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OPEN SOURCE DEVICES FOR HUMAN FACTORS RESEARCH

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The availability of increasingly powerful and versatile open source software and hardware products continues to open new possibilities for the design and development of experimental devices. The declining cost of many proprietary software and hardware solutions has further increased the options available to researchers. These new capabilities have led to an increasing number of people engaging in design and development of devices for research and other purposes. Capabilities that were previously only available to well-funded engineering organizations are now accessible to individuals and small teams with limited resources. The formation and growth of local and online support communities have provided access to existing solutions, guidance, and discussion.

Light emitting diodes (LEDs) are rapidly replacing incandescent sources for aviation signal lighting creating a need to evaluate the implications in terms of human visual processing in color vision normal and deficient individuals. Recent research at the Civil Aerospace Medical Institute (CAMI) evaluated whether individuals with certain color vision deficiencies were able to discriminate between the red and white lights in fielded approach light systems based on luminous intensity, even if unable to detect a difference in color (Milburn et al., 2013; Milburn & Gildea, 2012). Approach lighting systems, including the Vertical Approach Slope Indicator (VASI) and Precision Approach Path Indicator (PAPI) lighting systems present pilots on final approach to runways with a visual indicator of their height—either above or below—an optimal glide slope. Combinations of red and white lights convey visual glideslope information. For this experiment, we designed the device to ascertain whether individuals with certain color vision deficiencies were able to discriminate between the red and white lights in fielded approach lighting systems based on luminous intensity (Gildea & Milburn, 2013; Milburn, Gildea, Perry, Roberts, & Peterson, 2014; Figure 1).

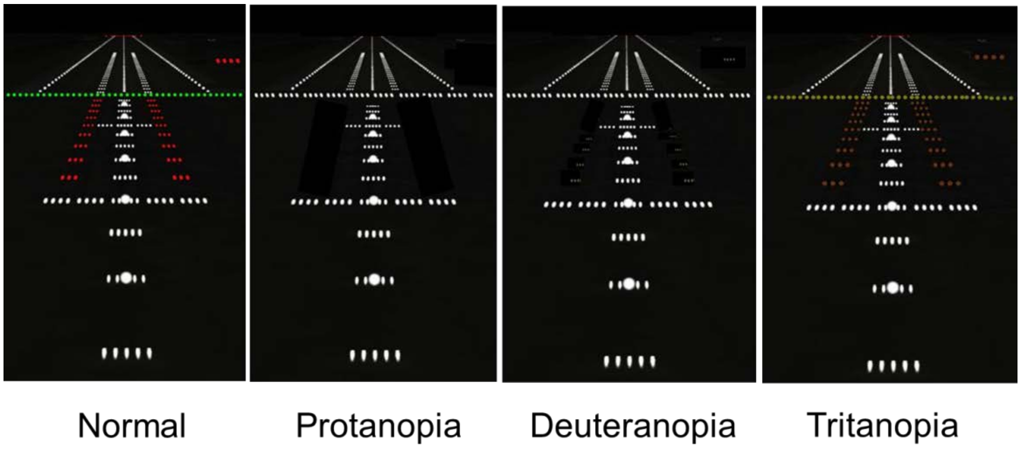

Figure 1. Approach lights as notionally perceived by those with normal and deficient color vision.

Traditionally, integrating controllers and writing software code for use in experiments required a significant amount of training. Now, software solutions, including open source, make programming the device relatively simple. Open source hardware and software are increasing the flexibility and capabilities of devices for controlled experiments. Open source solutions are often more accessible to those with limited research budgets. For instance, processing physiological data, auditory experiments, and vision researchers have utilized open source hardware and software (Christie & Gianaros, 2013; Hillenbrand & Gayvert, 2005; Teikari et al., 2012).

