stable, and easy to calibrate and use. Human observers can view the difference between two displayed colors, or match one existing color by adjusting one LED primary set. The use of the new prototype will create opportunities for further color science research and will provide an improved experiment experience for participating observers.*

## Introduction

Color is a perception. Color research then, frequently involves human observers. Understanding and quantifying the differences between observers with normal color vision is an important aspect of color science research. In the past several years, collaboration between the Program of Color Science at RIT and Technicolor Research and Innovation in Rennes, France has led to the development of theoretical models of differences in human color perception [1] and a practical instrument for measuring these differences, known as the Observer Calibrator.[2] A prototype Observer Calibrator was designed, constructed, and built for testing in previous research. However, that prototype is owned by Technicolor and resides in their facilities in France. It is also quite delicate and not easily transported for use outside of France. A new build prototype was necessary for use in research at RIT. A team of engineering students in the Multidisciplinary Senior Design program at RIT undertook a project to design and build an Observer Calibrator that would meet the needs of Color Science researchers.

The goal is to build a fully functional light production system with independently controlled and spectrally distinct primaries on each of two sides of the system with a module to mix light and present to the observer in a split field or two distinct fields. The system aims to have approximately twice the luminance level of the previous product. It will also have a USB interface to MATLAB running under Mac OS X. The finished product will be compact and easy to calibrate and transport. Testing will be performed to verify its function in research application scenarios with human observers. The expected end result is a functional device which can be used in future RIT color science research.

Documentation will be available for continued support in RIT color science research with the ability to build duplicate products, if needed. In this paper, the detailed design, build, and test processes are presented. Additionally, potential research applications of the Observer Calibrator are presented. The paper concludes with the status of the instrument and areas for future improvement.

## Experimental Methodology

There were two phases of this project. In the first phase, the project team evaluated the existing Observer Calibrator prototype and established customer requirements to generate engineering metrics. A design was developed with five subsystems: integrating spheres, device housing with stand, Arduino controller, MATLAB graphical interface, and LED electronics. In the second phase, each subsystem was built and was tested against the engineering metrics developed. Once each subsystem was verified, the final instrument was constructed by integrating all subsystems. At the end of the second phase, human subject tests will be performed to validate the use of the system.

### Integrating spheres

The team decided to design and 3D print the two integrating spheres used in the Observer Calibrator. This not only will allow for greater reproducibility by other institutions wishing to recreate the device, it also allows for further modification of the instrument in the future should larger arrays or spheres be desired for experiments. The sphere design was created in SolidWorks as 4" hemispheres connected with M4x25 mm bolts and nuts on a ring surrounding the hemisphere. The sphere was then printed on a MakerBot, using ABS. ABS was chosen due to its high temperature tolerance and ability to finish surfaces with acetone. The sphere was designed as a 90 degree sphere, with two 25 mm apertures for insertion of the large LED arrays and for a large field of view for the observer. The baffle for the sphere was inserted as a plexiglass circle of 30 mm diameter attached to a bolt running at a 45 degree angle to the upright position. See drawings for further clarification in Figure 1. The interior was painted with several coats of standard reflecting titanium white paint, which resulted in reasonable reflectance values for the chosen LED wavelengths (as shown in Figure 2).

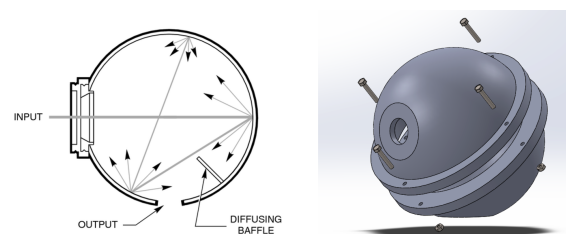
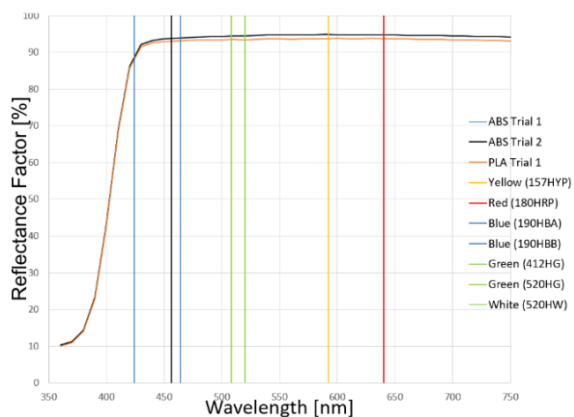


