CIRCADIAN LIGHT TRACKER

Preliminary Electronics Specification, Design and Implementation

ATLANTA, GA / APRIL 20, 2018

PERKINS+WILL

What is circadian light?

Circadian light is a framework for reasoning about how lighting conditions may influence the human body’s sense of time.

circa –di[es] -an

“about” (Latin)

“day” (Latin)

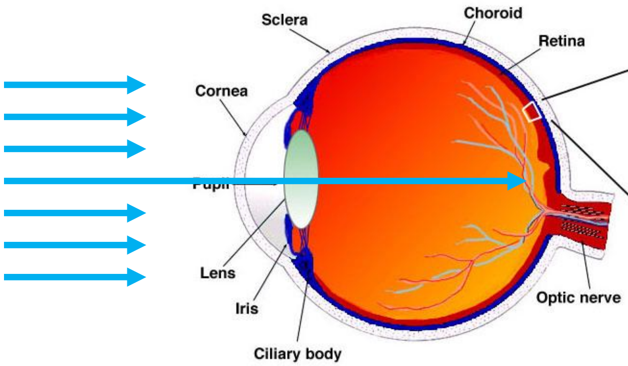
“of or relating to” (Middle English, Anglo-French, Latin)

INTRODUCTION

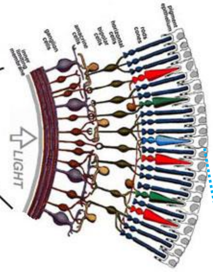
What is Circadian Light?

Visual Processing of Light

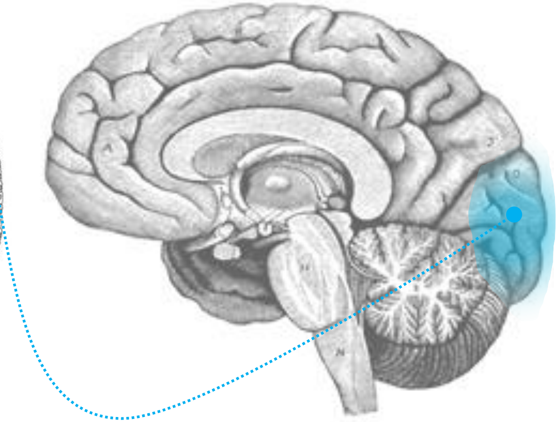
light from
environment



human eye



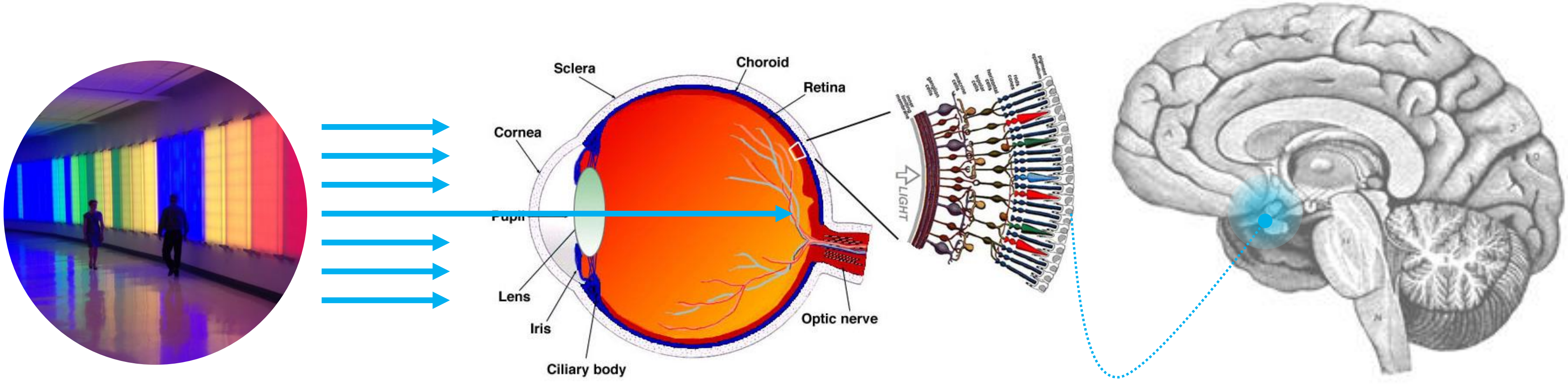
retinal rod and
cone cells



visual cortex

INTRODUCTION
What is Circadian Light?

Circadian Processing of Light



light from environment

human eye

rod cells, cone cells, and ipRGCs

suprachiasmatic nucleus (SCN)

INTRODUCTION

What is Circadian Light?

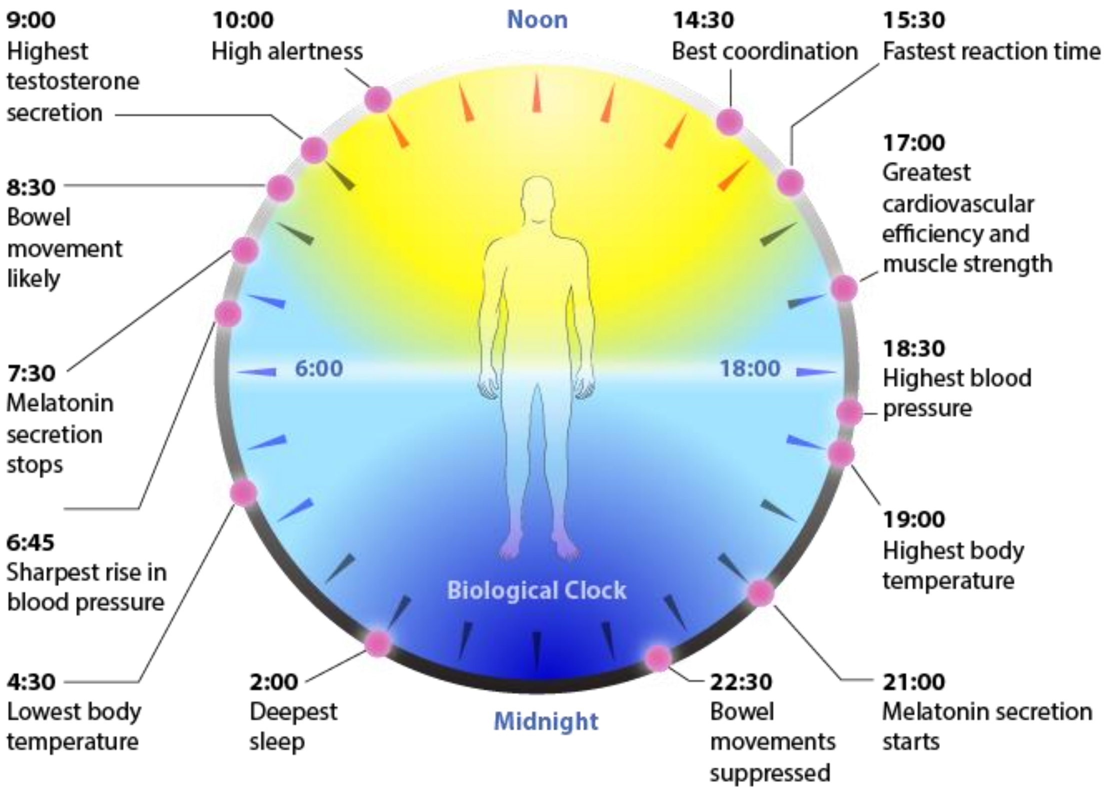


Diagram of how different physiological, endocrine, cognitive, and other functions ebb and flow in activity over the course of a day.

INTRODUCTION

Why should we care about circadian light?

INTRODUCTION
Effects of Lighting Exposure

- **Profound implications for health, wellness and performance**

Ansen Seale, *You Activate this Space,* Sky Tower at University Hospital in San Antonio.

INTRODUCTION
Effects of Lighting Exposure

- Profound implications for health, wellness and performance
- **Helps the body to schedule daily physiological and cognitive processes known as circadian rhythms**

From "Measuring and Using Light in the Melanopsin Age":

"...nearly every physiological, metabolic and behavioral system."

Source:

Lucas, R. J., S. N. Peirson, D. M. Berson, T. M. Brown, H. M. Cooper, C. A. Czeisler, M. G. Figueiro, P. D. Gamlin, S. W. Lockley, J. B. O'Hagan, L. L. Price, I. Provencio, D. J. Skene, and G. C. Brainard (2014, January). Measuring and Using Light in the Melanopsin Age. *Trends in Neurosciences 37*(1), 1–9.

INTRODUCTION
Effects of Lighting Exposure

- Profound implications for health, wellness and performance
- Helps the body to schedule daily physiological and cognitive processes known as circadian rhythms
- **Can be used to treat some sleep, neurological, physiological, and behavioral conditions**

UW Neighborhood Olympia Clinic; included at: http://www.thurstontalk.com/2016/10/31/seasonal-depression-treatment/

INTRODUCTION
Adverse Effects of Lighting in Buildings

- **AMA statement cites adverse health effects of environmental lighting, particularly at nighttime**

https://commons.wikimedia.org/wiki/File:San_Francisco_by_Night.jpg

INTRODUCTION

Adverse Effects of Lighting in Buildings

- **AMA statement cites adverse health effects of environmental lighting, particularly at nighttime**

From Executive Summary of "Adverse Health Effects of Nighttime Lighting":

"...potential carcinogenic effects related to melatonin suppression, especially breast cancer. Other diseases that may be exacerbated by circadian disruption include obesity, diabetes, depression and mood disorders, and reproductive problems."

Source:

Stevens, R. G., G. C. Brainard, D. E. Blask, S. W. Lockley, and M. E. Motta (2013, September). Adverse Health Effects of Nighttime Lighting. *American Journal of Preventive Medicine 45*(3), 343–346.

INTRODUCTION

Adverse Effects of Lighting in Buildings

- AMA statement cites adverse health effects of environmental lighting, particularly at nighttime
- **Calls for environmental lighting technologies that minimize circadian disruption**

From Executive Summary of "Adverse Health Effects of Nighttime Lighting":

"The AMA also supports the need for developing lighting technologies at home and at work that minimize circadian disruption, while maintaining visual efficiency."

Source:

Stevens, R. G., G. C. Brainard, D. E. Blask, S. W. Lockley, and M. E. Motta (2013, September). Adverse Health Effects of Nighttime Lighting. *American Journal of Preventive Medicine 45*(3), 343–346.