Lessons learned from the design and construction of a manually controlled precision approach path indicator (PAPI) experimental device (Milburn & Gildea, 2012) aided the design process. Early discussions led us to explore microcontrollers that could control LED luminance using pulse width modulation (PWM). This and other studies utilized an open source microcontroller called an Arduino (D'Ausilio, 2012, Teikari et al., 2012). In addition to the Arduino, there are a number of other microcontroller solutions available. Some of these devices are compatible with Arduino hardware and/or software, while others do not assure compatibility with the Arduino, but are similar in concept. There are also single-board computers that operate in conjunction with Arduino or similar devices providing increased capabilities. Some boards use various versions of Linux and provide additional options for programming languages.

The use of rapid development tools, open source options, and freeware solutions extends beyond the capabilities used for construction of the device. Design and prototype development are also areas that are amenable to hardware and software advances. Computer-Aided Design (CAD) programs, in association with Computer-Aided Manufacturing (CAM) tools, can reduce the likelihood of late modifications and reworks. Some CAD programs are capable of generating an associated parts list that can make it easier to estimate costs.

For designing and simulating integrated circuit functionality, there are several versions of SPICE (Simulation Program with Integrated Circuit Emphasis) are available, including the current version available from the University of California-Berkeley. LTspice™, Multisim™, Ngspice, TINA-TI™, and XSPICE are also available at no cost and are relatively easy to use. These software tools are useful in evaluating circuit designs prior to moving to a physical breadboard to test circuits.

For determining the physical layout on a printed circuit board (PCB), DesignSpark PCB, ExpressPCB™, and similar software packages provide a manufacturing file (e.g., RS-274 Gerber file format, Excellon format) that can be sent to certain custom PCB manufacturers for drilling and etching at a nominal fee (often <$100) with no limit on the number of boards manufactured. These manufacturers can deliver the board to the designer in a bare state with just the circuit conduction paths, or traces, and no components soldered to the PCB. Some software packages, including DesignSpark PCB and ExpressPCB™ prepare a list of components for direct order of the discrete components (e.g., resistors, capacitors, ICs). For an additional fee, some PCB manufacturers will deliver the board fully assembled (e.g., Pad2Pad®, Sunstone Circuits®).

Even with a “clean sheet” design, many components are often available commercially. There are generally a number of viable options for any given component or subsystem, as well as macro level design and implementation. In many instances, it is necessary to modify off-the-shelf components for uses other than for those originally intended. Such off-the-shelf devices are generally much cheaper than custom manufacturing or machining of components.

We needed a device that could present multi-condition stimuli representing: 1) a signal light gun, 2) PAPI lights as their current incandescent sources and as planned LED sources, 3) a tricolor PAPI LED condition, and 4) with the luminances controlled to match in-service incandescent (white 2 times brighter than red) or of equal luminance. Obviously, there was no off-the-shelf apparatus available to present any or all of those stimuli.

PAPI Experimental Device

There were two chromaticity conditions with the LED light source. Half of the LED groupings consisted of unicolor emissions with each of the three LEDs emitting the same wavelength. The other half of the groupings consisted of LEDs, each emitting a separate wavelength for a tricolor condition. The unicolor white LEDs were 5500 Kelvin (5500K), and the tricolor white LEDs were 3000K, 5500K, and 8000K. Unicolor red LEDs were 642nm with the tricolor red LEDs being 628nm, 642nm, and 660nm.

LED selection from commercially available sources is problematic in terms of chromaticity, luminance, and distribution pattern. There is a limited selection of chromaticities available from LEDs. For the purposes of this study, it was necessary to have an LED that had a dominant wavelength of 660nm, and the available LEDs with sufficient luminance for our purposes could provide a peak wavelength of 660nm — but the dominant wavelength from these LEDs was generally 652nm. This was too close to the 642nm emissions of some of the red LEDs for our experimental purposes. To address this issue, a bandpass filter was selected that would only pass 660nm +/- 2nm, and this was placed in front of a 642nm LED to provide the required emissions.

