

EmotiGlass

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All augmented reality devices so far provide an interactive experience of the real-world environment that is enhanced by computer-generated perceptual information. In contrast, the EmotiGlass project explores ways in which a computer can modulate the user's EMOTIONAL perception of reality. Our projects aims to develop the first "Modulated-Emotion Reality" device. EmotiGlass enables completely new applications in the field of augmented reality in which emotional biases can be manipulated by computer applications. Additionally, EmotiGlass has potential therapeutic applications as an aid to help control stress and anxiety.



To demonstrate and develop the EmotiGlass concept, a wearable prototype was designed and constructed. This open-source project was designed from the beginning to be easy to build using tools and materials widely available to makers and hobbyists. Full design files and detailed build instructions are available at the [hackaday.io project page](http://hackaday.io/project) so that anyone can reproduce or extend the EmotiGlass design.

NOTE: The potential therapeutic applications for EmotiGlass have not been reviewed by FDA or any other regulatory agency. Please see complete disclaimer in Section 10.

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1 Background

Does the sight of a dog make you happy or fearful? Are you comfortable around people of other races? We commonly think that the emotions aroused by events around us are the results of our biases and prior experiences. This is very true, but there is much more than meets the eye when it comes to understanding the way in which our brains attach emotional content to our perceptions.

We develop implantable cardiac medical devices for a living, and a few months ago, we came across an interesting journal article that caught our curiosity. In this paper [Azevedo, et al. 2017], researchers from the University of Sussex and the Royal Holloway University of London showed that presenting an image at different periods of the cardiac cycle would cause changes in the way that subjects would emotionally perceive that image.

The paper reported that racial biases could clearly be modulated by changing the timing at which an image is presented. In this study, pictures of dark-skinned or light-skinned individuals holding various objects were presented to coincide with either the heart's contraction (cardiac systole) or relaxation (diastole) (Figure 1). Results showed that if the image was presented during cardiac systole, subjects significantly misidentified innocuous objects as weapons when they were held by dark-skinned people (Figure 2). Remarkable!

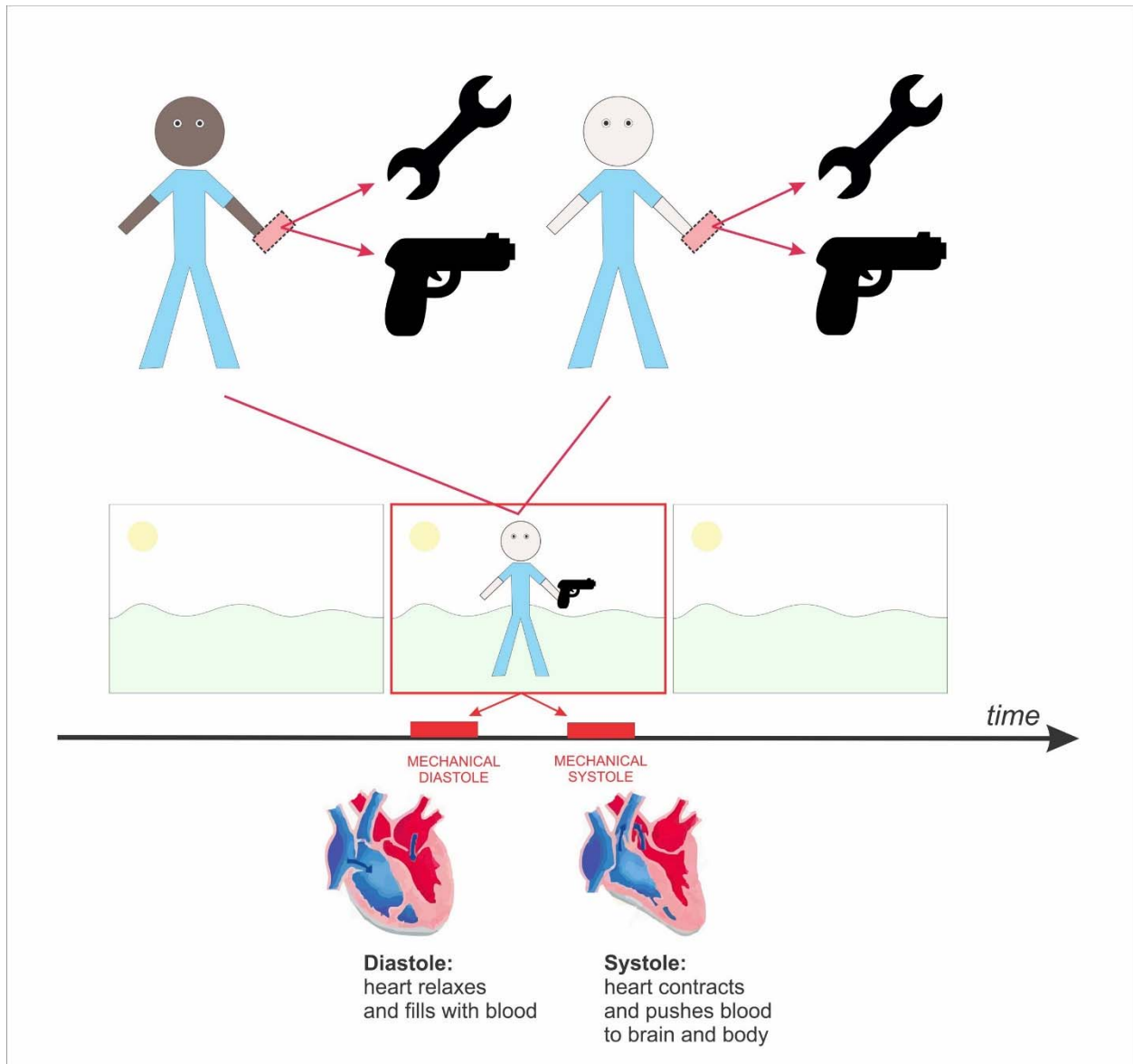


Figure 1 – In the study conducted by Azevedo, et al. [2017], participants were presented for a brief period (200 ms) with pictures of a light-skinned or dark-skinned male holding either a weapon or a harmless object in his hand, and were asked to decide whether to 'shoot' or 'don't shoot' him, respectively. Crucially, investigators time-locked the presentation of the target to coincide either with the cardiac systole or the cardiac diastole.

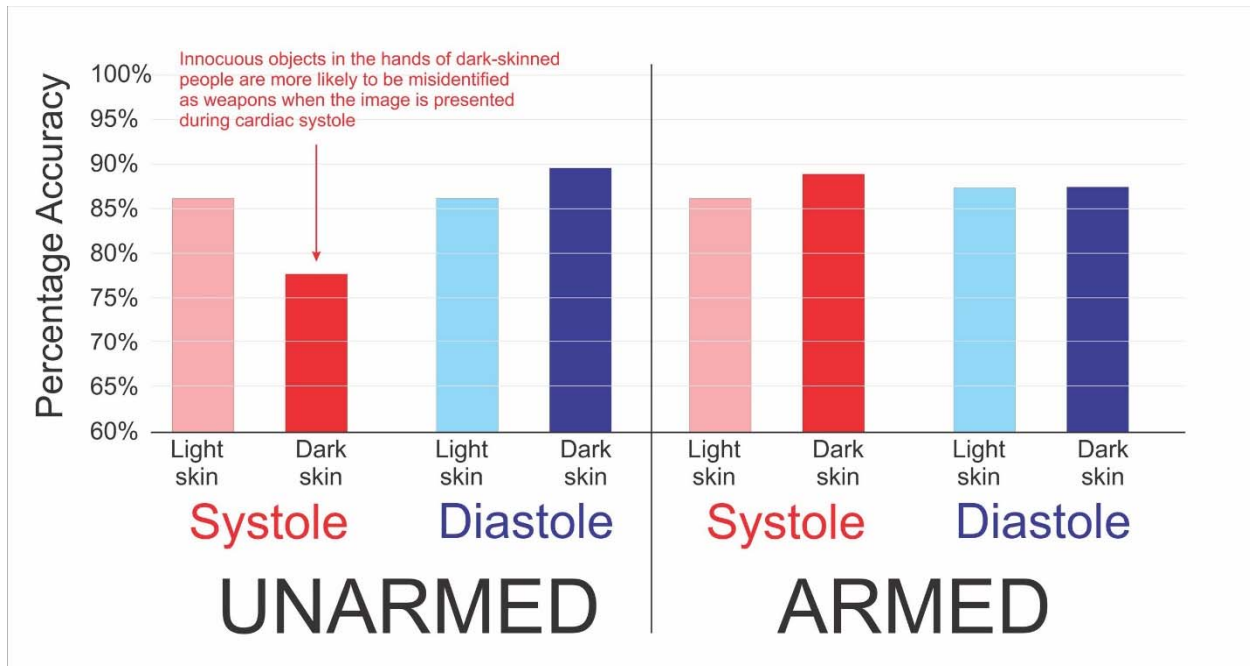


Figure 2 – Participants in the study by Azevedo, et al. [2017] were more likely to ‘shoot’ unarmed dark-skinned than unarmed light-skinned individuals when stimuli was perceived during systole compared to when perceived during diastole.

A group from University College London conducted a related study [Gray, et al., 2009] through which they found that sensory processing depends on when stimuli are experienced in relation to heartbeat timing. Specifically, the perception of pain – which is strongly biased by emotion—varied depending on when during the cardiac cycle noxious stimuli were delivered to the subjects.

As shown in Figure 3, the mechanism behind these effects seems to be that the emotional arousal caused by a stimulus depends on signals being received by the brain from the body’s internal blood pressure sensors (baroreceptors). Simply timing the delivery of stimuli against the cardiac cycle can change the way in which the brain processes stimuli!¹

¹ Two interesting presentations by University of Sussex researchers on these topics are available on YouTube:

- Sarah N Garfinkel, “Interceptive Signals from the Heart can Guide Cognitive and Perceptual Experience”, November 2017: <https://youtu.be/WqRss1NnEII>
- Hugo Critchley, “Interception, Emotion and Self: How the Heart Gates Feelings and Perceptions”, <https://youtu.be/xGqr5buHsXc>