INTRODUCTION

Adverse Effects of Lighting in Buildings

- AMA statement cites adverse health effects of environmental lighting, particularly at nighttime
- Calls for environmental lighting technologies that minimize circadian disruption
- **We also need tools for analyzing lighting that are informed by current circadian research**

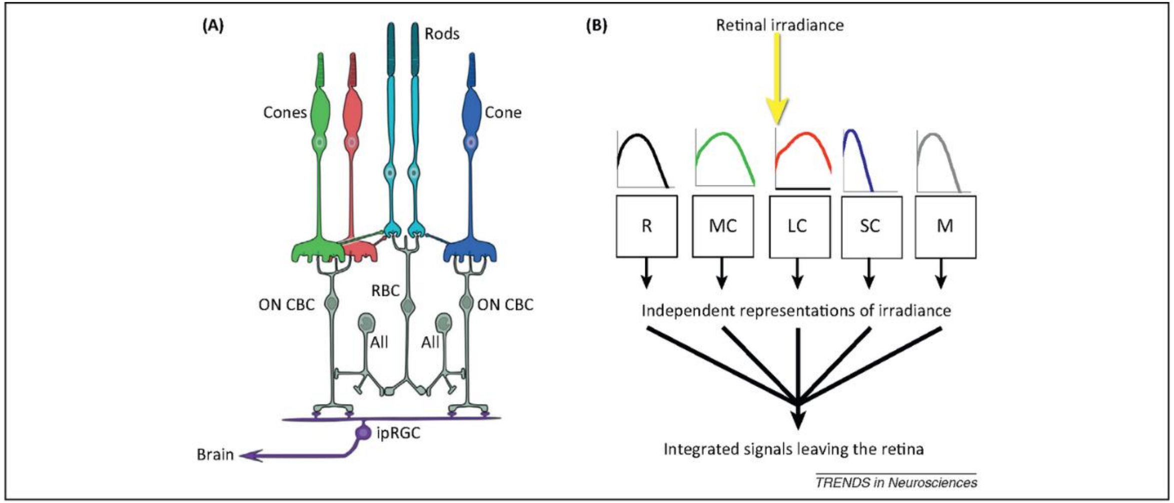
From Executive Summary of "Adverse Health Effects of Nighttime Lighting":

"…a need exists for further multidisciplinary research on occupational and environmental exposure to light-at-night, the risk of cancer, and effects on various chronic diseases."

Source:
Stevens, R. G., G. C. Brainard, D. E. Blask, S. W. Lockley, and M. E. Motta (2013, September). Adverse Health Effects of Nighttime Lighting. *American Journal of Preventive Medicine 45*(3), 343–346.

What do we know about the mechanisms for how light influences human circadian rhythms?

INTRODUCTION
Medical Research



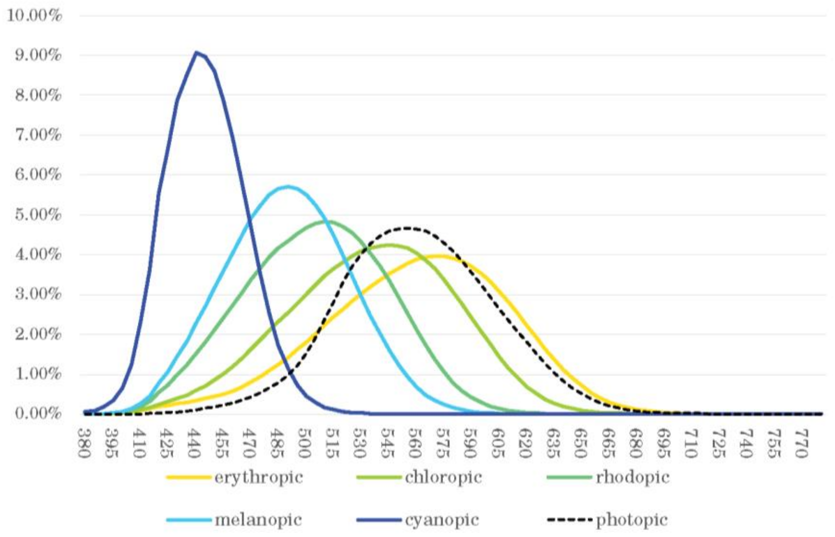
Photoreceptor	Photopigment	Spectral sensitivity function	Unit of measure[a]
Short-wavelength (S) cones	S-cone photopsin (cyanolabe)	Cyanolabe response function $N_{sc}(\lambda)$	Cyanopic illuminance (cyanopic-lux)
Medium-wavelength (M) cones	M-cone photopsin (chlorolabe)	Chlorolabe response function $N_{mc}(\lambda)$	Chloropic illuminance (chloropic-lux)
Long-wavelength (L) cones	L-cone photopsin (erythrolabe)	Erythrolabe response function $N_{lc}(\lambda)$	Erythropic illuminance (erythropic-lux)
ipRGCs (intrinsic photosensitivity)	Melanopsin	Melanopsin response function $N_z(\lambda)$	Melanopic illuminance (melanopic-lux)
Rods	Rod opsin	Rod opsin response function $N_r(\lambda)$	Rhodopic illuminance (rhodopic-lux)

- We know that circadian responses to light are a composite of all five known photoreceptors.
- Until a few years ago, research (2000 – c. 2015) was (and often still is) focused on intrinsically-photosensitive retina as the main explanation for circadian responses to light.
- Earlier than that (before 2000), the conventional rod and cone photoreceptors were assumed to be the likely culprit.

Lucas, R. J., S. N. Peirson, D. M. Berson, T. M. Brown, H. M. Cooper, C. A. Czeisler, M. G. Figueiro, P. D. Gamlin, S. W. Lockley, J. B. O'Hagan, L. L. Price, I. Provencio, D. J. Skene, and G. C. Brainard (2014, January). Measuring and Using Light in the Melanopsin Age. *Trends in Neurosciences 37*(1), 1–9.

MEDICAL RESEARCH

Five Spectral Filters for Circadian Lighting Analysis



Lucas et. al. (2014) surveyed currently available research on the topic of circadian stimuli, and proposed that the spectra and quantities of light stimuli be tabulated according to (at least) five spectral photosensitivity functions, corresponding to the eye's five major photoreceptor types – *until* the contributions of each photoreceptor class with greater specificity via real-world surveys and further scientific experiments.

Spectral Filter	Wavelength Range (nm)	Peak "Color" Name
Melanopic	460–480	Blue
Rhodopic	500–507	Cyan
Cyanopic	420–440	Blue-Violet
Chloropic	534–545	Green
Erythropic	564–580	Yellow

What are examples of proposed tools and methods for measuring circadian light (in the real world)?

INTRODUCTION

Previous Work

SunSprite

- **Feature(s)**
  - Consumer-grade device for helping users track and manage their own exposure to (photopic) light throughout the day and maintain beneficial circadian rhythms.
  - Claims that the *equivalent* dose of about 10,000 lux of light for at least 30 minutes is the "gold standard" for daily exposure.
- **Limitation(s)**
  - Is based on what was already becoming an outdated model of circadian photoentrainment – that solely rod/cone cells are responsible for influences on circadian rhythms, as opposed to other photoreceptors, such as ipRGCs.

Referenced at: Zenobase. "SunSprite." Blog | Zenobase, 2 Apr. 2015, blog.zenobase.com/post/115303836797. Cited on April. 11 2018.

INTRODUCTION

Previous Work

Daysimeter

- **Feature(s)**
  - Head-mounted device with photopic (combined rod and cone cells for vision) and melanopic (ipRGCs) photosensors.
  - Also measures head position and amount of movement (actigraphy).
- **Limitation(s)**
  - Measuring even photopic and melanopic light together might not always be enough to accurately characterize circadian responses for all potential lighting conditions a person may encounter.
  - Not available to the wider academic/professional community as of yet.

Bierman, Andrew, Terence R. Klein, and Mark S. Rea. "The Daysimeter: a device for measuring optical radiation as a stimulus for the human circadian system." *Measurement Science and Technology* 16.11 (2005): 2292.

Referenced at: "New Approach Sheds Light On Ways Circadian Disruption Affects Human Health." ScienceDaily, ScienceDaily, 17 July 2008, www.sciencedaily.com/releases/2008/07/080716111409.htm. Cited on April 11. 2018.

INTRODUCTION

Previous Work

Dimesimeter

- **Features**
  - Button-size device with that estimates photopic, melanopic, and cyanopic illuminances (along with the effects of macular pigments) using an RGB photosensor.
  - Actigraphy, in the form of an 'Activity Index' metric, is measured as well.
- **Limitations**
  - Still does not (yet) consider the potential contributions of all five major categories of photoreceptors to regulating circadian rhythms.
  - Not available to the wider academic/professional community as of yet.

Referenced in: "Light and Health | Research Programs | LRC." *Lighting Research Center*, www.lrc.rpi.edu/programs/lightHealth/projects/Dimesimeter.asp. Cited on Apr. 22 2018

INTRODUCTION

Previous Work

Sekonic C-7000 SpectroMaster

- **Features**
  - Measures ambient visible light (380-780 nm) and reports them in 1 nm increments.
  - Also reports multiple photometric and colorimetric values such as correlated color temperature (CCT), illuminance (lux), XYZ tristimulus values, color rendering index (CRI), etc.
  - Is used by Perkins+Will Human Experience Lab / 'Gadget Lab'.
- **Limitations**
  - Good for interior spatial surveys, but may be too big / bulky for extended personal logging of circadian light.
  - High cost per unit (~$2000) may also make it financially impractical for surveying lighting for anything larger than small groups of individuals.

Sekonic. "C-7000." Sekonic Light Meter: C-7000 SpectroMaster Exposure Meter - Overview, www.sekonic.com/united-states/products/c-7000/overview.aspx. Cited on Apr. 22 2018

INTRODUCTION

Previous Work

Hamamatsu C12666MA Micro-Spectrometer

- **Features**
  - Measures ambient visible light (380-780 nm) in 15 nm increments.
  - Convenient 'finger-tip' sized package: 20.1 × 12.5 × 10.1 mm
- **Limitations**
  - Does not appear to be available to purchase for non-industrial customers (i.e., not listed on Digi-Key, Mouser, Jameco, etc.)
  - Long lead time between production runs (6-8 weeks minimum).
  - Various current GroupGets postings online suggest that the base price of the chip is at least $200 per unit, which may be cost-prohibitive for some applications.

Referenced in: "Micro-Spectrometer Wins 2015 Prism Awards." EE Publishers, 9 Mar. 2015, www.ee.co.za/article/micro-spectrometer-wins-2015-prism-awards.html. Cited Apr. 22 2018

INTRODUCTION

Research Objectives

Develop a circadian light tracking prototype that:

- Is able to sample most or all of the human visible spectrum (380 – 780 nm);
- Is relatively low-cost, and can be deployed at moderate scales for institutional consumers (i.e., architecture firms interested in research);
- Consists of sensing and microcontroller component that can be implemented in a wearable form factor.