Figure 1 Design graph of integrating spheres

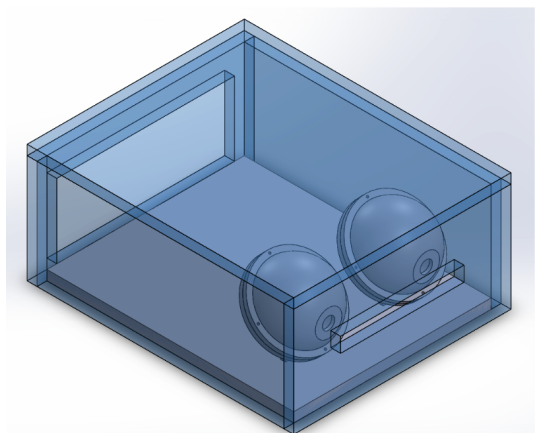


**Figure 2** Paint reflectance testing with peak values of the two sets of selected LEDs highlighted

### Device housing with stand

The housing was constructed using wood. This was chosen for its structural integrity, as well as its ease of assembly and attachment for the components. The housing was designed as a simple box, with four sides affixed to the base permanently with screws, and one side hinged to allow better access to the internal components (as shown in Figure 3). The top was designed to be removable, and sits on brackets mounted on two of the sides. A handle was also installed to allow for ease of removal for the top. The four encoders for changing the LED output were mounted in holes above the integrating spheres, along with the push button for signaling completion of the current task. Holes were cut for the integrating spheres' output holes for the viewer to observe the color. The entire housing was painted matte black to absorb stray light and focus the observer's attention on the lighting from the spheres.

For the housing, 1/2 inch birch plywood was used, which, while sturdy, was significantly heavier than anticipated. However, due to the lack of local availability of 1/4 inch plyboard with the same stiffness and rigidity, 1/2 inch board was used. Although the housing structure stayed within the customer's design specifications, in future construction, it is recommended that lighter weight, thinner material be used. Additionally, a more sophisticated attachment method for the optical front end (for easier interchangeability) would be preferable.

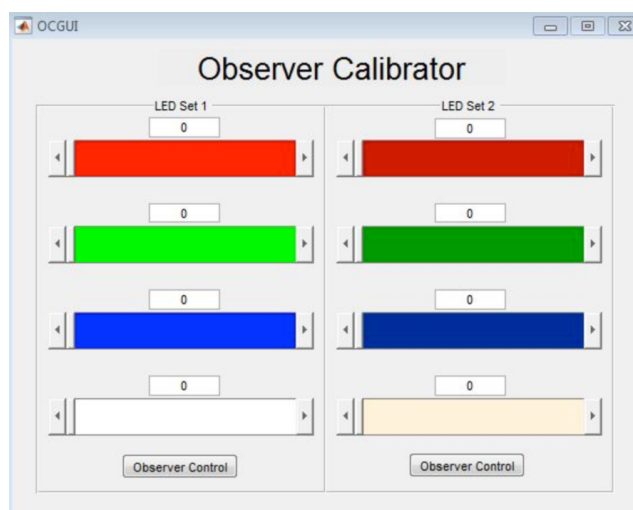


**Figure 3** Design graph of device housing

Several different stands were considered to support the instrument and to provide adjustment to the observer's viewing level. The decision between an X shape stand, an I shape beam, a folded stand and a tripod was made based on couple criteria: stability, angle adjustment, height adjustment, and weight supported. After comparison, the final decision for instrument support was the tripod, for its stability and adjustability. It is also easy to maintain and replace.