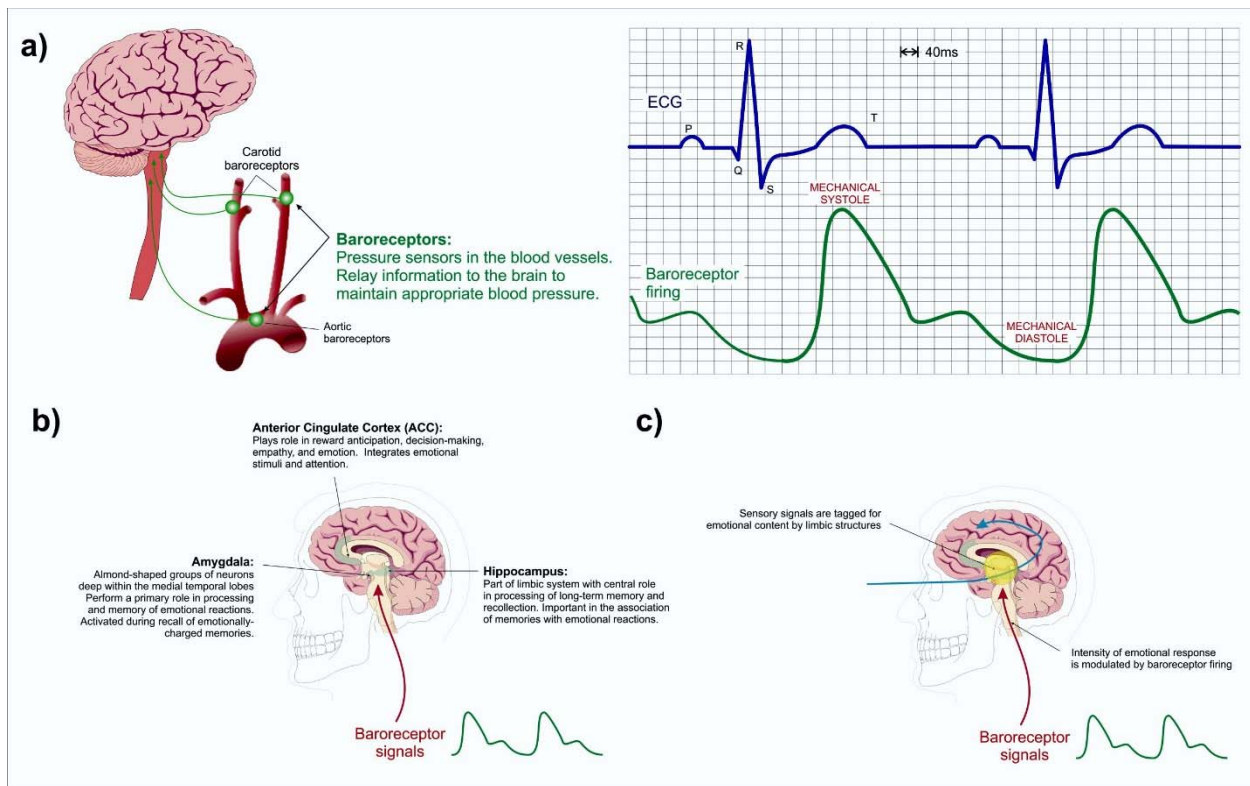


Figure 3 – Baroreceptors are pressure sensors in the blood vessels which relay information to the brain so that the autonomic nervous system can maintain appropriate blood pressure. The firing frequency of these baroreceptors tracks the blood pressure wave (a). (b) Baroreceptor signals also reach structures within limbic structures of the brain that are responsible for the perception of emotional salience. (c) These structures “tag” sensory input with emotional content, and research shows that the intensity of the emotional response is modulated by baroreceptor firing.

It’s not only the timing component of a stimulus that can change the emotions that it arouses. The spatial component also has major effects on the emotional perception of visual scenes. In his exciting book “Of Two Minds: The Revolutionary Science of Dual-Brain Psychology”, Dr. Fredric Schiffer [1998], a Professor of Psychiatry at Harvard Medical School and Attending Psychiatrist at McLean Hospital, showed that very distinct emotions can be evoked by selectively blocking access of the visual field to one of the brain’s hemispheres.

Spatio-temporal changes in the visual field also cause deep changes in emotional response. EMDR (Eye Movement Desensitization and Reprocessing) [Shapiro, 2017] is a known psychotherapy technique whereby causing side-to-side eye movements is believed to unlock a memory mechanism that can be used to reprocess traumatic events. Outside of the therapeutic setting, mild side-to-side sweeping of the visual field appear to decrease the emotional impact of distressing events.

The objective of the EmotiGlass project is to develop a pair of active glasses that can be controlled to selectively occlude vision with the proper timing and/or spatial distribution to allow a computer to modulate the user’s EMOTIONAL perception of reality. Unlike augmented-reality devices that limit themselves to enhancing reality with computer-generated content, we aim to develop the first device that can modulate the perceived emotional content of reality.

2 The EmotiGlass Concept and Conceptual Requirements

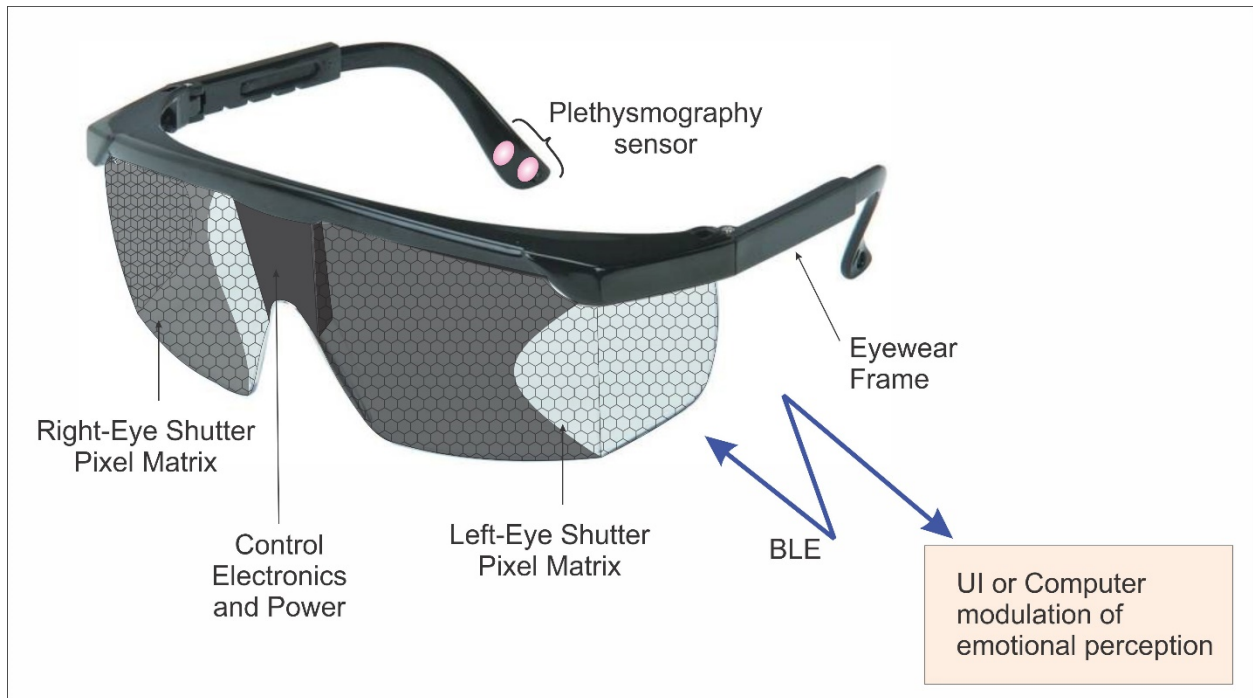


Figure 4 – Conceptual view of the EmotiGlass goggles

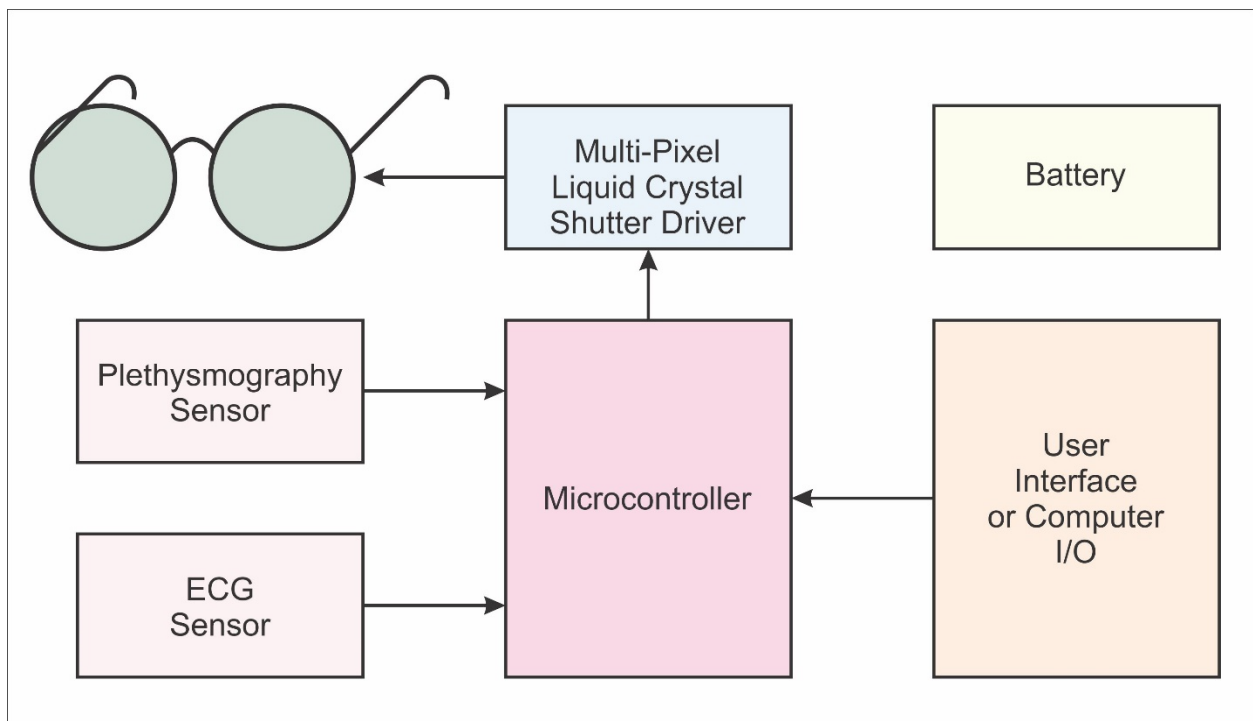


Figure 5 – Conceptual block diagram for the EmotiGlass goggles

Figure 4 presents a conceptual view of the EmotiGlass goggles, while Figure 5 presents a general block diagram. The concept calls for eyewear frames with multi-pixel light shutters that can be controlled by

an on-board microcontroller to selectively occlude the visual field. Furthermore, the occlusion may be timed to occur in synchrony with the cardiac cycle as detected by a photoplethysmographic sensor or an ECG channel. The emotional valence of reality can then be modulated by a computer or by the user through a user interface. For the sake of convenience, the eyewear can incorporate all of the real-time electronics, while control of operating mode can be done wirelessly via BLE.

The therapeutic applications of EmotiGlass are obvious as an aid to help control stress and anxiety. However, EmotiGlass enables completely new applications in the field of augmented reality. For example, the emotional biases of police and other first responders could be dampened to lessen inappropriate use of force. On the other hand, increased emotional arousal could be used in entertainment applications to enhance movies and gaming applications.

2.1 EmotiGlass Conceptual Requirements Specification

The EmotiGlass prototype developed under this project shall fulfill the following requirements:

2.1.1 Hardware

1. The EmotiGlass device shall be constructed as goggles wearable by an adult user.
2. The EmotiGlass device shall incorporate a microcontroller to control its operation such that further development can be done by reprogramming the device with no need for hardware changes.
3. The EmotiGlass device shall incorporate a sensor for detecting the wearer's heartbeat.
4. The EmotiGlass goggles shall be stand-alone (with exception of the GUI device) and be fully self-contained.
5. The EmotiGlass goggles shall be controlled via a wireless user interface, preferably one that can run as an app on the user's smartphone or similar portable device.
6. Hardware selected for the EmotiGlass Device shall be widely available. With the exception of custom PCBs and frame, all electronic components shall be in current production and available in small quantities from easily-accessible vendors to enable experimenters to replicate the device for personal use.