01 // INITIAL EXPLORATIONS

INITIAL EXPLORATIONS

Consideration of Sensor Design Options

Potential approaches to sensor design for circadian light tracking could include the following:

- **Spectral filter design:** Find or design an electronic photosensor that has a spectral response curve that mimics that of each of the human eye's five major categories of photoreceptors.
- **Spectrometry:** Select a range of photosensors with spectral responses (ideally tight spectral bands) that cover (at a minimum) the range of the visible human spectrum as evenly as possible.
- **Machine learning:** Given a light source of arbitrary spectra, filtered through some group of photosensors with random/unique spectra, "teach" a machine learning algorithm to predict the various circadian responses to the given light stimuli. [speculative]

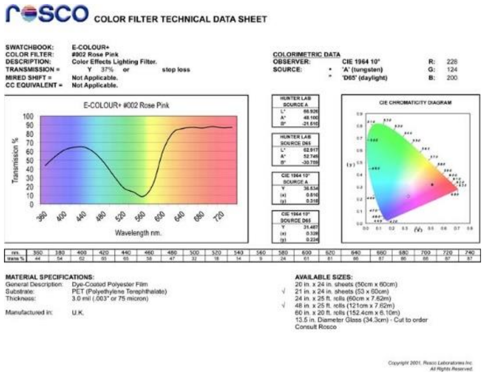
INITIAL EXPLORATIONS

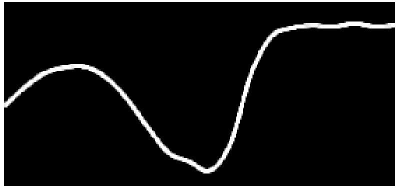
An Experiment: Filter Design

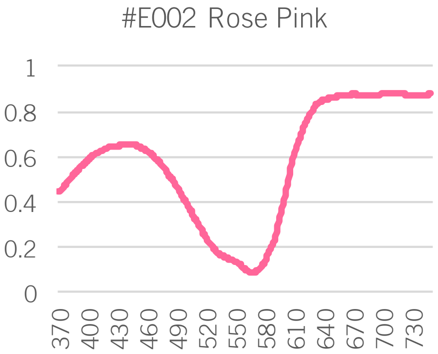
Initial research exploration included developing methods for searching for a photosensor filters mimicking human photoreceptor response spectra as a combination of (1) one or more gel filter layers, and (2) the response spectra of the photosensor itself. As precedent to this approach, the Daysimeter developed by the Lighting Research Center at Rensselaer Polytechnic Institute adopted a similar approach for the design of a filter for a 'circadian stimulus' sensor.

Methodology:

- Developed Python web-scraping script to automatically detect and download 781 images of the 914 gel filter options offered by Rosco, a major gel filter manufacturer;
- Implemented a technique for (specialized) semi-automatic graph data extraction using (1) Photoshop actions for datasheet cropping and manipulation, and (2) Python scripts for automated parsing of spectral data black-and-white of each graphs (same X/Y range for all images), which were then written to CSV files.







Top Left: One of 791 datasheets 'web-scraped' from Rosco website using Python scripting.

Above: B&W input image for automated graph data extraction, created with Photoshop actions.

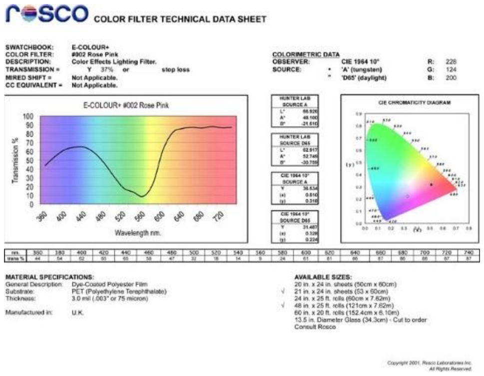
Left: Datapoints extracted from input image (above) using another custom Python script. Graph data could be used as input for a full-factorial search for filter combinations that match circadian photosensitivity functions.

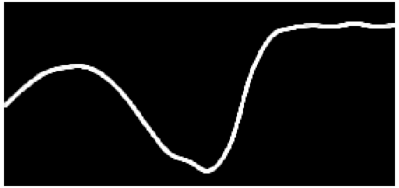
INITIAL EXPLORATIONS

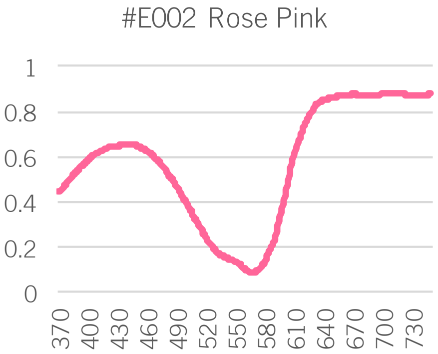
An Experiment: Filter Design Permutations

Methodology (continued):

- From this measurement dataset, single-, double-, and triple-gel filter permutations could be convolved, and the best-fitting (R^2 test) solution for each pentachromic sensitivity function can be determined.







Top Left: One of 791 datasheets 'web-scraped' from Rosco website using Python scripting.

Above: B&W input image for automated graph data extraction, created with Photoshop actions.

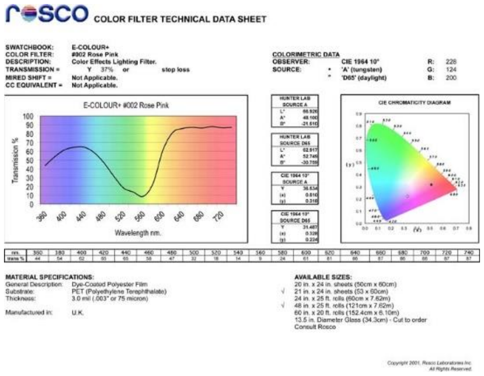
Left: Datapoints extracted from input image (above) using another custom Python script. Graph data could be used as input for full-factorial search for filter combinations that match circadian photosensitivity functions.

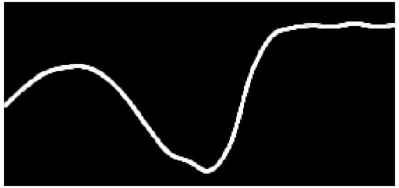
INITIAL EXPLORATIONS

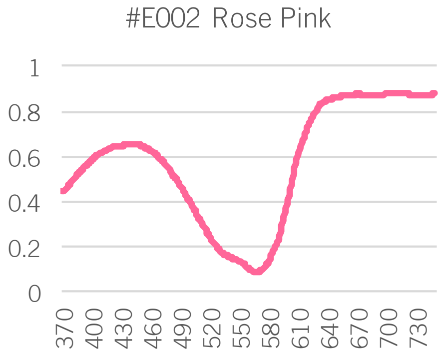
An Experiment: Filter Design Permutations

Observations/Results:

- This analysis methodology was eventually set aside for this project for several concerns about the validity of the spectral data being downloaded:
  - Graphs did not plot full visible spectra (360 – 720 nm for the Rosco datasheets vs. 380 – 780 nm for the standard CIE visible spectrum);
  - Requires several assumptions about the data that has been provided, including (1) that gel filter spectra measurements were in compliance with NIST-spectrophotometric measurement protocols, (2) that transmittance spectra remain consistent batch-to-batch during production, and (3) potential other influences.
- Further, the requirements for setting up scientifically-validated equipment/techniques for measuring gel filter spectra reach beyond the scope of this research project.
- Finally, the number of permutations to search through, combined with the number of candidate photosensor chips, may 'require more effort than it's worth.'







Top Left: One of 791 datasheets 'web-scraped' from Rosco website using Python scripting.

Above: B&W input image for automated graph data extraction, created with Photoshop actions.

Left: Datapoints extracted from input image (above) using another custom Python script. Graph data could be used as input for full-factorial search for filter combinations that match circadian photosensitivity functions.

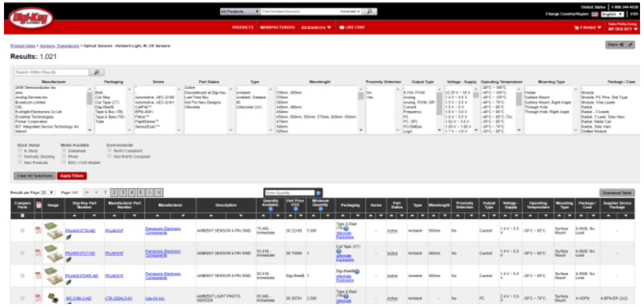
INITIAL EXPLORATIONS

Digi-Key + Mouser Multi-Spectral Photosensor Search

Development of a multi-spectral array of photosensors was chosen as another approach to explore.

Method:

- Searched Digi-Key and Mouser (electronic components suppliers) for photosensors individual or multi-spectra (other than RGB, RGBY, CMY, CMYK, or other ‘color’ photosensors);
- Read through product pages and device datasheets of various photosensors for (informal) preliminary evaluation of:
  - Cost (relative to comparable sensors)
  - Spectral response characteristics
  - Signal output (analog, digital)
  - Complexity of reference design schematic (How hard would it be to design a custom working implementation of the given sensor? Are additional electronic components needed to make it “talk” to an Arduino, and how many? etc.)



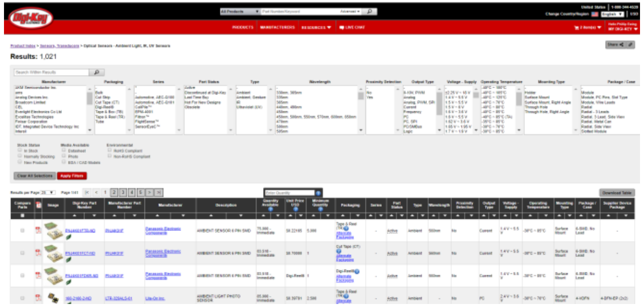
Digi-Key landing page for “Optical Sensors - Ambient Light, IR, UV Sensors”

INITIAL EXPLORATIONS

Digi-Key + Mouser Multi-Spectral Photosensor Search

Method:

- Many photosensors were far too sensitive to near-infrared light (700-1400 nm) to be useful for applications emulating human visual or circadian responses. (This is a known constraint with silicon-based photosensors; cameras, for example, typically incorporate an infrared-blocking filter onto the image sensor array by default.)
- Photosensors with peak spectral responses near the short-wavelength end of human vision (roughly in the range of 380-420 nm) were very rare or non-existent.
  - It is particularly telling that Digi-Key's search filter feature for optical sensors by peak wavelength(s) skips from 365 nm (near-ultraviolet or UVA) to 440 nm (already past the peak short-wavelength cone cell response wavelengths, which is around 420 nm when isolated in-vitro in experiments).
- Closest match for short-wavelength sensitive photosensors was typically in the near-ultraviolet range; these options, too, were often limited.
  - Out of approximately 1,021 in-stock optical sensors offered by Digi-Key around February 2018, only 8 were ultraviolet.