### Arduino and MATLAB programming

A Graphical User Interface (GUI) was created in MATLAB to allow the researcher to control the brightness level of each LED as shown in Figure 4. The sliders and text edit fields in the GUI, when changed, call a MATLAB function to send a serial transmission to the Arduino to tell it which LED to set and what value to set it to. The GUI also has buttons associated with each set of 4 LEDs. When a button is clicked, the GUI calls a second MATLAB function. This function sends a serial transmission to tell the Arduino to have the LED set associated with the button be controlled by the observer via the encoders. The MATLAB function then waits for the Arduino to transmit the LED values that the user selects, and exports these values to a CSV (comma-separated values) file. The process is described in the flowchart shown in Figure 5.



**Figure 4** Graphical User Interface (GUI) in MATLAB

A function was also created in MATLAB that allows the researcher to automate the test process by providing some initial variables for the program to use as inputs to the functions called by the GUI (as shown in Figure 6). The Arduino code, in its main loop, waits for a serial transmission from MATLAB. Upon receiving a transmission, it determines whether it needs to change a particular LED or execute one of the encoder control functions. In the case of the former, the LED is assigned the new value, and the Arduino waits for the next command. In the latter case, the encoder control function for the appropriate set of LEDs is executed. The encoder control function stays in a loop as long as a digital push button is not pressed. The loop performs polling I/O for the four encoders, checking to see if any have changed and, if so, in what direction. The value of each encoder's assigned LED is incremented or decremented depending upon the direction the encoder is turned.

When the button is pressed, the loop exits and the values of the four LEDs are sent via serial transmission to MATLAB. The encoder control function then returns to the main loop of the Arduino code, which begins waiting for the next MATLAB command.

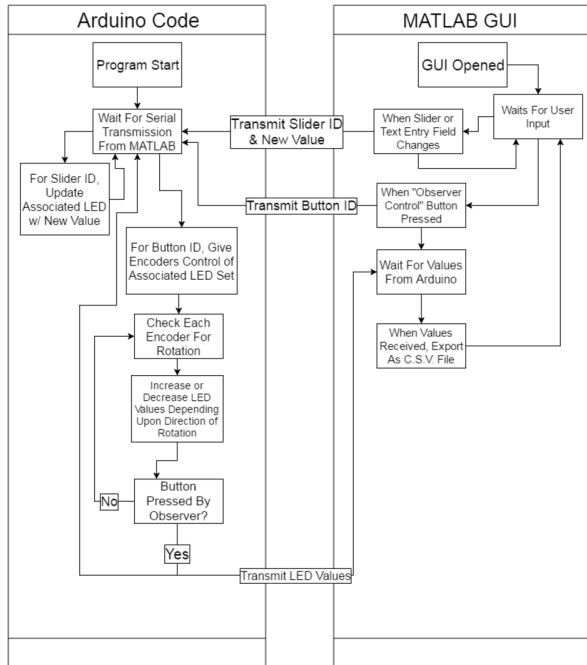


Figure 5 Process for GUI control and Arduino code interactions

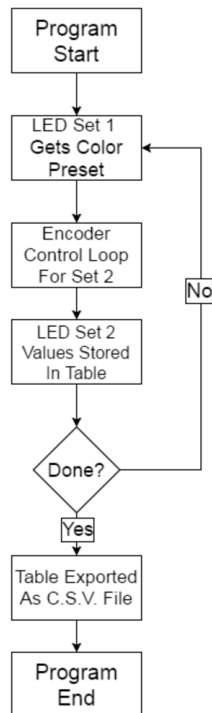


Figure 6 Automation function

### LED drive circuitry

The drive circuit used to control the LEDs is a pulse-width modulated (PWM) drive circuit with MOSFET transistors (as shown in Figure 7). Since LEDs are current driven light sources, resistors were individually chosen for each LED to properly set the current given a known voltage drop across the LED. Using the data sheets to determine the voltage drop across the LEDs and the maximum current that the LEDs can draw, and assuming a standard 5 volt power supply would be used, the resistors were selected using the following equations:

$$5V\text{-LED voltage drop} = \text{Voltage drop on resistor}$$

$$R = (\text{Voltage drop on resistor}) / (\text{Max current through LED})$$

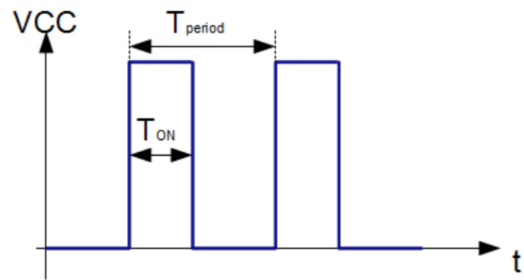


Figure 7 Pulse-width modulated (PWM) drive circuit

To vary the brightness of the LEDs, the 5 volt input to the drive circuit needed to be adjustable. This is where the PWM signal and transistors are utilized. When a PWM signal is applied to the gate of a MOSFET transistor, it acts as a switch that conducts current while the PWM signal is high and prevents the flow of current while the PWM signal is low. If the drain of the transistor is tied to the negative lead of the LED then it will prevent the LED from being on while the PWM signal is low, and allow it to turn on when the PWM signal is high. The duty cycle of the circuit is the ratio of time that the signal is high versus the time that it is low for one period of the signal. The duty cycle can be represented by a percentage from 0% to 100%, with a duty cycle of 0% being low the whole time, and a duty cycle of 100% being high the whole time, as illustrated in Figure 8.

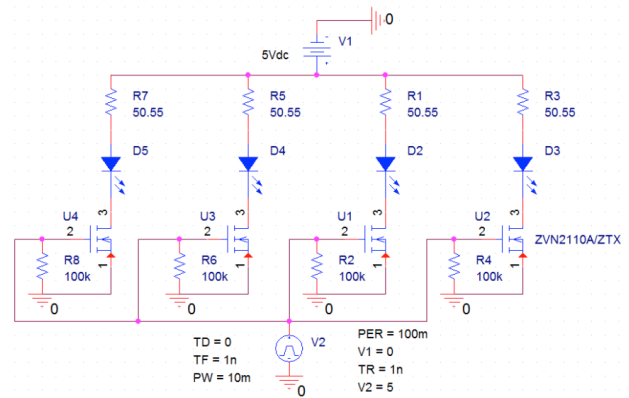


Figure 8 Schematic of LED drive circuit

Since the human eye typically cannot distinguish frequencies over 60Hz, switching the LED on and off faster than 60Hz will create the impression that it is always on. The effective average current through the LED is then proportional to the duty cycle. Since the resistors were selected to allow maximum current with the full 5 volts being applied (equivalent to a duty cycle of 100% being applied to the gate of the transistor) then the LEDs should dim as the duty cycle is decreased and brighten as the duty cycle is increased. In order to control the PWM duty cycle being applied to the LEDs without the use of the MATLAB GUI, quadrature encoders were selected to act as knobs (as shown in Figure 9). The digital pins on the Arduino are used to read the previous and current states of the encoder in order to determine which way it is being spun. Depending on which way the encoder is spun, the duty cycle is either incremented or decremented (resulting in the LED brightening or dimming).