The luminance intensities of the commercially available LEDs also presented challenges. LEDs that presented identical luminous intensities for all of the necessary wavelengths were not available. The solution was to select LEDs that provided a higher luminous intensity than was necessary and then adjust those luminous intensities with a combination of current-limiting variable resistors/potentiometers and PWM control from the Arduino.

Code for the Arduino microprocessor. As mentioned in the *Hardware* section, The Arduino microcontroller board uses an 8-bit, 16 MHz Atmel AVR microprocessor. The microprocessor is programmed using an open-source, Wiring-based language that is similar to C/C++. The software runs on Windows®, Mac OS X®, and Linux. For a detailed explanation of programing with the Arduino, see http://arduino.cc/en/Tutorial.

Another method of controlling luminous intensity with software is using the ShiftPWM library that creates outputs using shift registers. The code and additional information for the use of ShiftPWM is readily available online. There are additional integrated circuit options for control of luminous intensity. Dedicated LED drivers are available including the LTC3220, TLC5940 16-Channel LED Driver, LM3409HV, and the MY9221 with the addition of external current-limiting resistors. The ARD127D2P Rainbowduino ATmega328 board is an Arduino-compatible board constructed specifically for controlling LED matrices with the use of MY9221 integrated circuits as the modulation controllers.

A SainSmart relay board controlled the incandescent bulbs, although we considered constructing a relay board from discrete components. The cost of a custom relay board, even without considering the labor involved, was significantly more than that of the SainSmart solution. Designers and developers will likely find that to be the case with many devices when weighing options between COTS devices (e.g., microcontroller boards, integrated circuits) and constructing custom devices. However, for those who are unable to find workable commercial solutions, there are often examples of workable circuits online.

Solutions for LED luminous intensity control included constant current devices and the current limiting variable resistors (potentiometers wired using only two of the leads). Several commercial devices are available for constant current control of LEDs; these include the LuxDrive™ 3023 Wired BuckPuck Modules, TLC5940 16-Channel LED Driver, and LM27964 White LED Driver System with I2C Compatible Brightness Control.

The main concern with control of the luminous intensity was stability and repeatability of the stimuli. We were also operating on a very constrained budget, so we sought a solution that was both cost-effective and would provide a stable output. We took repeated measures of the output of the LEDs under the control of several mechanisms with an integrating sphere. The luminous intensity was repeatable across multiple days when using the potentiometers. If we construct another device in the future, we would use constant current devices for LED control.

Ultimately, the authors tested the LED control circuit design using three sample LEDs, each combined with a potentiometer, 200-ohm resistor, and a digital output from the Arduino Mega. The breadboard enabled us to validate the ability to control luminous intensity, timing, and sequence of presentation. Following this test, we constructed the final circuits using perforated circuit boards. Perforated circuit boards used at this stage provided the flexibility to modify the circuit, if necessary, without the challenges of a custom etched circuit board.

Although there are digital devices for controlling of the incandescent bulb luminous intensities, in the final device, bidirectional triode thyrister (TRIAC) switches controlled the incandescent bulbs. The intensities of the bulbs remained constant with repeated measurements using the integrating sphere. The main drawback of using the potentiometers and dimmer switches for luminous intensity control is the labor-intensive task of manually setting each control.

Ultimately, the apparatus we designed and used facilitated the experiment by precisely controlling the stimulus duration, the inter-trial time, luminance, and automatically announcing the trial number. These enhancements were a definite improvement over our previous, manually operated device. Further enhancements could easily incorporate a response device that would automate data collection.

For researchers seeking to design custom devices, there are a number of open source solutions. As with the design of most stimulus-presentation devices for research use, or probably most other unique devices, developers should anticipate modifications of plans, hardware, and software. The challenges are those experienced with any prototype in terms of designing, implementing, testing, and modifying. If a researcher can purchase the necessary device off-the-shelf—buy it; if not, expect to test and modify after the initial design.

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