Digi-Key landing page for "Optical Sensors - Ambient Light, IR, UV Sensors"

INITIAL EXPLORATIONS

Digi-Key + Mouser Multi-Spectral Photosensor Search

Result:

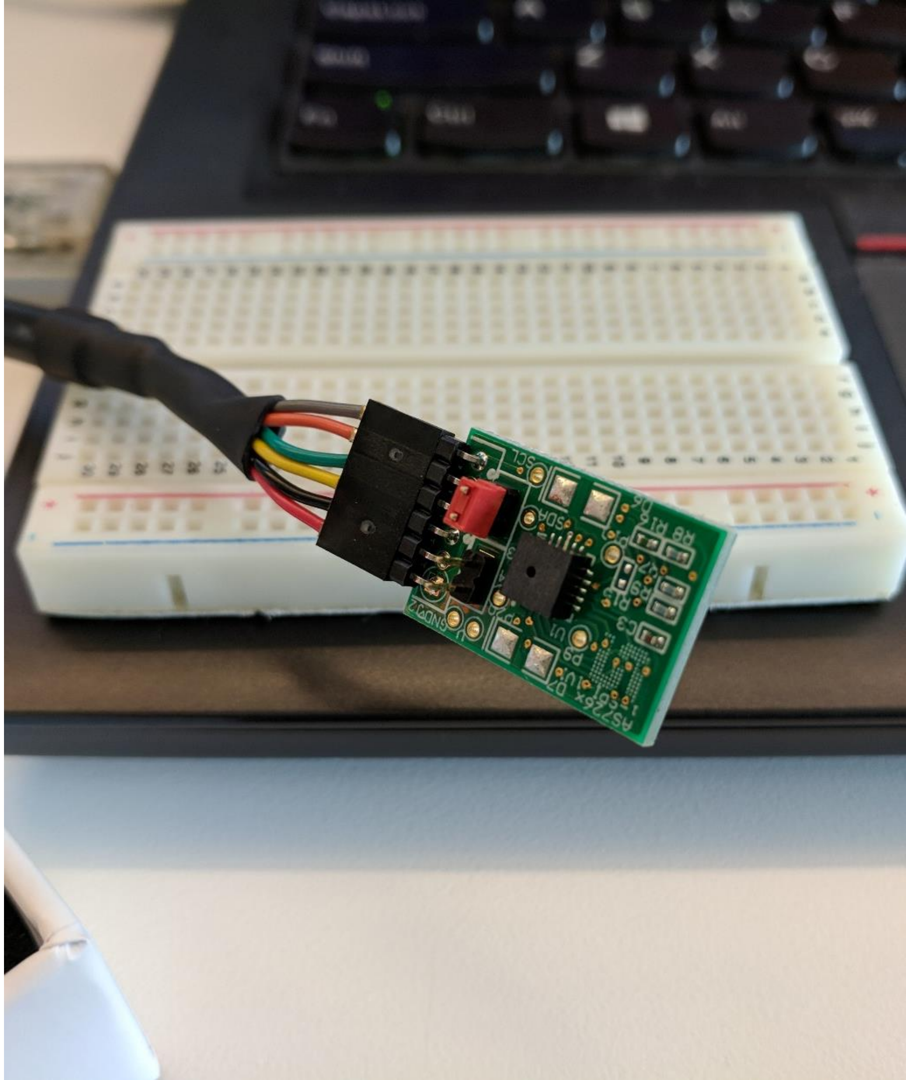
The AMS AS726x group of six-channel, multi-spectral digital photosensors appeared to yield the greatest potential with respect to spectrometry and/or circadian logging applications.

AMS AS726x IC package, magnified.

INITIAL EXPLORATIONS

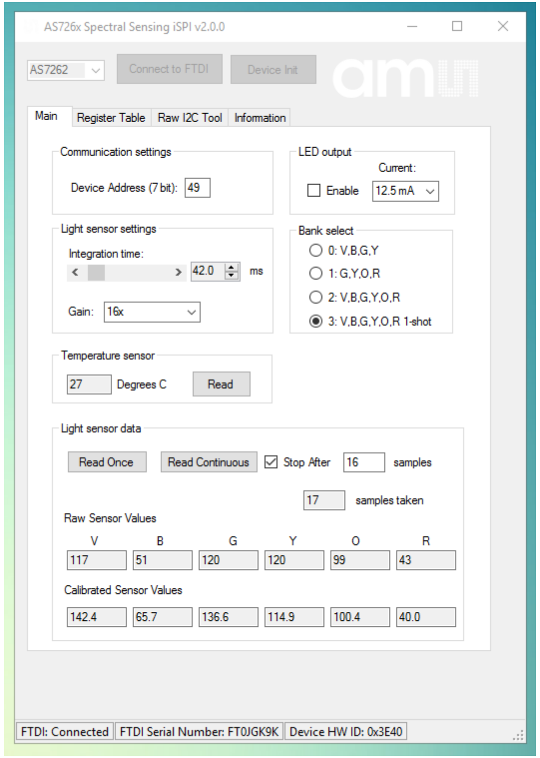
AMS AS7262 Demo Kit Evaluation

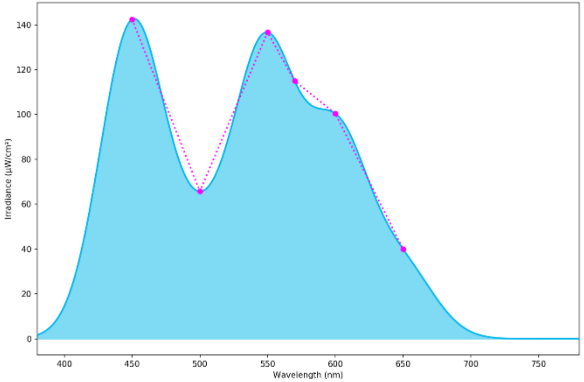
- Ordered AMS demonstration kit for AS7262 breakout board as intermediate step to developing custom implementation.
- Avoids problem of having to debug hardware and software simultaneously during circuit schematic design.
- Captured and plotted static and time-series data using Python (Matplotlib) under daytime office desk conditions (i.e., the author's desk and immediate surrounding areas).

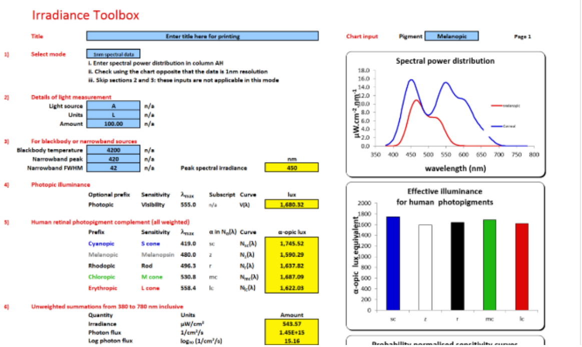


INITIAL EXPLORATIONS

AMS AS7262 Demo Kit Evaluation







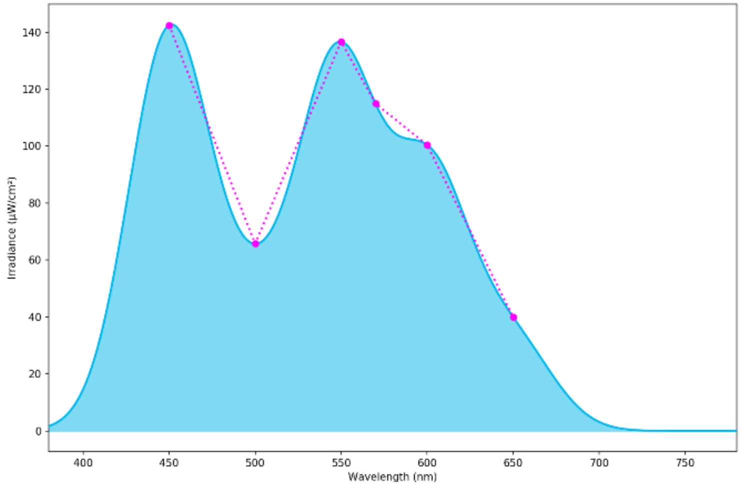
Left: GUI interface provided by AMS for reading measurements and reading/writing settings to AS7262 demonstration board.

Above, Middle: With the sensor board aimed directly at a white area on an LED computer screen, a single spectral measurement was performed and input into a custom Python script (using Matplotlib for plotting) for interpolation and analysis. The magenta line shows the original spectral measurement values from the sensor, with linear interpolation between datapoints. The blue line shows the same values interpolated/extrapolated using Gaussian radial basis functions (RBFs).

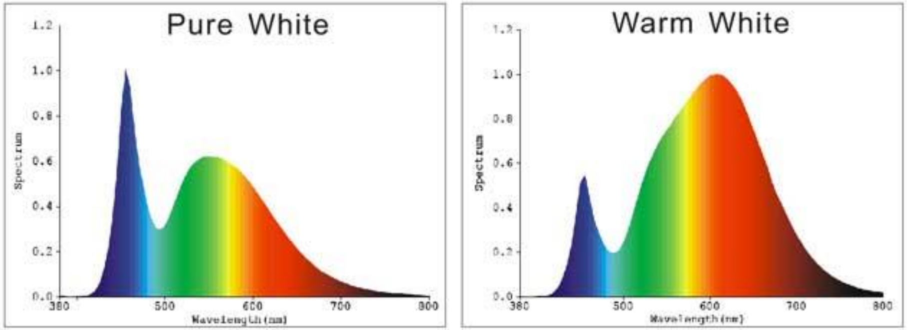
Above, Right: The interpolated values (previous figure, blue line) were input into the Irradiance Toolbox spreadsheet to calculate pentachromic circadian illuminance values for the given spectral measurement.

INITIAL EXPLORATIONS

AMS AS7262 Demo Kit Evaluation



With the sensor board aimed directly at a white area on an LED computer screen, a single spectral measurement was performed and input into a custom Python script for interpolation and analysis. The magenta line shows the original spectral measurement values from the sensor, with linear interpolation between datapoints. The blue line shows the same values interpolated/extrapolated using Gaussian radial basis functions.