2.1.2 Firmware

1. The firmware for the EmotiGlass device shall implement the following operating modes:
 - a) Clear
 - b) Dark
 - c) Auto-Dark
 - d) Lateralized Brain Stimulation
 - e) Occlusion synchronized to Baroreceptor Activation
 - f) Interoceptive Awareness
 - g) Visual Sweep
2. The firmware for the EmotiGlass device shall implement the logic layer for communicating with the wireless user interface, preferably one that can run as an app on the user's smartphone or similar portable device.
3. Firmware shall be written in an easily-accessible language, and shall use only open-source modules to enable experimenters to replicate and modify the device for personal use.

2.1.3 User Interface

1. The user interface shall be intuitive and easy to use
2. If possible, the user interface shall run as an app on the user's smartphone or portable device
3. Software for the user interface Firmware shall be written in an easily-accessible language, and shall use only open-source modules to enable experimenters to replicate and modify the device for personal use.

3 Operating Modalities

3.1 Visual Occlusion Synchronized to Baroreceptor Activation

It has been demonstrated that visceral afferent signals to the brain influence thoughts, feelings, and behavior regardless of whether or not these signals reach conscious awareness. For example, experiments performed by Critchley and his collaborators [Gray et al. 2011, Critchley et al. 2015] at the University of Sussex (Brighton, UK) have shown that the emotional centers of the brain more easily detect fear and assign greater emotional salience to stimuli presented during cardiac systole than when presented at diastole.

In these experiments, subjective and brain responses were measured to pictures of faces showing emotions presented before and during cardiac systole. Facial expressions of disgust were judged as more intense when presented at systole, and rebound heart rate increases were reduced after expressions of disgust and happiness. Neuroimaging studies showed that activity in the emotional centers of the brain changed with cardiac timing. As mentioned in the background section, such timing-dependent changes influence emotional judgements, so powerfully that test subjects erred in the identification of items as weapons when held by people with dark skin, but not by people with light skin if the images are presented during cardiac systole. It is thus indisputable that there exists a close coupling of visceral and emotional processes, and that regions in the body that receive internal information have a strong influence on affective judgment.

Selectively occluding vision during parts of the cardiac cycle thus makes it possible to modulate the emotional response to a scene. As shown in Figure 6, visual blanking may be synchronized to cardiac activity either by using the ECG signal, or the plethysmography signal (which may be detected using the light reflected off the skin as blood enters and leaves the small blood vessels near the pickup sensor). As depicted in Figure 7, the hypothesis is that this will reduce the intensity of the emotional content assigned to the scene by the limbic system.

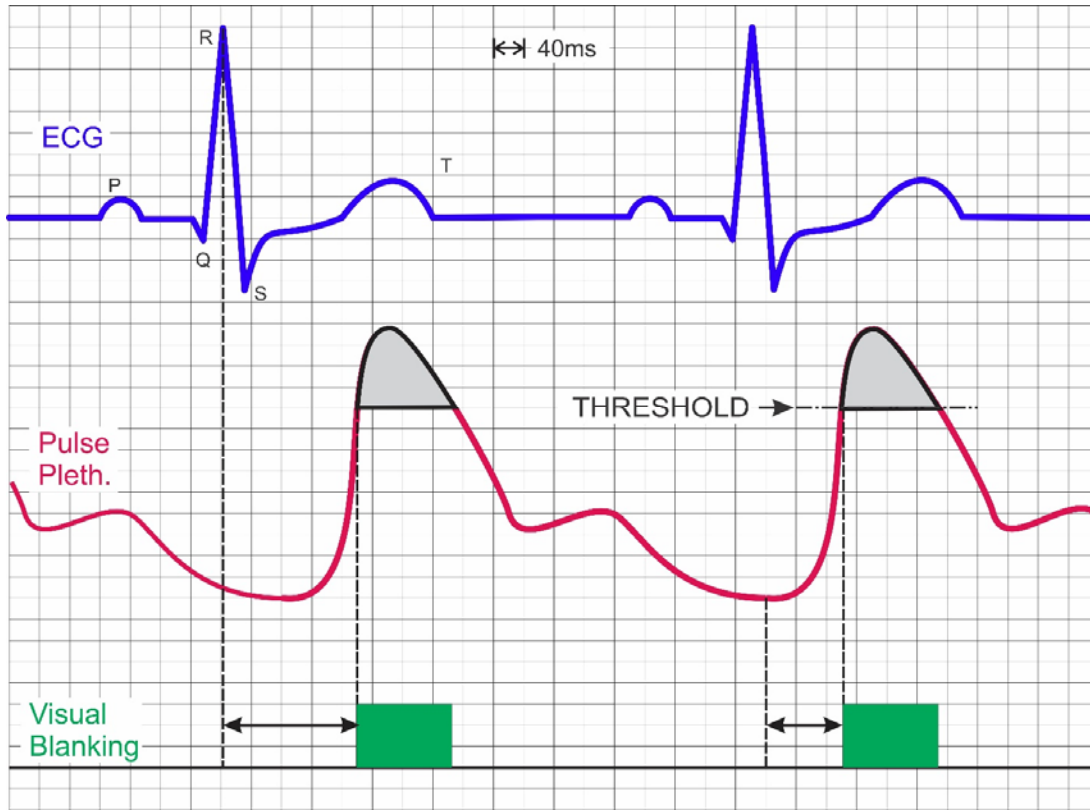


Figure 6 – Visual occlusion may be applied in synchrony with either the top-of-R of the ECG (left) or when the pulse plethysmography signal crosses a certain threshold.

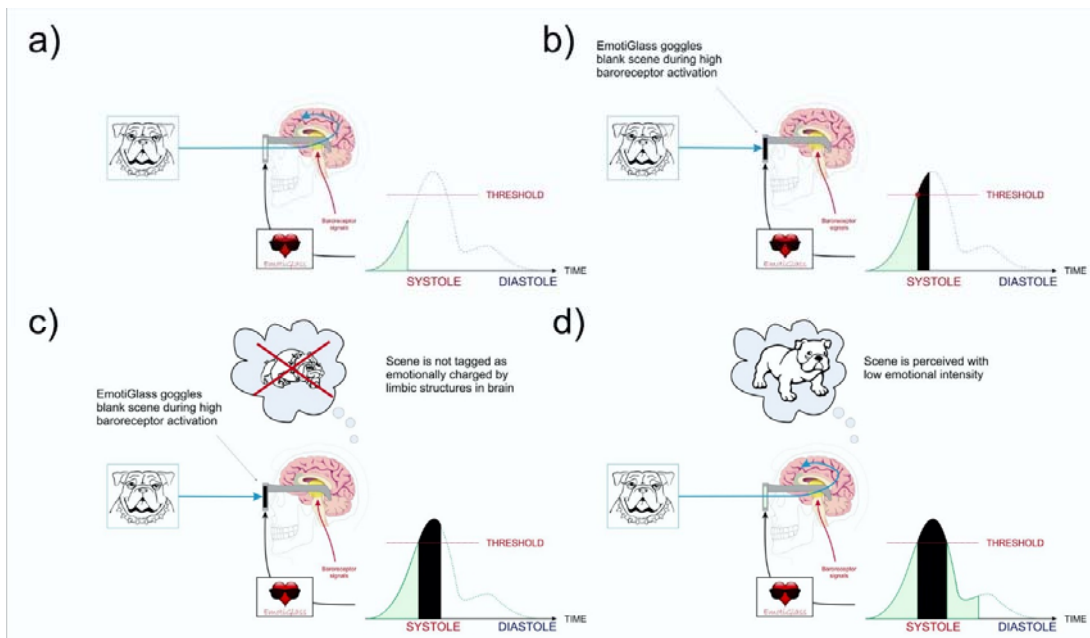


Figure 7 – The EmotiGlass device allows the user to see a scene while baroreceptor firing is low (a and d), but blocks the scene when baroreceptor activity is high (b and c). The hypothesis is that this will reduce the intensity of the emotional content tagged to the scene by the limbic system (see Figure 3)

Photoplethysmography is probably the better alternative because it requires just a LED and a photosensor placed in contact with the skin to detect the heartbeat. The ear lobe or skull are good points to place the sensor, and calculating timing is not necessary because the pressure signal detected at those locations is virtually the same as that which excites the baroreceptors that innervate the brain.

3.2 Lateralized Brain Stimulation

It is well known from the study of split-brain patients that the right brain and left brain are capable of having their own mentation and actions, whereby the right hemisphere can have intact mental faculties, separate from and often beyond the awareness of a person's left-sided mind. Dr. Fredric Schiffer [1998], a professor of psychiatry at Harvard Medical School and Attending Psychiatrist at McLean Hospital, has demonstrated that this is not only the case in split-brain patients, but rather that everyone has two autonomous minds - one associated with the left brain and one with the right brain - and that in healthy individuals, these two minds cooperate harmoniously towards a balanced personality.

However, troubling behavioral symptoms may happen when a strong imbalance exists between the two minds since an unhealthy person-to-person relationship can develop between these two autonomous minds, whereby the same type of psychological issues and conflicts that would apply between two people may apply to the relationship between the two minds in a single individual. The dominant hemisphere can thus markedly and negatively affect an individual's personality.

Dr. Schiffer [1999]² uses glasses that selectively occlude vision such that only one side of the brain is stimulated, having static transparent and opaque regions to selectively stimulate only the right brain or the left brain (Figure 8, left). When used during a psychotherapy session, a patient can be asked to alternate between lateral visual fields and induce both an increase and a decrease in his symptoms to show him that his fears reside only in a part of his mind. The glasses can also be used outside the context of a psychotherapy session in order to reduce stress and anxiety. These glasses have fixed occlusion zones and thus need to be specifically constructed for each user.

Based on Schiffer's work, others have designed therapeutic glasses using moveable screens to selectively occlude the patient's vision. For example, in U.S. Patent No. 6,141,797 "Opaque goggles having openable window" (Figure 8, right), Robert Buck describes glasses that have moveable opaque windows. These are commercially available under the name "NeuView" (www.neuviewglasses.com).

² An ABC 20/20 segment on this topic is available at: <https://youtu.be/dSq3kklNe10>

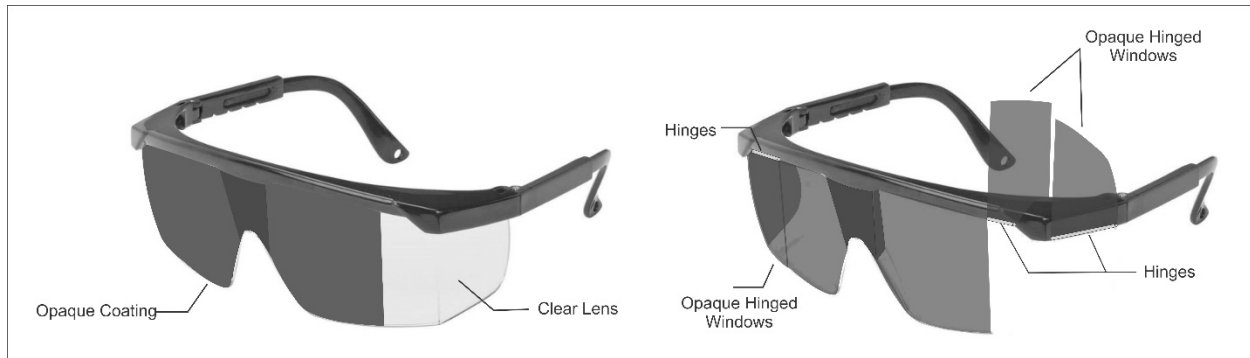


Figure 8 – Goggles of the type used by Dr. Fredric Schiffer to selectively occlude vision such that only one side of the brain is stimulated.