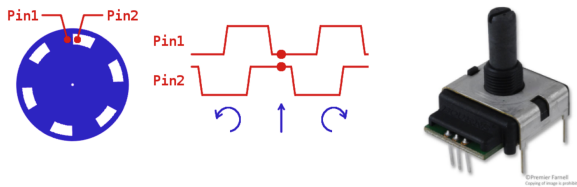


Figure 9 Quadrature encoder

### Integration test

To test the integration properties of the integrating sphere with the LED drive and control electronics, luminance and spectral power measurements were taken. The primary focus of this test was to ensure that the integrating sphere was reflective enough to meet the desired luminance specifications. The interior of an integrating sphere was coated with reflective paint, and spectral power data were obtained in a dark environment. Two sets of LED primaries, the MATLAB control interface, and one integrating sphere were included in the test setup. A Photo Research PR655 SpectraScan spectroradiometer was used to capture the spectral power data, and the LED drive circuitry was implemented on a breadboard, powered by an external power supply. Figure 10 shows the experiment setup with lights turned on for demonstration purposes.

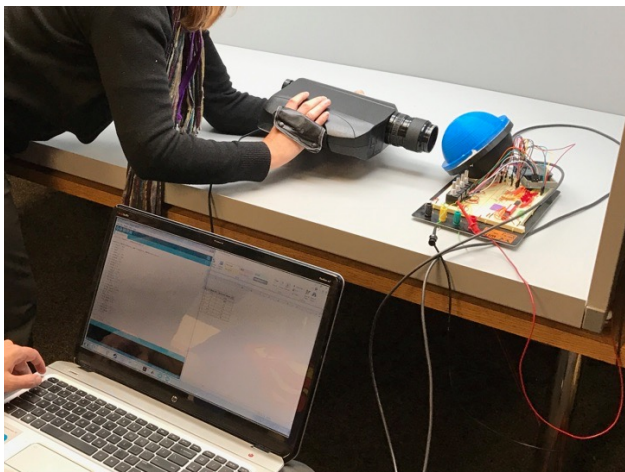


Figure 10 Experimental setup for LED measurement

Several observer individuals with normal color vision will be recruited to participate in the subjective experiment to validate the use of the Observer Calibrator. All the participating observers will be given instructions on the use of the instrument. Following the instructions, an observer will be requested to perform two test scenarios: First, the observer will be shown sequences of similar colors and the observer must determine if they perceive a match between the colors. Second, one color will be shown to the observer on one set of primaries, and they must adjust the second set of primaries to match that color.

### Results and Discussion

The integration properties of the integrating sphere with the LED drive, control electronics, luminance level were tested. Spectral power data were measured using a Photo Research PR655 SpectraScan spectroradiometer. Most of the test measurement results met the engineering specifications, that the luminance level of each LED is above 15 cd/m<sup>2</sup>, as listed in Table I. Notably, the 190 HBA LED (one of the blues) did not meet the specification. The spectral radiance curves for the two LED sets are shown in Figure 11.

The luminance of the 190 HBB led was unexpectedly low. In prior tests without the integrating sphere, the measured luminance was much higher. The integrating sphere is known to be less reflective at low wavelengths, which lowered the luminance value below the required threshold. The other LEDs, specifically those which showed extremely high luminance such as the greens, will be adjusted in software to alter their maximum brightness.

Table I Measured luminance for each LED made using a Photo Research PR655 SpectraScan spectroradiometer

| LED Part #      | Set Number | Luminance (cd/m <sup>2</sup> ) |
|-----------------|------------|--------------------------------|
| 180 HRP (Red)   | 2          | 37.63                          |
| 157 HYP (Amber) | 1          | 34.66                          |
| 520 HG (Green)  | 2          | 113.9                          |
| 412 HG (Green)  | 1          | 225.0                          |
| 190 HBA (Blue)  | 1          | 11.14                          |
| 190 HBB (Blue)  | 2          | 72.09                          |
| 520 HW (White)  | 1, 2       | 269.4, 276.4                   |