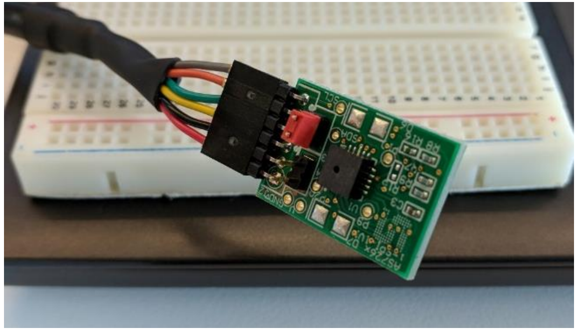


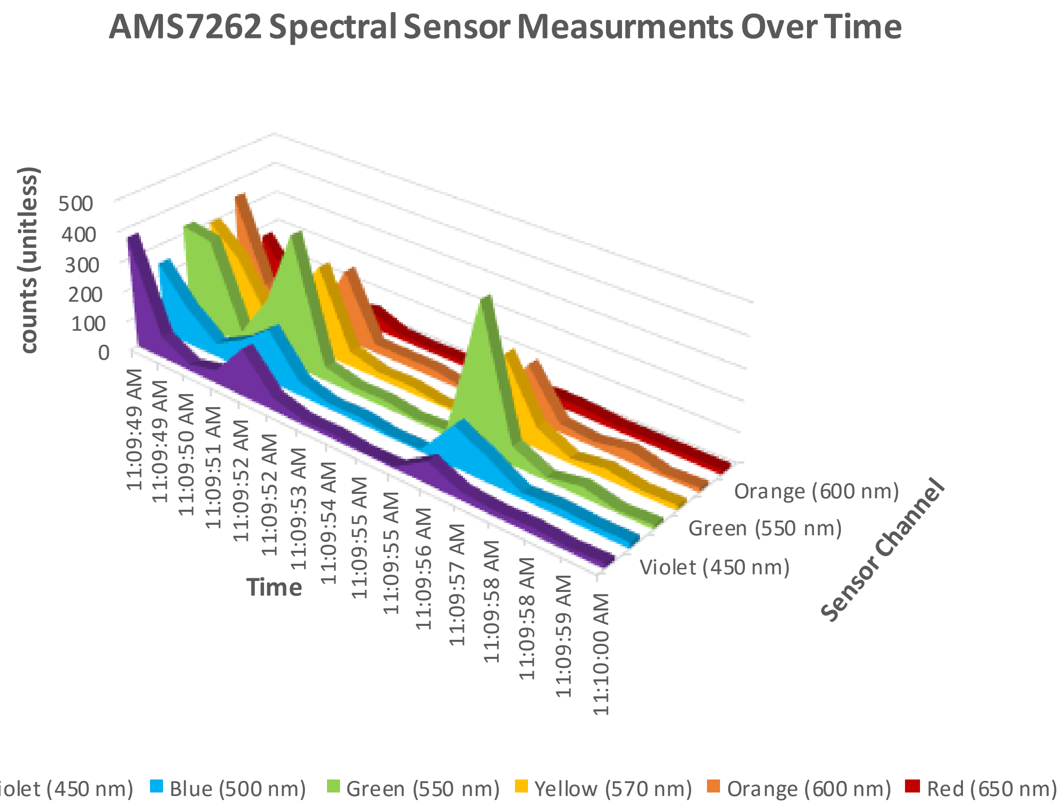
Comparison with typical spectral power distributions for white LEDs (shown above) demonstrates that the spectral measurement yielded by the AMS AS7262 demonstration sensor (previous figure) is already “plausible” for proof-of-concept purposes.

INITIAL EXPLORATIONS

AMS AS7262 Demo Kit Evaluation

- Continuous logging mode over an approximately 10-second period
- At desk; various target directions



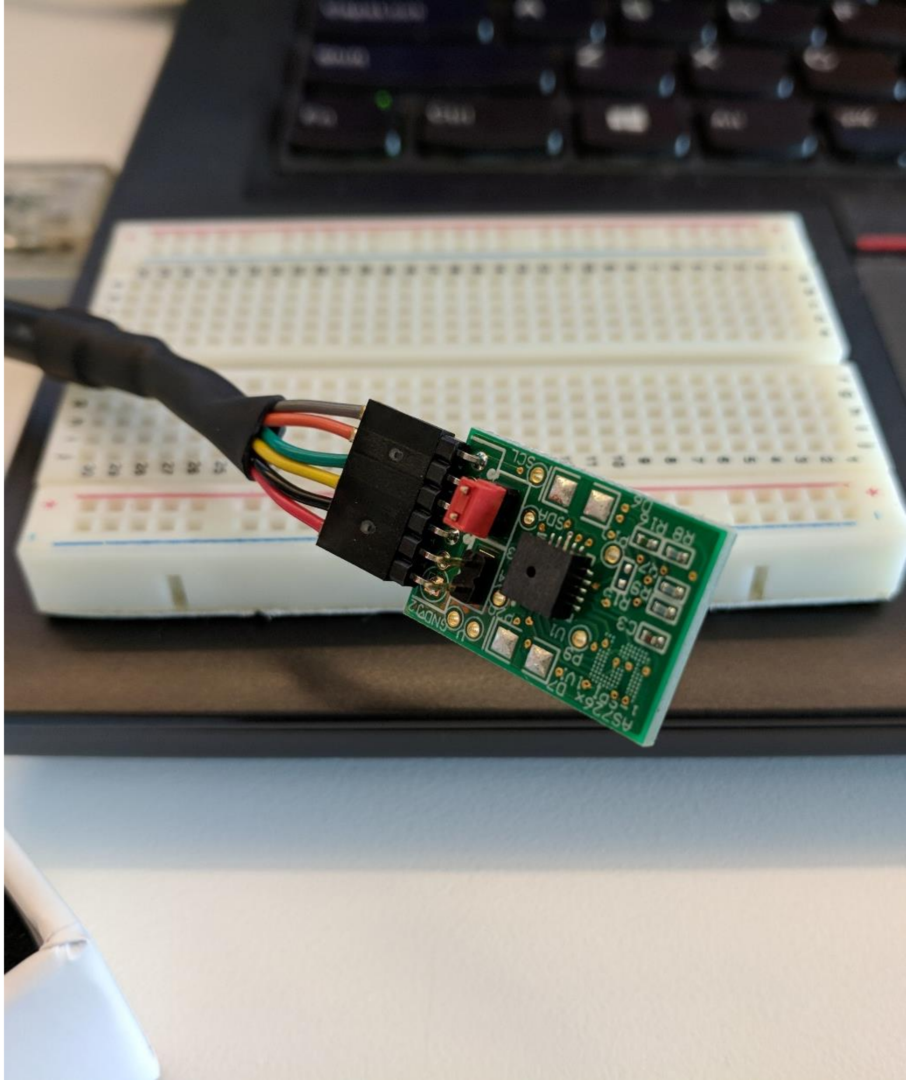


INITIAL EXPLORATIONS

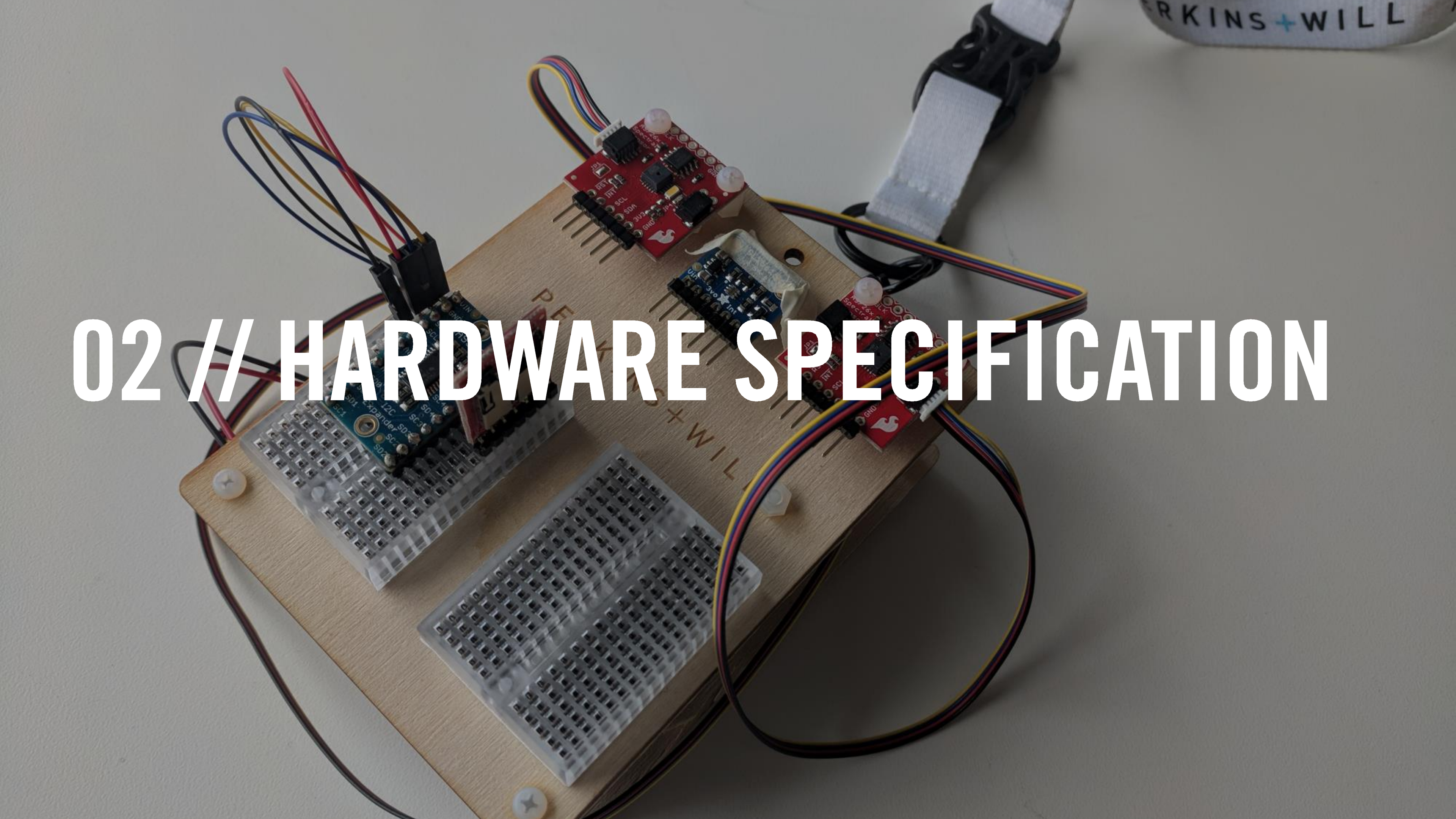
AMS AS7262 Demo Kit Evaluation

Additional Observations:

- AMS AS7262 (VIS) and AS7263 chips report spectral quantities for each channel in terms of "counts," and cannot be converted directly to photometric/radiometric terms without knowing overall spectral illuminance irradiance first;
- The shortest-wavelength channel provided on the AMS AS7262 is 'violet' (450 nm); additional sensors would be needed to extend the spectral range of a circadian light tracker to the short-wavelength end (380 nm) of the human visible spectrum.



02 // HARDWARE SPECIFICATION



HARDWARE SPECIFICATION

Sparkfun AMS A7262x Breakout Boards

Objective:

- Integrate AS726x multispectral sensors (particularly AMS AS7262 (VIS) and AS7263 (NIR)) into an Arduino-compatible embedded programming environment.

A solution:

- It was discovered that Sparkfun (electronics retailer) offers some versions (AS7262/AS7263, but not AS7261) as Arduino-compatible breakout boards and interface libraries (.h files).