These existing eyeglasses for selective lateral stimulation are simple devices through which the temporal and spatial distribution, as well as magnitude of the occlusion cannot be finely controlled. In addition, these devices do not look like regular eyewear, thus attracting attention, which may be undesirable when treating stress, anxiety, and other mental disturbances.

In contrast, the EmotiGlass goggles can selectively block a subject’s field of vision with controllable spatial distribution and magnitude of the occlusion, and when fully developed into a product, can do so while maintaining the semblance of a normal pair of sunglasses.

The science behind this modality is fascinating! The basic principle is that the right brain and left brain are capable of having their own mentation and actions, whereby the right hemisphere can have intact mental faculties, separate from and often beyond the awareness of one’s left-sided mind. As such, a person can have two autonomous minds, one associated with the left brain and one with the right brain. Schiffer [1998] has demonstrated that a person-to-person relationship can develop between these two autonomous minds, whereby the same type of psychological issues and conflicts that would apply between two people may apply to the relationship between the two minds in a single individual. The dominant hemisphere can often markedly determine a person's personality.

For example, in a certain person the left mind might “dominate” and “suppress” his right mind. In another, the right mind may be dominant. In mentally-healthy people, the two minds coexist in harmony with mutual respect and cooperation. However, troubling behavioral symptoms may happen when a strong imbalance (and hence conflict) between the two minds occurs.

According to Schiffer’s experiments, those who have been affected by emotional trauma lateralize the effects, perhaps in an effort to maintain more-or-less-normal functioning. One hemisphere or the other gets stuck in the past, and acts out through the patient's symptoms.

Schiffer has demonstrated that by restricting vision to a portion of the retina of an eye that is connected to a particular hemisphere of the brain, that hemisphere can be stimulated preferentially, causing changes in the psychological state of a person that may be therapeutically beneficial.

This is possible because the eyes are connected to the brain so that vision to the left side of a person goes primarily to the opposite (right) hemisphere and vision to the right side of a person goes primarily to the left hemisphere. Figure 9 shows that the image of objects are projected by the lenses onto the retinas.

Each retina is divided into a medial and lateral aspect. Image points projected on the lateral aspect of the retina of the left eye go directly to the brain's left hemisphere, while points projected on the medial aspect of the retina of the left eye go to the brain's right hemisphere. Similarly, image points projected on the lateral aspect of the retina of the right eye go directly to the brain's right hemisphere, while points projected on the medial aspect of the retina of the right eye go to the brain's left hemisphere. Images conveyed to only one hemisphere by the optic nerves can be communicated to the other hemisphere via the corpus callosum.

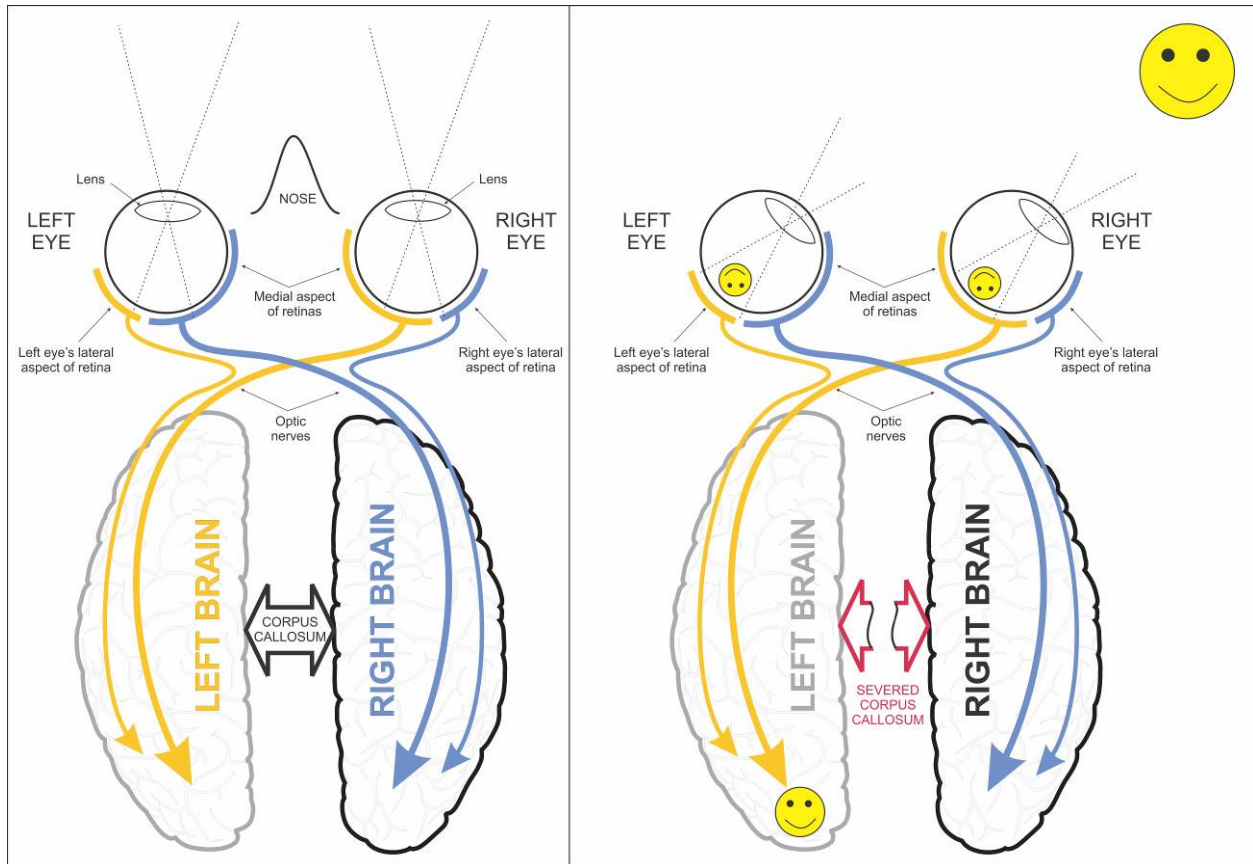


Figure 9 – Connections between the eyes and the brain. Left: Healthy. Right: Lateralized vision in split-brain patient

For the lateralized brain stimulation modality, the glasses need to occlude the visual field such that only the parts of the retinas that innervate the left or right brain are illuminated by the scene. This requires at least four distinct vertical regions as shown in Figure 10.

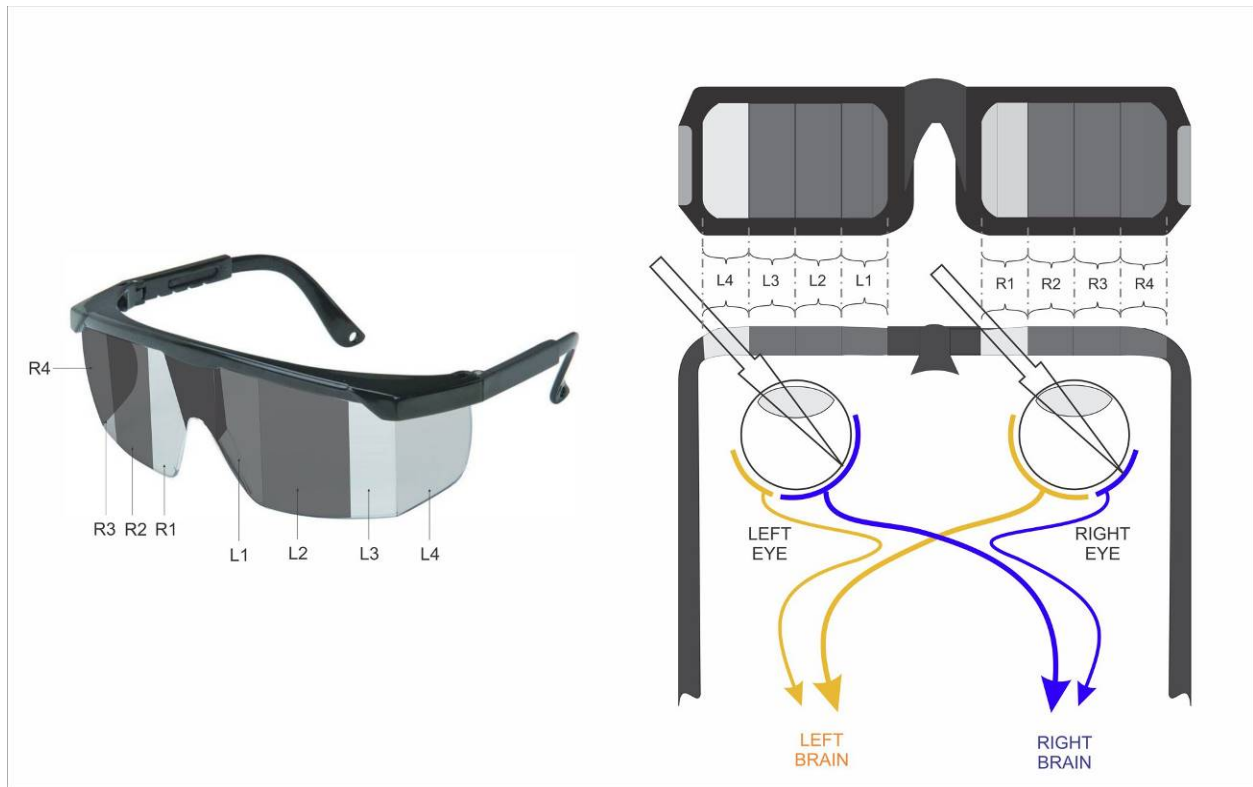


Figure 10 – Distribution of occlusion for lateralized brain stimulation. Figure on the left shows the configuration to preferentially stimulate the subject’s right brain hemisphere through both direct innervation (from the right retina’s lateral aspect) and contralateral innervation (from the left retina’s medial aspect).

The front side of the glasses need to be able to create a clear window of around 1cm width (or narrower), and it should be programmable to allow fine tuning for each individual. A good programmability range would be between 4 mm and 20 mm with 2mm resolution. It must be noted that since vision in the far periphery of the visual field has low resolution, replacing the side shutters by simple light valves (not pixelized, one for each side) should not result in any loss of therapeutic effectiveness.

3.3 Swept-Visual Stimulation

Eye Movement Desensitization and Reprocessing (EMDR) therapy was born in 1987 when psychologist Dr. Francine Shapiro realized that side-to-side eye movements appeared to decrease the negative emotion associated with her own distressing memories. She hypothesized that eye movements had a desensitizing effect, and went on to test it under controlled clinical conditions [Shapiro, 2017].

The concept has led to a standard procedure that is commonly used to treat victims of psychological trauma. Although the underlying mechanism is not known, it has been hypothesized that side-to-side movement of the eyes activates the same neuronal networks responsible for REM sleep. Experimental evidence seems to indicate that actual eye movement is not necessary, and that the same neural activation can be elicited by side-to-side movements in the light patterns of the visual field.

It is thus hypothesized that sweeping a clear window back-and-forth through EmotiGlass will decrease the emotional impact of distressing events.