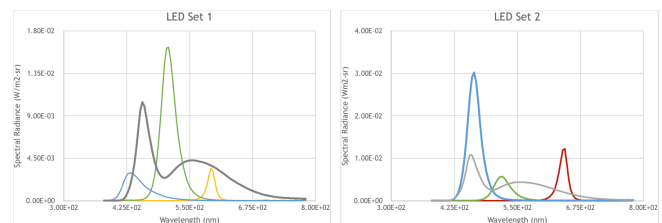


Figure 11 Measurement results of the two sets of LEDs made using a Photo Research PR655 SpectraScan spectroradiometer

## Conclusions and Future Work

This Observer Calibrator prototype updates the previous existing instrument developed by Technicolor, France. Compared to the previous instrument, the new prototype increases the luminance level, adds a USB interface to MATLAB running under Mac OS X, and can be integrated with various optical front ends. The new prototype is also designed to be lightweight, inexpensive, stable, and easier to use and calibrate than the previous instrument. This new prototype can be easily replicated for laboratory color research.

Future work may include the selection of new LED primaries for ongoing color research. The LEDs in this project were chosen such that their peak wavelengths targeted areas of high differences in color perception. However, LED Set has limited power in the longer wavelengths. Future studies may wish to obtain finer control over displayed wavelengths. Additionally, future efforts may involve the selection of a paint for the integrating sphere that more effectively reflects lower wavelength light (380-430 nm).

## Acknowledgments

The authors wish to thank Dr. Lynn Fuller, for his assistance in designing the LED drive circuitry, Dr. David Wyble, for his assistance in measuring spectral data and in creating the MATLAB GUI, and Dr. Michael Murdoch, for his assistance on the design of the integrating sphere.

## References

1. Asano Y, Fairchild MD, Blondé L (2016) Individual Colorimetric Observer Model. PLoS ONE 11(2): e0145671. doi:10.1371/journal.pone.0145671.
2. Morvan, P., Sarkar, A., Stauder, J., Blondé, L., & Kervec, J. (2011, July). A handy calibrator for color vision of a human observer. In 2011 IEEE International Conference on Multimedia and Expo (pp. 1-4). IEEE.

## Author Biographies

*Zhen Zhou is pursuing her BS in Industrial and System Engineering and ME in Engineering Management from Rochester Institute of Technology. Her main responsibilities in this project are project management and human subject tests. Her career focus leads to process improvement and project management.*

*Kevin Kruse is a fifth-year B.S./M.S. student in Electrical Engineering. His responsibilities included the selection of the LEDs to produce the desired spectra at the proper luminance and the design of the PCB containing the LED drive circuitry. He will complete his bachelor's and graduate degrees in May 2017 with a focus in Digital and Computer Systems.*

*Antonio DeVale is a fifth-year BS student in Electrical Engineering student at RIT. He takes particular interest in microcontroller, Robotics, and Verification & testing. He chose to be in charge of software design for this project given his experience with MATLAB and Arduino.*

*Ben Grotton is in his final semester of a dual B.S./M.Eng. degree in Mechanical Engineering at RIT. The main focus for his responsibilities as the mechanical engineer of the team was designing a housing for the electronic components, and designing and testing a 3D-printed integrating sphere.*

*Alex Skinner is in the final semester of his fifth year at RIT. His main focus during this project was the design and selection of hardware components and circuitry. Upon completion of his degree in Electrical Engineering from RIT, Alex will enter the United States Navy as a Nuclear Propulsion Officer in the submarine fleet.*

*Susan Farnand is a Visiting Assistant Professor in the Program of Color Science at the Rochester Institute of Technology. Her research interests include human vision and perception, color science, cultural heritage imaging and 3D printing. She received her BS in engineering from Cornell University, her Masters in Imaging Science and her PhD in Color Science from the Rochester Institute of Technology. She is Publications Vice President of IS&T and an Associate Editor for the Journal of Imaging Science and Technology.*