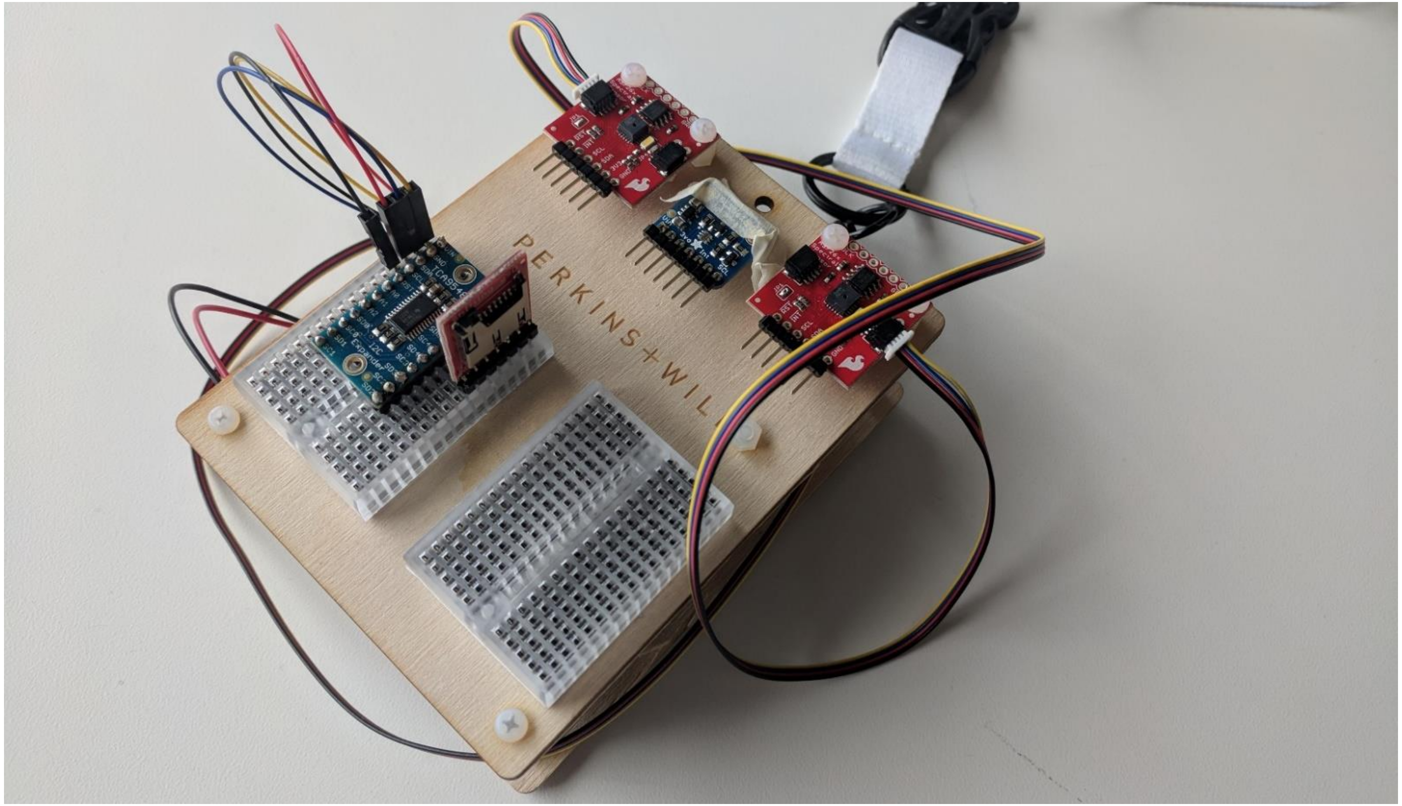
AMS726X spectral sensor breakout board, produced by Sparkfun.

Next step:

- Develop sensor test-chassis for testing.

HARDWARE SPECIFICATION

Test Chassis for Circadian Light Tracker Sensors



HARDWARE SPECIFICATION

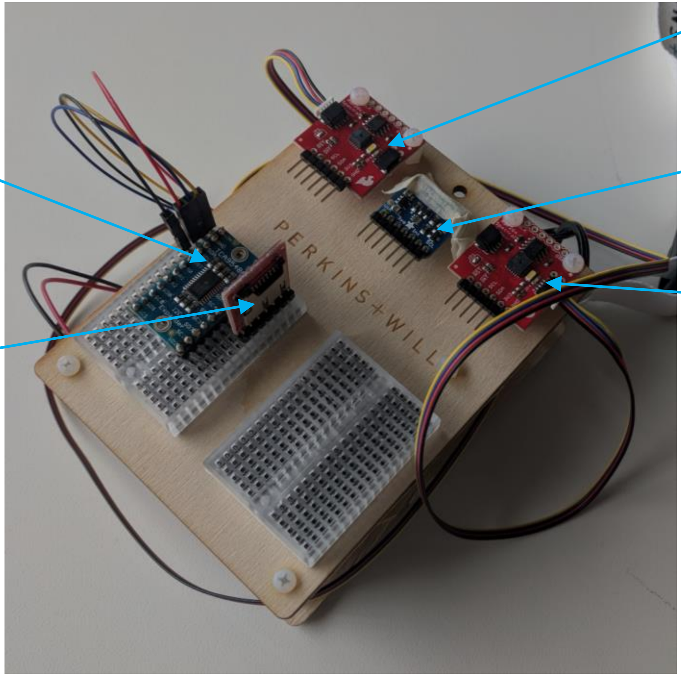
Test Chassis for Circadian Light Tracker Sensors

8-channel I^2C bus multiplexer; resolves potential device address conflict – the AS7262 and AS7263 spectral sensors are hard-programmed with the same "name" (0x47) with respect to instructions coming from the Arduino microcontroller

Micro SD card slot for data logging; incorporates 5V/3.3V digital logic level shifting

Hidden in view:

- Arduino Uno microcontroller
- SparkFun Qwiic Shield (for easy I^2C bus hookup)
- 9V battery power supply
- Perkins+Will lanyard (for wearability)



AMS AS7262 spectral sensor; measures six spectral irradiance datapoints (450-650 nm) in the visible light spectrum (380-780 nm)

AMS TSL2591 high dynamic range digital light sensor; measures photopic lux, for calibration purposes

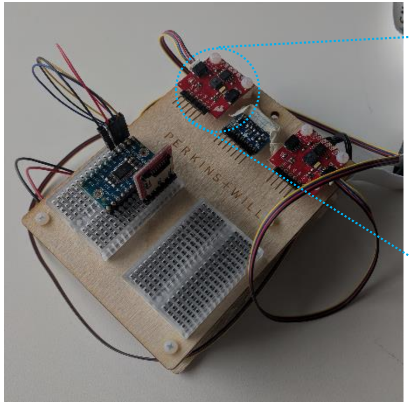
AMS AS7263 spectral sensor; measures six spectral irradiance datapoints (680-860 nm) in the red to near-infrared spectrum

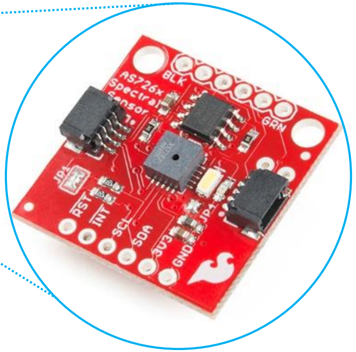
Not yet included in this version:

- Vishay VEML6070 UVA digital light sensor (to improve short-wavelength accuracy)
- ST LIS3DH 3-axis accelerometer (for approximating user physical activity levels)
- Maxim Integrated DS1307 real-time clock module (for precise date-time stamps in data logging)

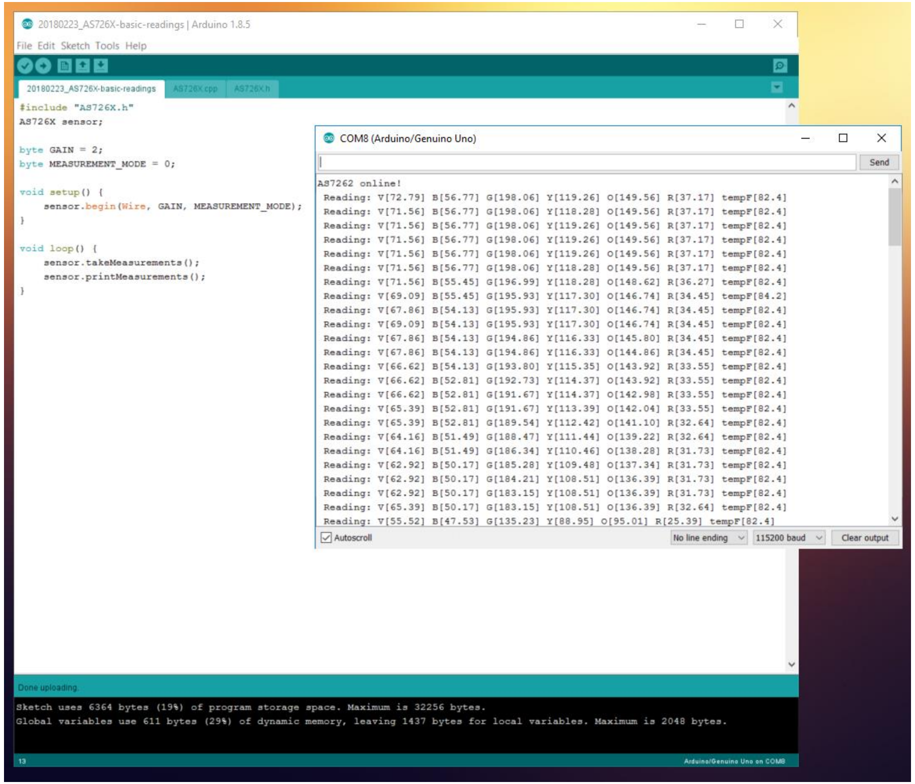
HARDWARE SPECIFICATION

Reading Spectral Measurements from Arduino UNO





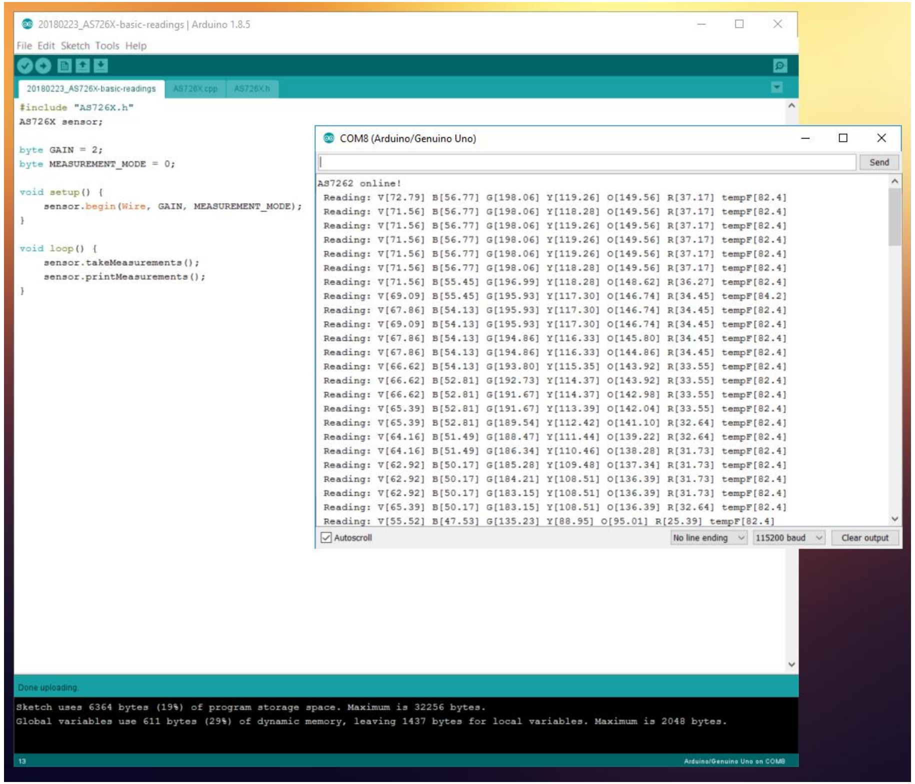
Reading measurements from the AS7262 spectral sensor on the test-chassis (above) using an Arduino microcontroller was successful; microcontroller reports calibrated sensor values (and device temperature) to the computer via serial interface.