Figure 11 – Swept visual stimulation with the EmotiGlass goggles.

For this modality, as shown in Figure 11, the clear window should have an approximate width of 1cm, while the opacity of the occluded area should have a programmable range of about 20% of the clear window and up to 100%. In classical EMDR, the approximate sweeping rate used to solidify a positive experience is approximately 0.5 to 1Hz, while reprocessing of traumatic memories is done in a therapeutic setting at sweep frequencies of up to 3 Hz. The most common spatial pattern is simple side-to-side, but diagonal or figure-of-8 sweeps are also used, especially in conjunction with fast movements.

3.4 Interoception Enhancement

Interoceptive awareness is our sensitivity to our own internal sensations. Receptors throughout our body gather information that enables us to feel hunger, satiety, itch, internal pain, body temperature, nausea, need for the bathroom, tickles, physical exertion, sexual arousal, and other internal states.

Sensations from the interoceptive system alert us that our internal system is out of balance and requires us to take action to restore the balance. For example, the sensation of thirst compels us to drink in order to restore the body's electrolyte concentration that is unbalanced by the loss of fluids to sweat and urination.

Introceptive sensations are also important in the way in which we perceive, conceptualize, and remember our affective experiences and other cognitive processes. These sensations allow us to feel our emotions.

For example, before speaking in public, we may feel our heart racing, slight nausea, muscle tension, and shakiness in our hands. Not feeling these sensations would make it difficult to clearly identify the emotions of anxiousness and nervousness.

Not being able to interpret our interoceptive signals in itself causes anxiety, and many biofeedback techniques rely in fact on helping people learn how to “read” their own body. For example, a well-conducted study demonstrated that improving heartbeat perception in patients with medically-unexplained symptoms reduces symptom distress [Schaefer, 2014]. In addition, anxiety in autistic individuals has been shown to decrease quite dramatically when heartbeat feedback is provided to the subject, and is now the subject of a controlled clinical trial [Critchley, 2017].³

The EmotiGlass goggles are fully equipped to unobtrusively provide direct heartbeat feedback to the user, for example by dimming the side panels in synchrony with the plethysmographic signal. In fact, after the subject is “trained” to perceive the side dimming as a proxy for heartbeat, the rhythm of the dimming can be artificially modulated by a computer to change the emotional state of the user.

3.5 Automatic Sunglasses

Although not a feature to modulate the emotional response of the user, automatically-darkening sunglasses can be easily implemented by the addition of a light sensor, so why not...

4 Basic Hardware Selection

From the discussion above, and as shown in Figure 4, a practical implementation of the EmotiGlass concept requires a pixelized light shutter with the following characteristics:

- Spatial resolution of at least 2mm
- Variable opacity and high contrast
- Response speed in the tens of milliseconds or better

After researching possible solutions for fully pixelized electro-optical elements, we settled on modular LCDs for the front lenses. We chose the DOGM128E-6 made by Electronic Assembly GmbH (Zeppelinstraße 19, D-82205 Gilching, Germany) because it allows full control of the pattern of visual occlusion, as well as the opacity level of the occluded and non-occluded areas. The DOGM128E-6 is sold by Mouser and Digikey (around \$23 each).

The DOGM128E-6 (Figure 12) is a high-contrast, 128x64 pixel LCD supertwist display with 15µm dot gap. It incorporates a ST7565R controller with SPI interface. The display module requires just a single 3.0 to 3.3V power supply (270µA typical) and can be directly mounted on a PCB. The LCD is compact (55x46x2 mm) with a large viewing area of 51x31 mm.

³ Short videos about this research are available from the BBC at: <http://www.bbc.com/future/story/20180423-how-a-s>

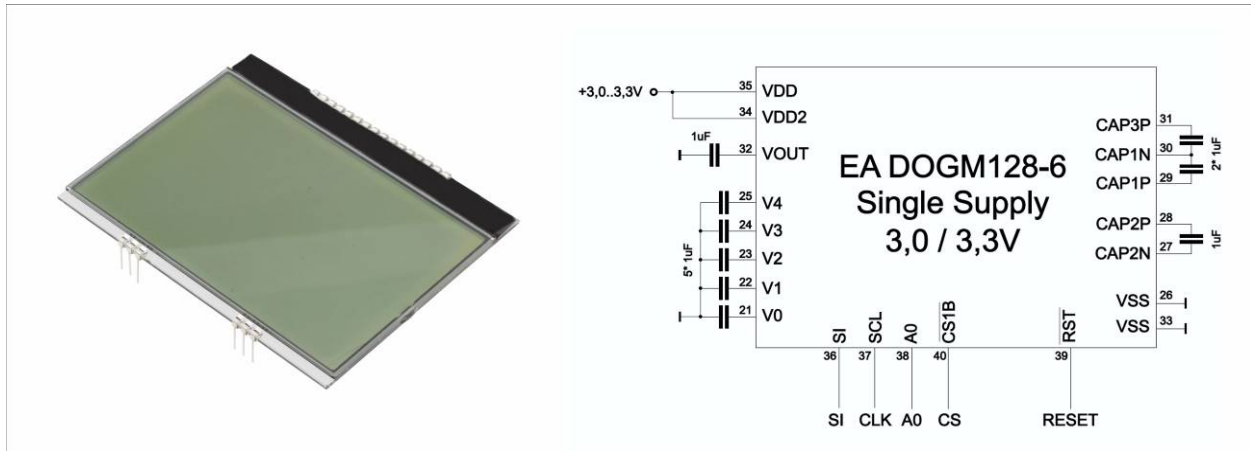


Figure 12 – The DOGM128E-6 is a high-contrast, 128x64 pixel LCD supertwist display with a large viewing area of 51x31 mm. It requires 9 external capacitors to operate from a 3.0 to 3.3V supply.

For the side panels we chose the “Small Liquid Crystal Light Valve - Controllable Shutter Glass” distributed by Adafruit as Product number 3627 (\$2.95 each). The viewing window is 31x33 mm, while the panel size is 36x36x2 mm, making it suitable to mount on the sides of goggles based on the DOGM128E-6. The device is a transmissive twisted nematic panel and requires an AC drive voltage in the 3.0V range.

5 EmotiGlass Development

5.1 First Conceptual Prototype Breadboard

To make the EmotiGlass as open-source as possible, we chose the controller to be an Arduino IDE-compatible Adafruit Feather M0 Bluefruit LE (Adafruit Product ID: 2995, \$29.95). Power is derived from a 3.7V 150mAh lithium ion polymer battery (Adafruit Product ID: 1317, \$5.95) that can be recharged directly from the Feather.

For the conceptual EmotiGlass prototype shown in Figure 13, we chose a ready-made plethysmography sensor (Pulse Sensor Amped, Adafruit Product ID: 1093, \$25.00). A GA1A12S202 log-scale analog light sensor (on breakout board, Adafruit Product ID: 1384, \$3.95) is used for the “automatic sunglasses mode”. GUI control is via the Bluefruit Control Pad for iOS.

A simple oscillator and analog H-bridge is used to drive the side panels at an amplitude set by two MCP4725A1 DACs are used to control the side-panel shutters (MCP4725 Breakout Board - 12-Bit DAC w/I2C Interface, Adafruit Product ID: 935, \$4.95).

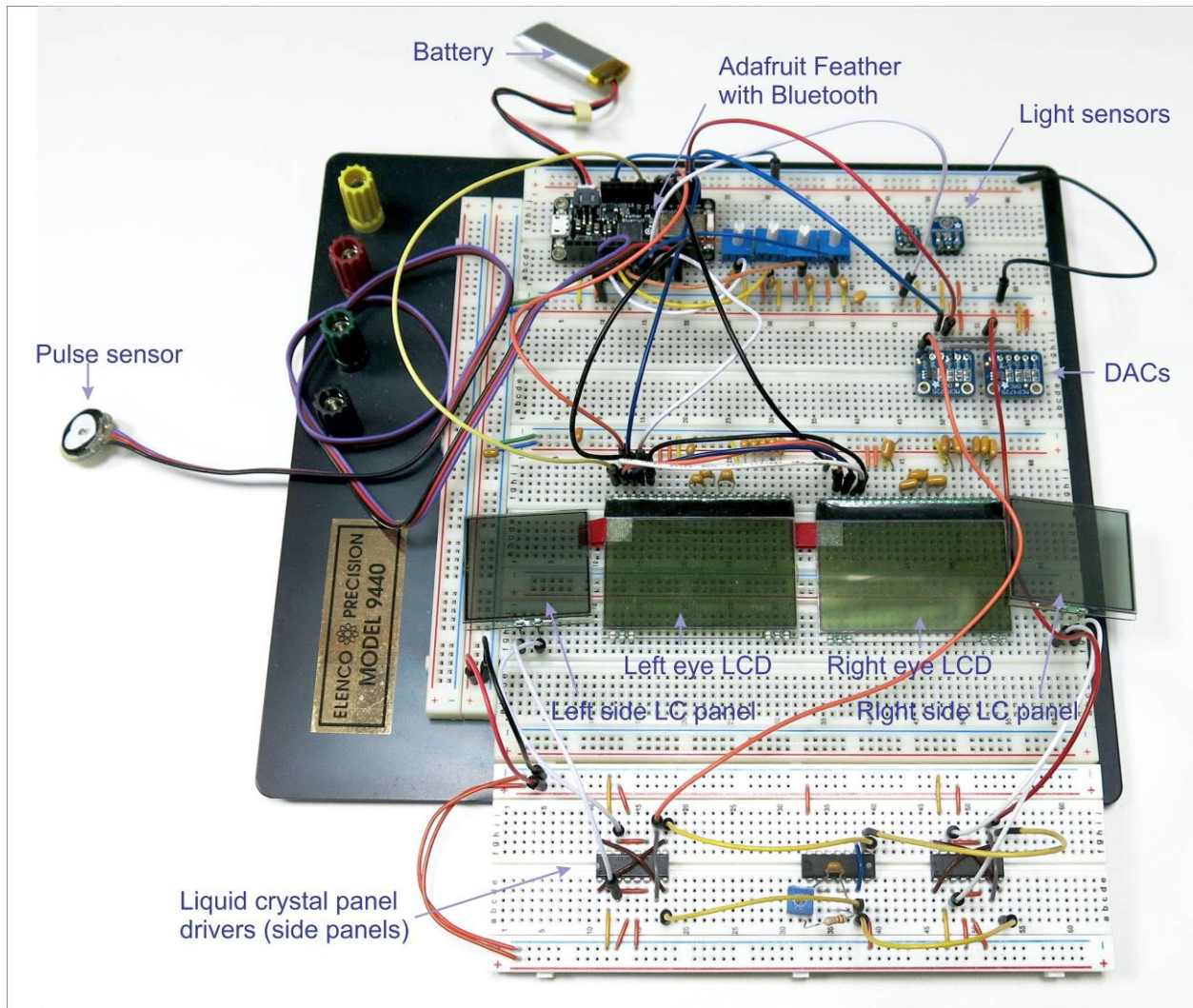


Figure 13 – First breadboard prototype of the EmotiGlass goggles.

Code to run the EmotiGlass breadboard prototype was posted to the Hackaday.io project page for EmotiGlass. A dedicated controller was then written under Evothings Studio as shown in Figure 14

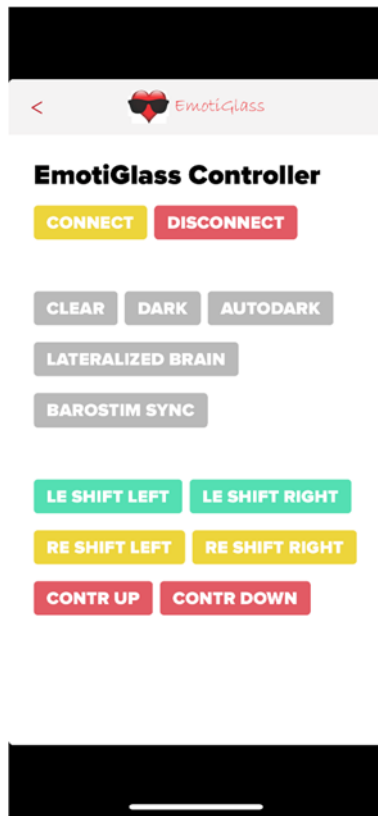


Figure 14 – Dedicated BLE controller for the first breadboard prototype of EmotiGlass

5.2 Wearable Prototype Design

IMPORTANT NOTE: The purpose of this section is to describe and explain the design. However, since improvements are constantly being made to this project, please do not rely on the design files presented in this document to construct an EmotiGlass device. The latest design files are available at <https://hackaday.io/project/160615/files>

5.2.1 Electronics

The circuitry for the EmotiGlass device is shown in the schematic diagrams in Appendix A. Although simple, the circuit needed to be distributed so that it would fit the goggle frames, so it was partitioned into four PCBs, and these schematics correspond to each of the PCBs.

Two boards are stacked together with the Adafruit Feather M0 Bluefruit LE (Adafruit Product ID: 2995). The “Right Side” PCB is used as a convenient method for connecting with the LCDs, liquid-crystal light shutters, and battery board to board wires. This board also holds a SMD fuse in series with the battery, and an ON/OFF switch that is used to disable the Feather M0.

The “Right Side Dev” PCB implements the DC-to-AC converter to drive the liquid-crystal shutters. Although the shutters darken when DC is applied, twisted-nematic liquid-crystal devices are damaged over time through electromigration when under DC drive. For this reason, an oscillator built around U5A-U5D (CD40106BE) is used to drive the switches of two H-bridges implemented through MAX392 quad analog switches U1 and U3. These convert the DC levels produced by MCP4725A digital-to-analog converters U2 and U4 into an AC signal to drive the liquid-crystal shutters.

It must be noted that we have made provisions in the implementation to greatly simplify the electronics at the expense of writing a custom driver by using the microcontroller's PWMs. The idea is to set up two PWMs 180° out of phase to produce the square wave with alternating polarity to drive the liquid-crystal shutter. Two pairs of PWMs would be needed to control the two shutters. Changing the pulse width would then change the optical density of the LC shutter. This has the same effect as the current implementation of varying the amplitude of the AC drive, but obviates the need for the DACs and DC-to-AC circuitry.

The circuits for the front PCBs contain all of the capacitors needed by the charge pumps of the LCD drivers shown in Figure 12. In addition to pass-through connectors, the right-front PCB differs from the left-front PCB because it also includes an Everlight ALS PT-19 light-to-current sensor used to implement the auto-darkening sunglasses mode.

The PCBs were designed to use the largest surface-mount packages available for ICs (mostly SOICs) and 0603 passives (with plenty of space between them) so that the boards will be reasonable easy to assemble with only a basic soldering iron.

5.2.2 Mechanical

The wearable prototype frame is 3D printed. The frame is designed in 3 pieces (front and 2 sides). This allows the front piece which holds the glass LCD displays and shutters to be printed from a stiff plastic, allowing it to provide the most protection possible to the glass. PLA is being used currently, but switching to a CPE family material will allow the device to survive a higher temperature. At the same time, the sides are printed from a more flexible material from the Nylon family (the prototype uses Taulman 645), which allows the Emotiglass prototype to fit on heads of different sizes without being uncomfortable. The three frame pieces are keyed together and secured with screws. The frame was designed to use the same size screw everywhere except the board stack, and can use either inch or metric hardware. The mechanical components are shown in Figure 15.

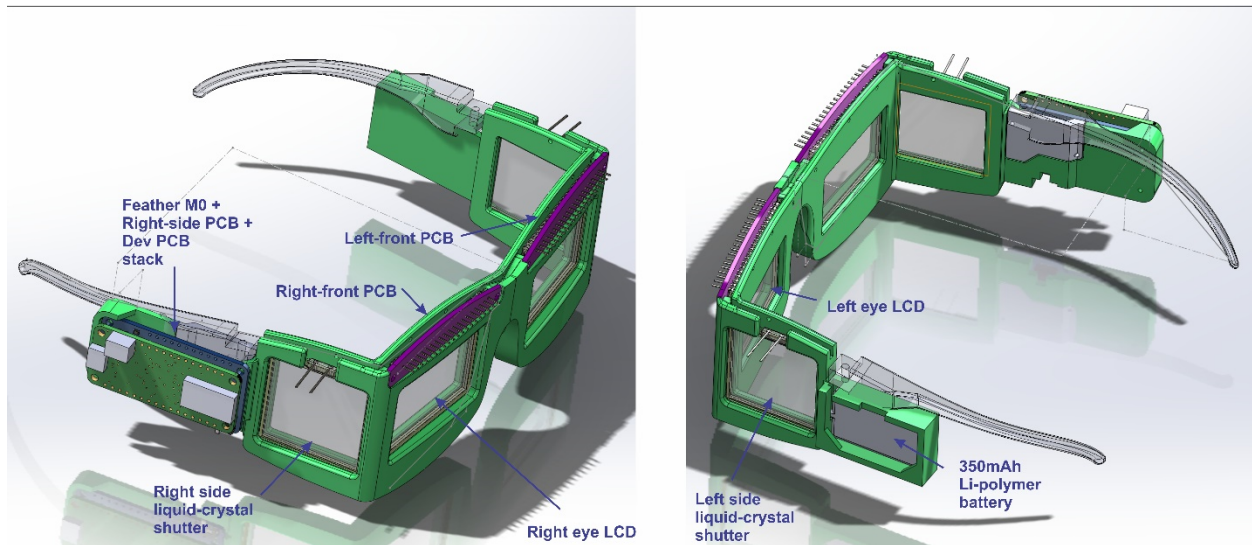


Figure 15 – EmotiGlass mechanical components

5.2.3 Firmware

WARNING: Firmware was written by hardware engineers. This code may be offensive to some audiences. Reader discretion is advised.

The firmware for EmotiGlass is coded as a sketch under the Arduino Development Environment. Its principal functions are:

- Communicating with the GUI via BLE and setting operating parameters
- Controlling the LCDs
- Controlling the liquid crystal light shutters
- Sampling the plethysmography signal
- Sampling ambient illumination

The code itself, available at the project page is well documented, but some explanations regarding the various functions are in order, as follows.

The occlusion areas in the LCDs are drawn using the function *rectangle(start_column, start_page, end_column, end_page, pattern)* of the *dog_7565R* library. This function draws a filled rectangle on the screen. The filling is given through the pattern byte. Variables are: *start column* (0..127), *start page* (0..7), *end column* (0..127), *end page* (0..7), *pattern-byte*. LCD coordinates are shown in Figure 16.

The “single pixel” liquid crystal shutter for the side of the visual field is considered to be the 128th column (where LCD columns are 0...127). The single-pixel shutters are controlled by *leftsideEnable* and *rightsideEnable*.

This version of EmotiGlass limits the shape of the occlusion to be rectangular, where the full height (Pages 0 ... 7, with full fill pattern) of each column is either filled or remains blank.

Contrast of the LCDs is controlled via *DOG.contrast*(0..63), while the optical density of the liquid-crystal shutters is controlled by *leftsideContrast* and *rightsideContrast* by writing to their respective MCP4725 digital-to-analog converters using the *Adafruit_MCP4725.h* library’s *dac.setVoltage*(0..4095, *storeflag=false*). *Storeflag* tells the MCP4725 whether or not it should store the value in EEPROM. This function is not used in EmotiGlass.

Mode 1 (CLEAR) is simply implemented by clearing an applying zero contrast to the LCDs and shutters. Mode 2 (DARK) fills a solid rectangle from column 0 through column 127 of the LCDs and applies maximum contrast to the LCDs and shutters. Mode 3 (AUTODARK SUNGLASSES) does the same as Mode 2, but modulates the contrast as a function of the light intensity measured from the light sensor via input A5.

Mode 4 (LATERALIZED BRAIN STIMULATION) is implemented by simulating a dark curtain (the “occlusion curtain” of Figure 16) which can slide past the LCD and liquid-crystal shutter. When the curtain hits the “nose” (LCD column 0), it simply folds over itself and leaves the “ear” side of the LCD/shutter empty. The position of the curtain is controlled by the variable *span*. If *span* is < 128, then the curtain is fully contained within the LCD. For values of 128 and above, the curtain slides over the shutter and starts to leave the “nose” side of the LCD clear.

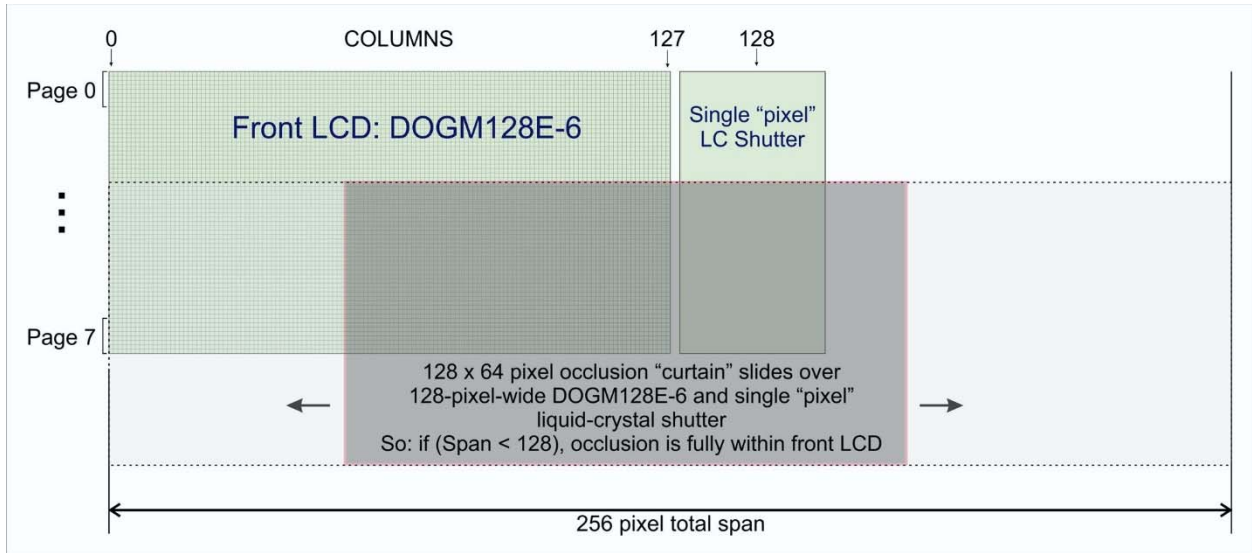


Figure 16 – A software “occlusion curtain” slides over the LCD and side liquid-crystal light shutter to define the regions being occluded for selective lateral brain stimulation. It should be noted that the left eye and right eye use the same windowLCD() function, but they are applied after using either DOG.view(VIEW_BOTTOM) or DOG.view(VIEW_TOP) in updateLCDs().