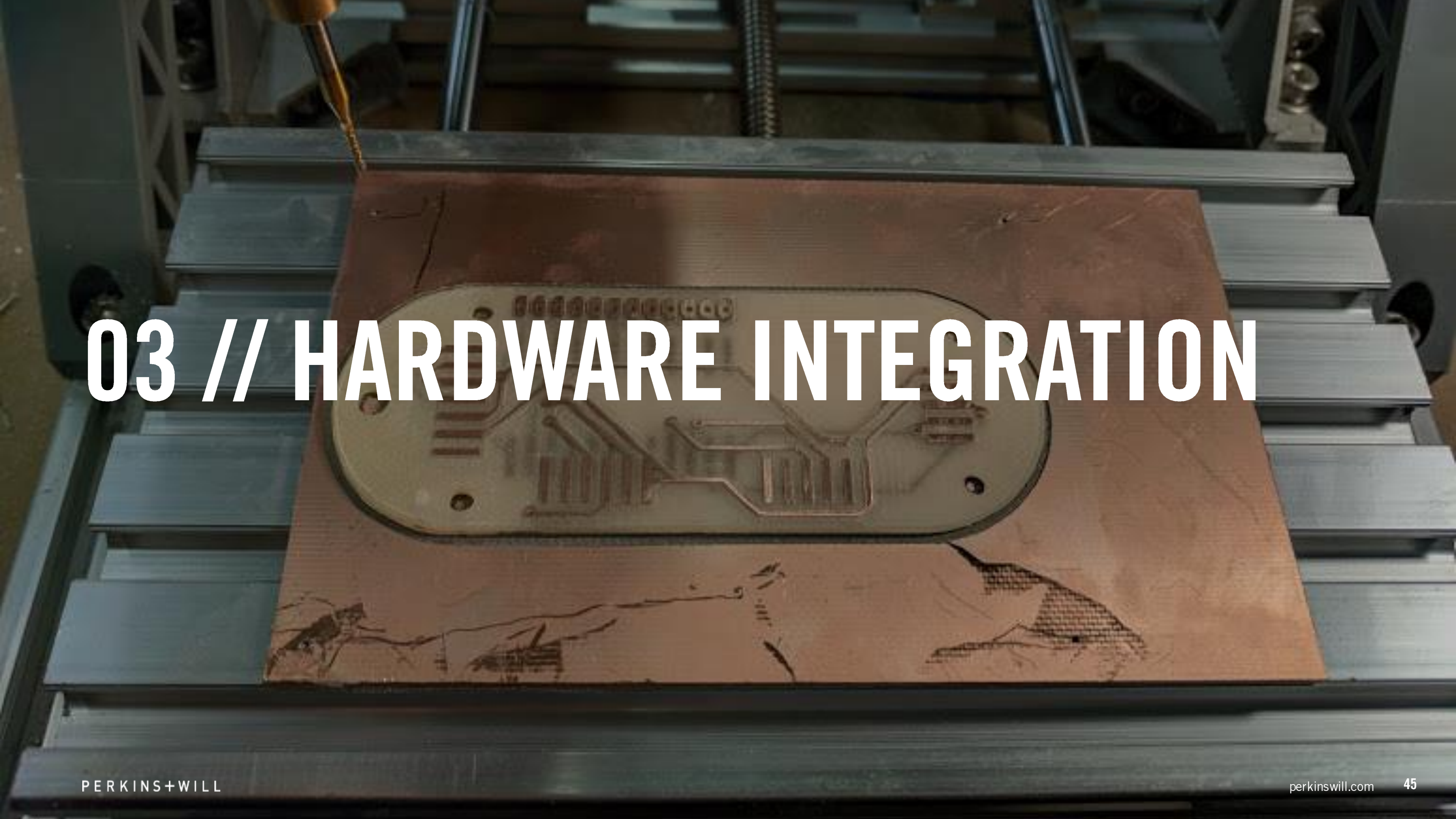
HARDWARE SPECIFICATION

Hardware Integration Challenges and Potential Solutions

- Avoiding I²C device 'name' collision(s)
  - The visible spectrum and near-infrared versions of the AS726x series of spectrophotometers have the same device 'name' (seven bit binary equivalent of the hexadecimal number 0x49);
  - Inserting a multiplexer chip as a 'gate switch' between different version of the multispectral chip helps to avoid potential digital communication ambiguities.
- Ensuring bi-directional data transmission (SDA wire in I²C) between 3.3V and 5V digital logic levels
- Maintaining some degree of flexibility in PCB fabrication options
  - Double-sided printed circuit board is designed to use surface-mount components where possible to make 'vias' (paths between different sides of a circuit board) more likely to be electromechanically-sound.

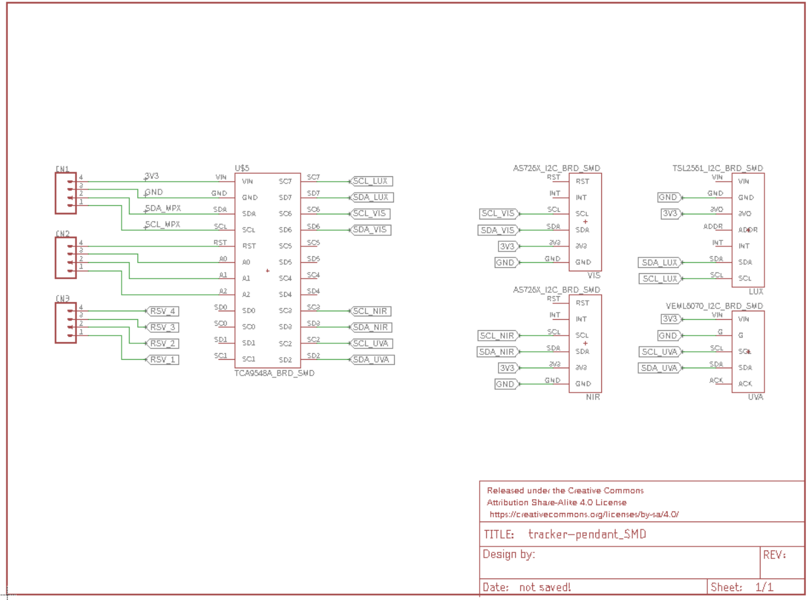


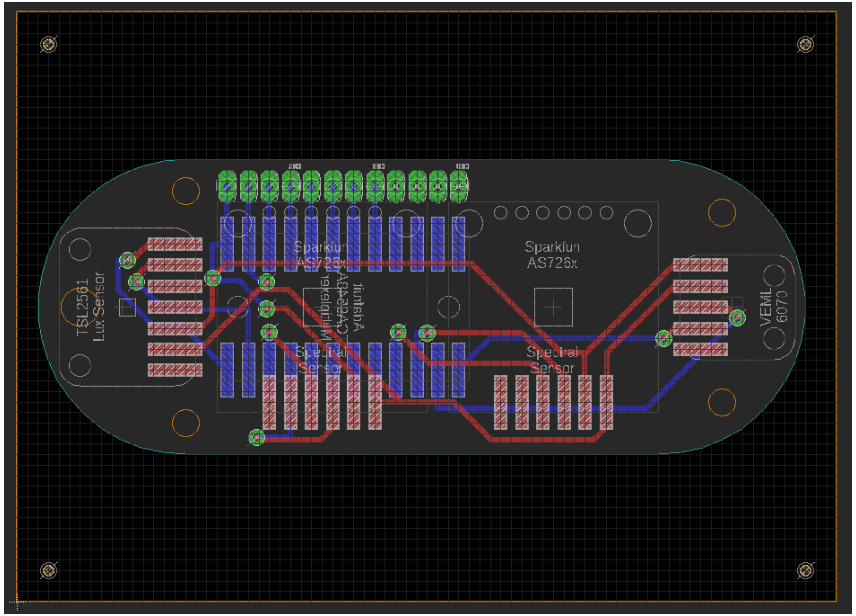
03 // HARDWARE INTEGRATION



HARDWARE INTEGRATION

Fabrication Process



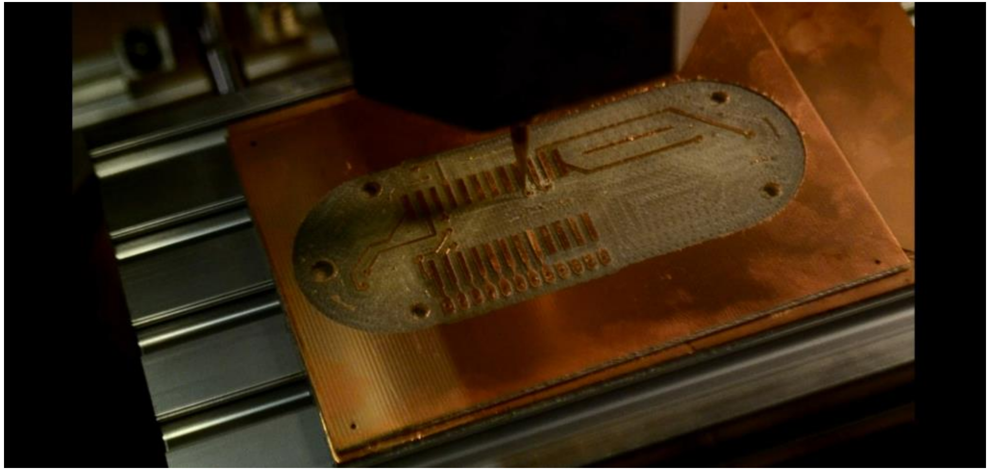


Autodesk EAGLE is used to create circuit schematics where ‘net’ (wire) labels may be used to describe connections between components, in addition to direct graphical links.