Mode 5 (BARORECEPTOR SYNCHRONIZATION) is implemented as in Mode 2, but with contrast turned on during a programmable blanking period after the plethysmographic signal crosses a programmable threshold. A refractory period is started after the trigger to prevent retriggering on the same cardiac cycle. In the STIMULATION mode, vision is occluded during most of the cardiac cycle, except for the time when baroreceptors are active with the same criteria as for blanking. In the INTEROCEPTION mode, only the side liquid crystal panels are activated to provide the user with heartbeat feedback.

Mode 6 (VISUAL SWEEP) is implemented by a “for” loop that uses an internal switch (x) to cause a back-and-forth scan of a clear window between the left-eye and right-eye LCDs (Figure 17). The GUI variable *sweepwidth* is used in this mode to define the width of the sweeping clear window.

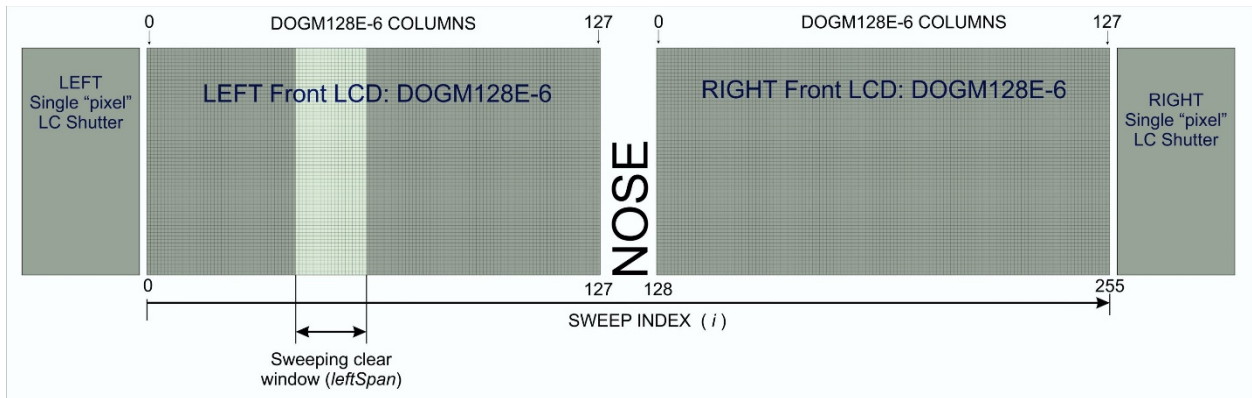


Figure 17 – A clear window sweeps back and forth between the LCDs in Mode 6.

6 GUI Design

We developed a BLE GUI for EmotiGlass that runs under the Evothings platform. Evothings Studio is a development tool for creating mobile applications for IoT applications using web technologies and open-source software components.

The operating modes and GUI controls are detailed as follows:

6.1 Initial GUI Screen

The initial GUI screen shows a stylized figure of EmotiGlass as seen by the user. Pressing “CONNECT” establishes the BLE connection. A BLE session must be established before allowing the user to select any of the modes. If a mode button is pressed without connecting, a message is displayed prompting the user to connect.

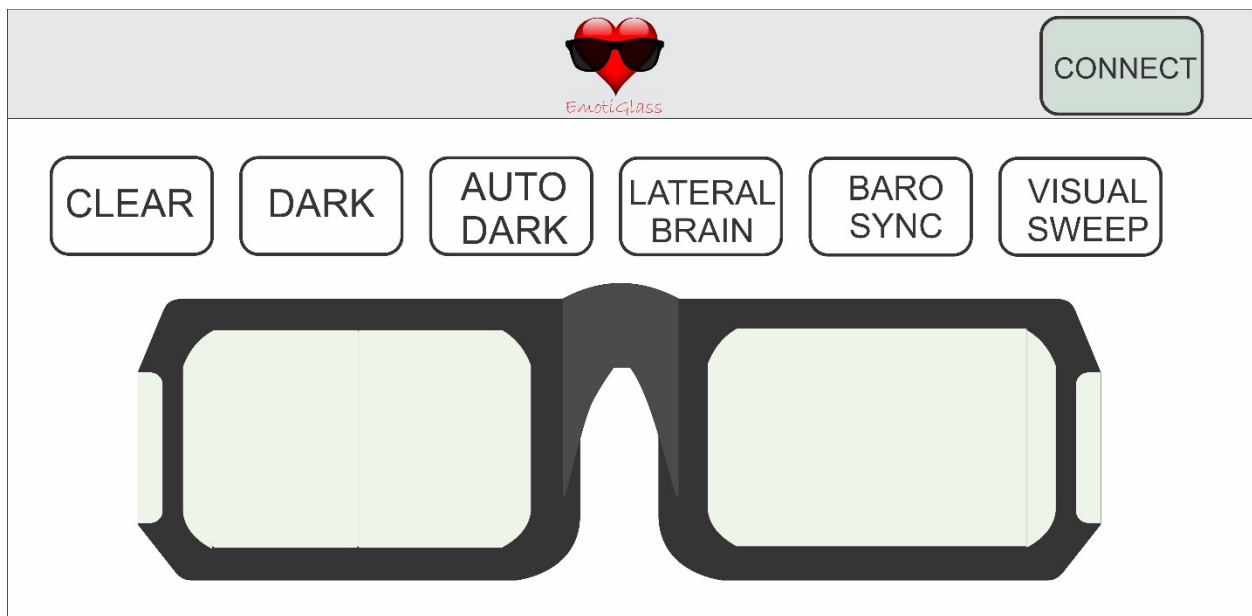


Figure 18 – Wireframe for the initial GUI screen for EmotiGlass. BLE Connection must be established before enabling any of the operating modes.

6.2 Clear

This mode causes the LCD panels and side liquid-crystal shutters in EmotiGlass to be as clear as possible.

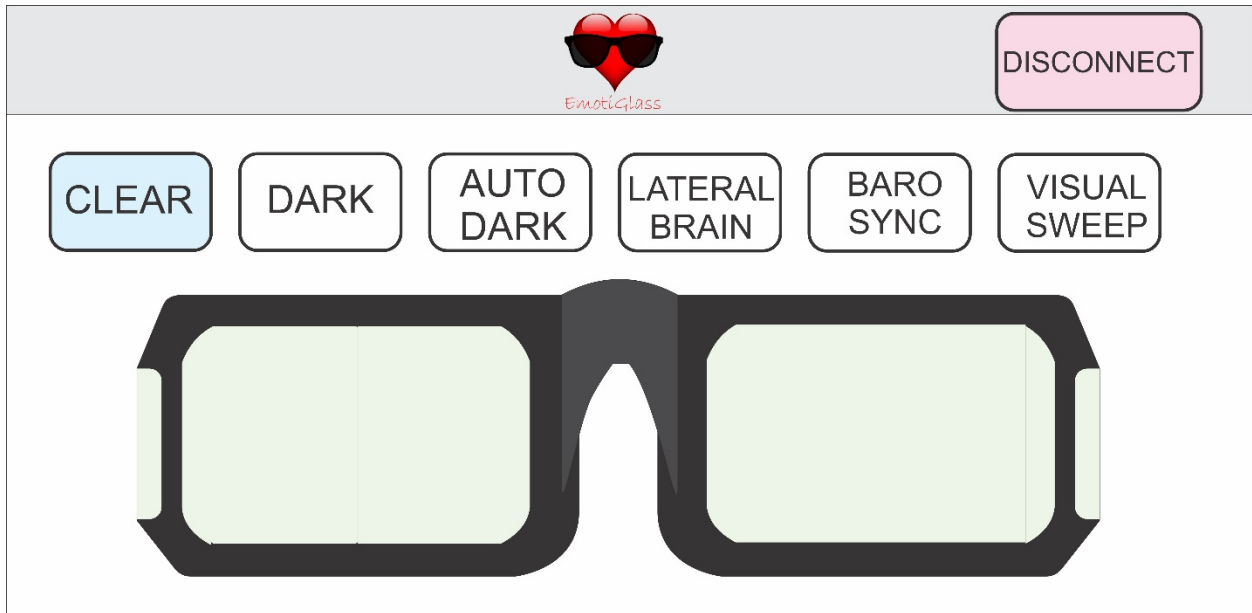


Figure 19 – EmotiGlass GUI wireframe for CLEAR mode

6.3 Dark

This mode causes EmotiGlass to behave as sunglasses. The optical density is set to maximum.

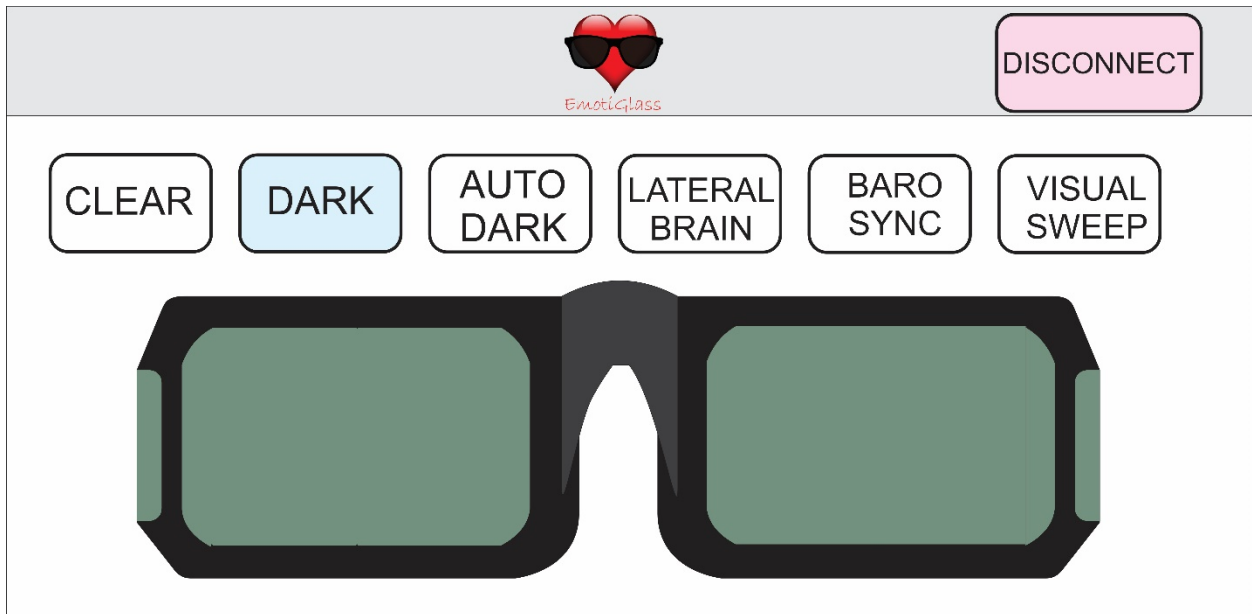


Figure 20 - EmotiGlass GUI wireframe for DARK mode

6.4 Auto-Dark

This mode causes EmotiGlass to behave as auto-darkening sunglasses. The optical density of the LCDs and shutters varies between maximum and minimum as a function of ambient illumination.