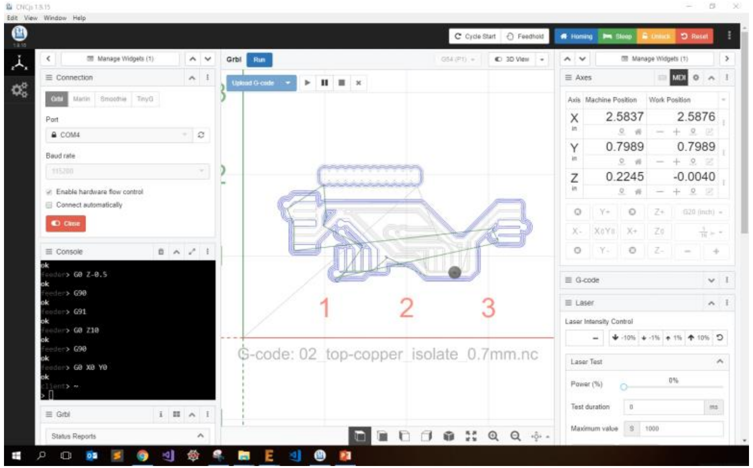
The board design context of EAGLE allows placement of components in arbitrary positions and auto-generation of optimal circuit trace patterns. These board patterns are then exported as PNG images to generate tool paths using the online version of [Fab Modules] developed by the Center for Bits and Atoms at MIT.

HARDWARE INTEGRATION

Fabrication Process

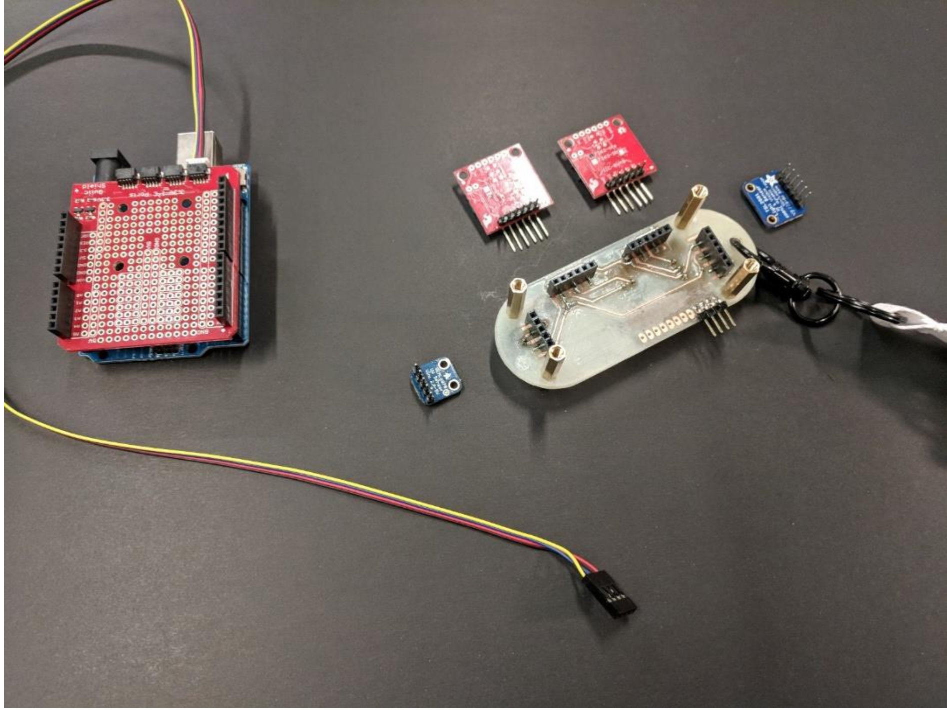


Circuit traces are milled in multiple passes on a Linksprite desktop CNC milling/laser engraving machine.



The controller desktop application CNCjs feeds G-code instructions to the Linksprite CNC mill, which runs the controller program Grbl (very common for open-source digital fabrication devices) on a microcontroller board.

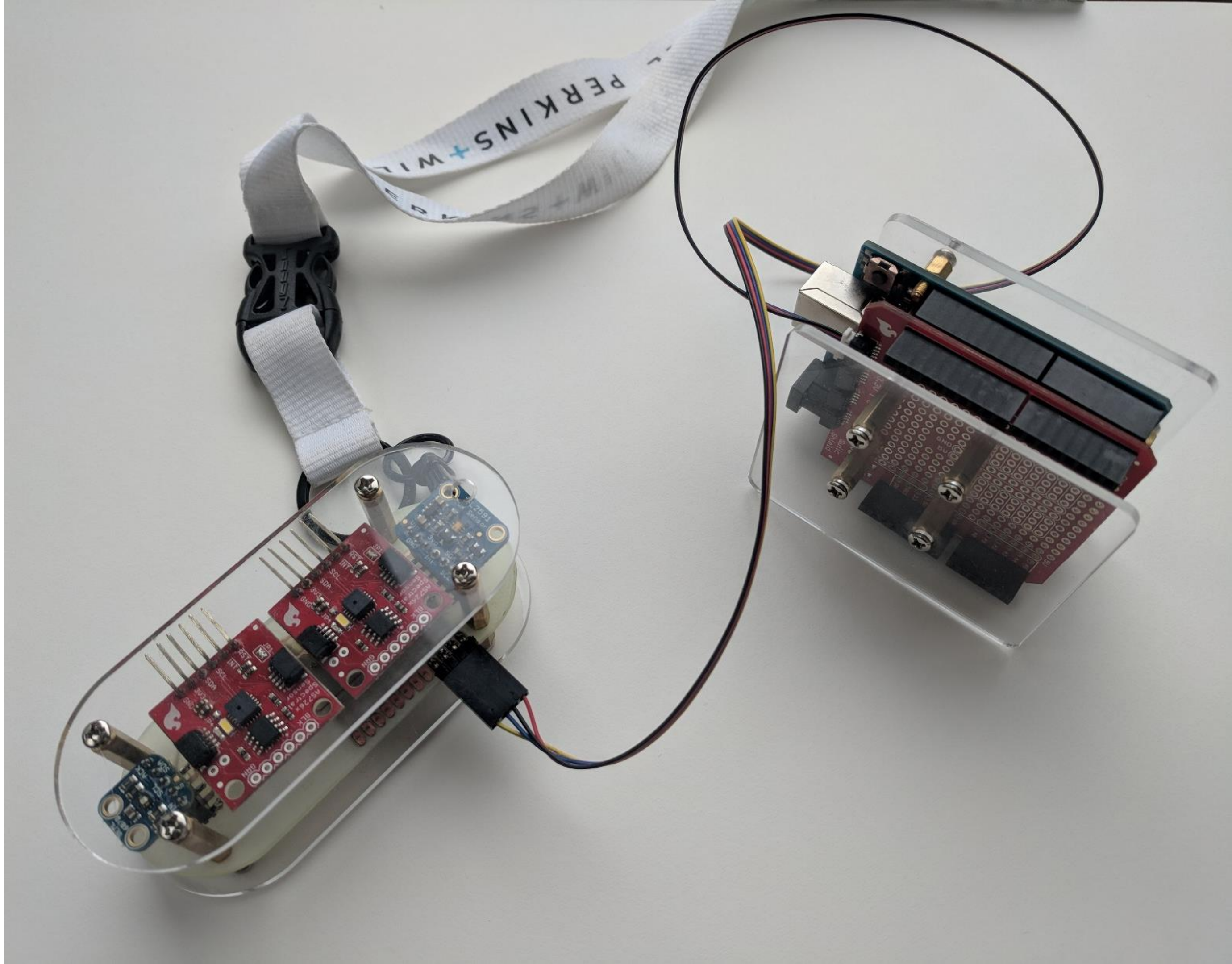
HARDWARE INTEGRATION
Fabrication Process



Top: Socket for the four spectral sensor boards (instead of direct connections) allow some degree of physical configurability for different lighting measurement applications.

Left: The fully-machined PCB board, with translucent effect of milled FR4 (fiberglass) substrate.

HARDWARE INTEGRATION
Revised Prototype



HARDWARE INTEGRATION

Revised Prototype

04 // CONCLUSION

CONCLUSION
Review

Objectives

Develop a circadian light tracking prototype that:

- Is able to sample most or all of the human visible spectrum (380 – 780 nm);
- Is relatively low-cost, and can be deployed at moderate scales for institutional consumers (i.e., architecture firms interested in research);
- Consists of sensing and microcontroller component that can be implemented in a wearable form factor.

Accomplishments

Developed the hardware for a circadian light tracking prototype that:

- Integrates a family of spectral sensors covering a combined spectral range of 350 – 860 nm;
- Consists of sensors that can be purchased for $12 or less apiece (although breakout boards may increase cost);
- Is *technically* 'wearable' in its current form factor, but can be greatly reduced with further electronics design.

CONCLUSION

Next Steps + Potential Future Applications

Next Steps

- Implementing needed software to make all sensors on the prototype fully operational;
- Continued refinement of the board design and form factor as more information about the sensor and microcontroller's inner features become more transparent;
- Desktop application for parsing and interpreting the light trackers' data logs to generate circadian illuminance values with respect to time;

Potential Future Applications

- Post-occupancy evaluation of patients and healthcare practitioners in hospital settings;
- Evaluation of student and teacher wellness and/or performance in educational settings, prior to a proposed design intervention;
- Machine learning-boosted design, where a database of circadian illuminance and human feedback have been aggregated and analyzed for interactively informing the effects of design choices on circadian lighting performance goals;
- (The list goes on…)

CONCLUSION
Additional References

"AS7262-BLGT." *Ams | Sensors, Transducers | DigiKey*, www.digikey.com/product-detail/en/ams/AS7262/AS7262CT-ND/6219609. Cited Apr. 19, 2018.

Bierman, Andrew, Terence R. Klein, and Mark S. Rea. "The Daysimeter: a device for measuring optical radiation as a stimulus for the human circadian system." *Measurement Science and Technology* 16.11 (2005): 2292.

"Dimesimeter – Light and Activity Measurement System Description and Calibration." Lighting Research Center, Lighting Research Center, 15 Nov 2011, http://www.lrc.rpi.edu/programs/lightHealth/pdf/DimesimeterDoc.pdf. Cited on Apr. 22 2018.

Ewing, Phillip H., John Haymaker, and Eve A. Edelstein. "Simulating Circadian Light: Multi-Dimensional Illuminance Analysis." International Building Performance Simulation Association, 7 Aug. 2017.

Golden, Robert N., et al. "The efficacy of light therapy in the treatment of mood disorders: a review and meta-analysis of the evidence." *American Journal of Psychiatry* 162.4 (2005): 656-662.

Instructables. "Make a Fabduino!" *Instructables.com*, Instructables, 30 Oct. 2017, www.instructables.com/id/Make-a-Fabduino/. Cited Apr. 13, 2018.

"International WELL Building Institute." International WELL Building Institute, www.wellcertified.com/. Cited on Apr. 13, 2018.

K.K, Hamamatsu Photonics. "Micro-Spectrometer C12666MA." *Home*, www.hamamatsu.com/eu/en/C12666MA.html. Cited Apr. 2, 2018.

Sekonic. "C-7000." *Sekonic Light Meter: C-7000 SpectroMaster Exposure Meter - Overview*, www.sekonic.com/united-states/products/c-7000/overview.aspx. Cited on Apr. 19, 2018.

Wearable Sun & Light Tracker." Wearable Sun & Light Tracker | SunSprite, www.sunsprite.com. Cited on Feb. 07, 2018.

Special thanks to Marcel W. Foster for modeling the circadian light tracker prototype in photos.

// THANK YOU