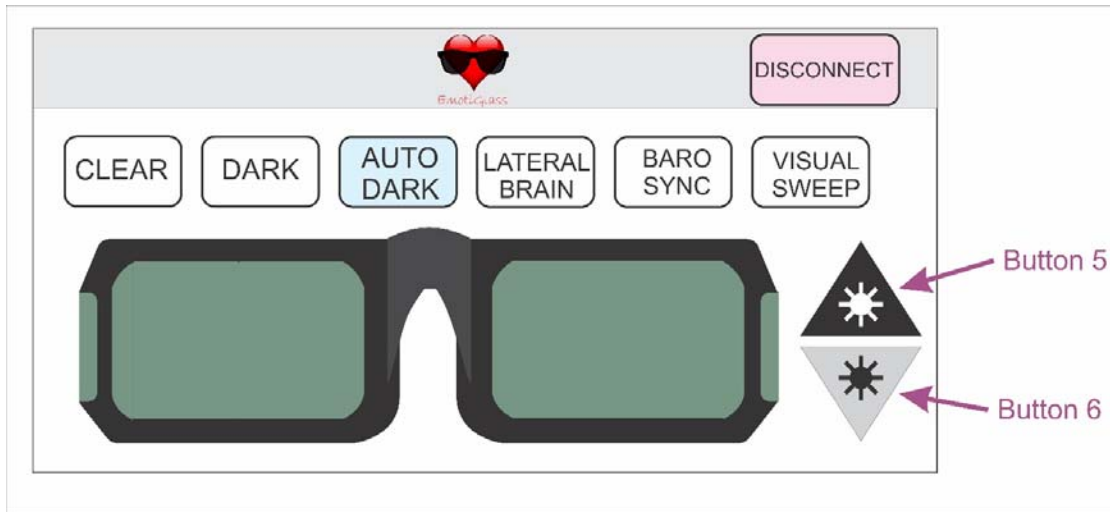


Figure 21 - EmotiGlass GUI wireframe for AUTO-DARK mode

6.5 Lateralized Brain Stimulation

In this mode, the EmotiGlass goggles occlude the visual field such that only the parts of the retinas that innervate the left or right brain are illuminated by the scene. A “curtain” that can be moved laterally is displayed in front of each eye. The position of the “curtain” in front of each eye can be controlled via the buttons under the image of EmotiGlass. The contrast of the occluding “curtain” is controlled via the buttons on the side of the figure representing EmotiGlass.

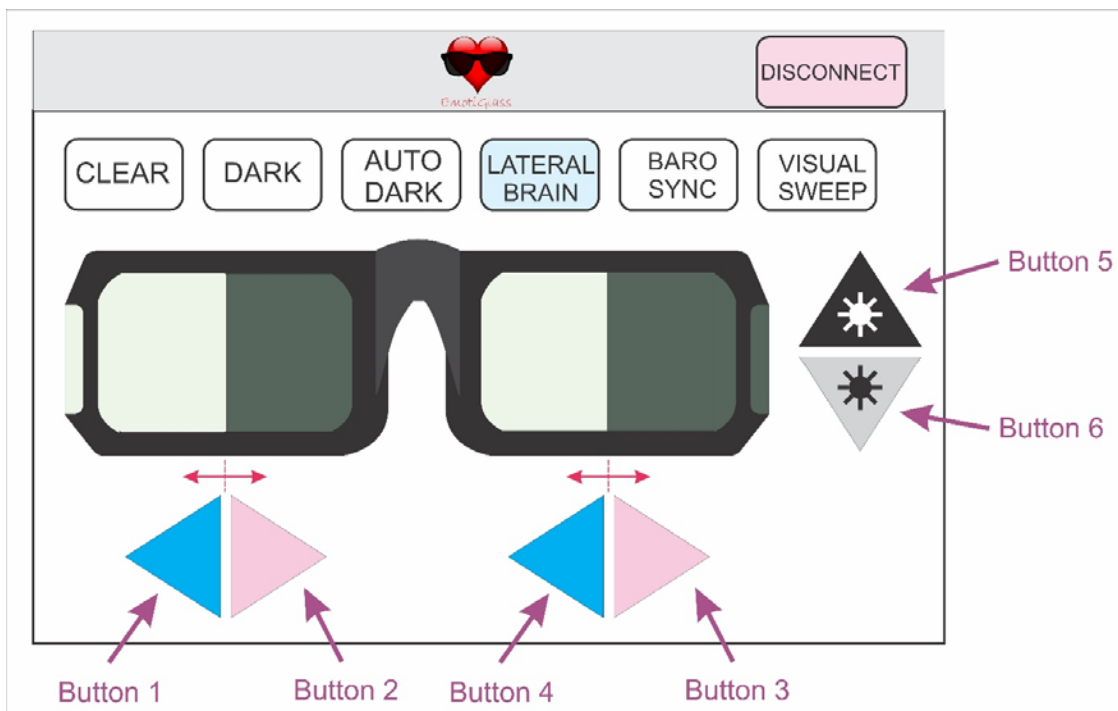


Figure 22 - EmotiGlass GUI wireframe for LATERALIZED BRAIN STIMULATION mode

6.6 Visual Occlusion Synchronized to Baroreceptor Activation

In this mode, the scene is occluded in synchrony with baroreceptor activation. The threshold applied to the plethysmographic signal picked up from the earlobe is programmable via the arrow buttons on top and bottom of the line representing threshold. Vision may be occluded by EmotiGlass either when the baroreceptors are deemed to be active or not. This is controlled via the toggle button labeled “BLANK/STIM” (Figure 24). “BLANK” is meant to dampen the emotional response to a scene, while “STIM” is meant to enhance it. The contrast during the occlusion time is controlled via the buttons on the side of the figure representing EmotiGlass.

Unobtrusively providing direct heartbeat feedback to the user is implemented by selecting the “INTEROCEPTION” mode (button under the contrast arrow buttons). This causes the side panels to dim or lighten (as selected by “BLANK” or “STIM”) in synchrony with the plethysmographic signal.

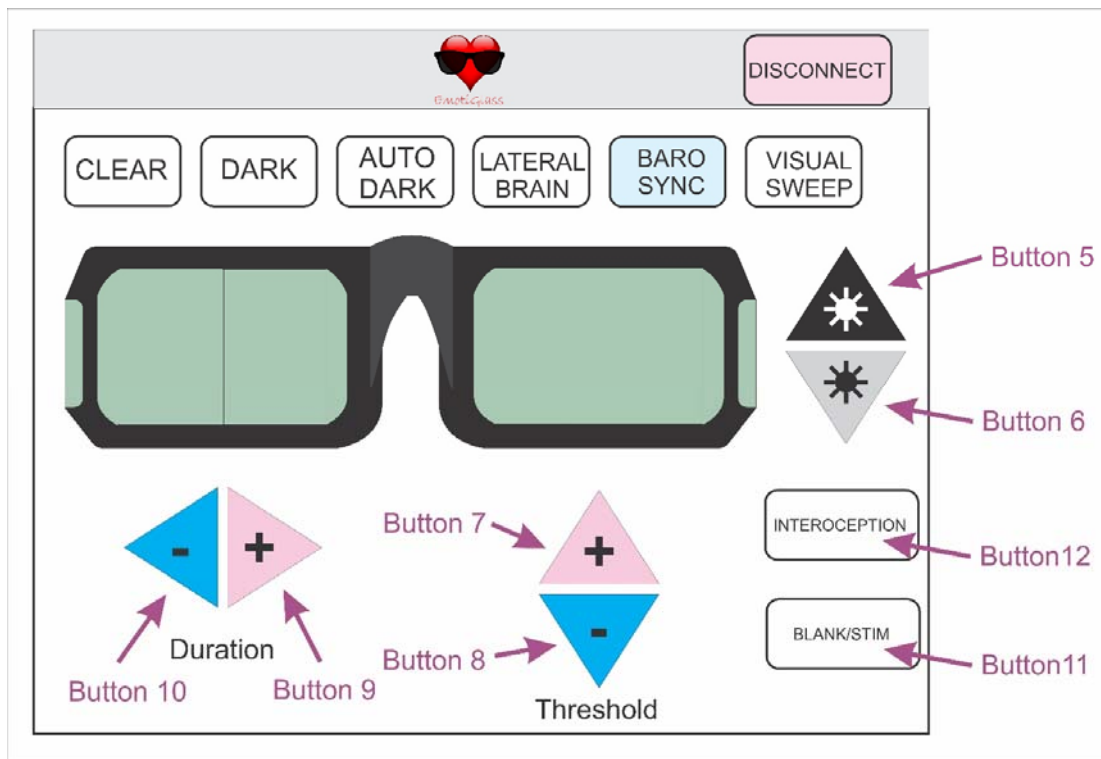


Figure 23 - EmotiGlass GUI wireframe for BARORECEPTOR-SYNCHRONIZED BLANKING mode

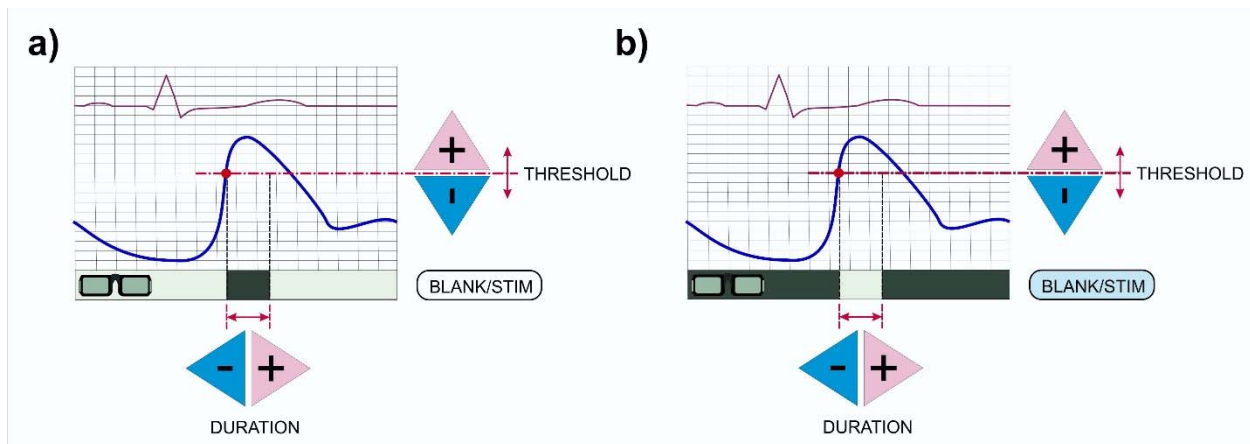


Figure 24 – Operation of EmotiGlass in the baroreceptor-synchronized mode in **a)** BLANK mode and **b)** STIM mode.

6.7 Visual Sweep

In the “Visual Sweep” mode, a clear window of programmable width is displayed in front of each eye. The width is controlled via two arrow buttons under the figure depicting the left lens of the EmotiGlass goggles. The sweep frequency is controlled by the arrow buttons under the right lens image. The contrast of the occluded regions is controlled via the buttons on the side of the figure representing EmotiGlass. The FULL/STIM toggle button reuses the command for Button 12 because it has the same effect as pressing the “INTEROCEPTION” button in Mode 5 – i.e. leaves the front LCDs clear, while only activating the side shutters.

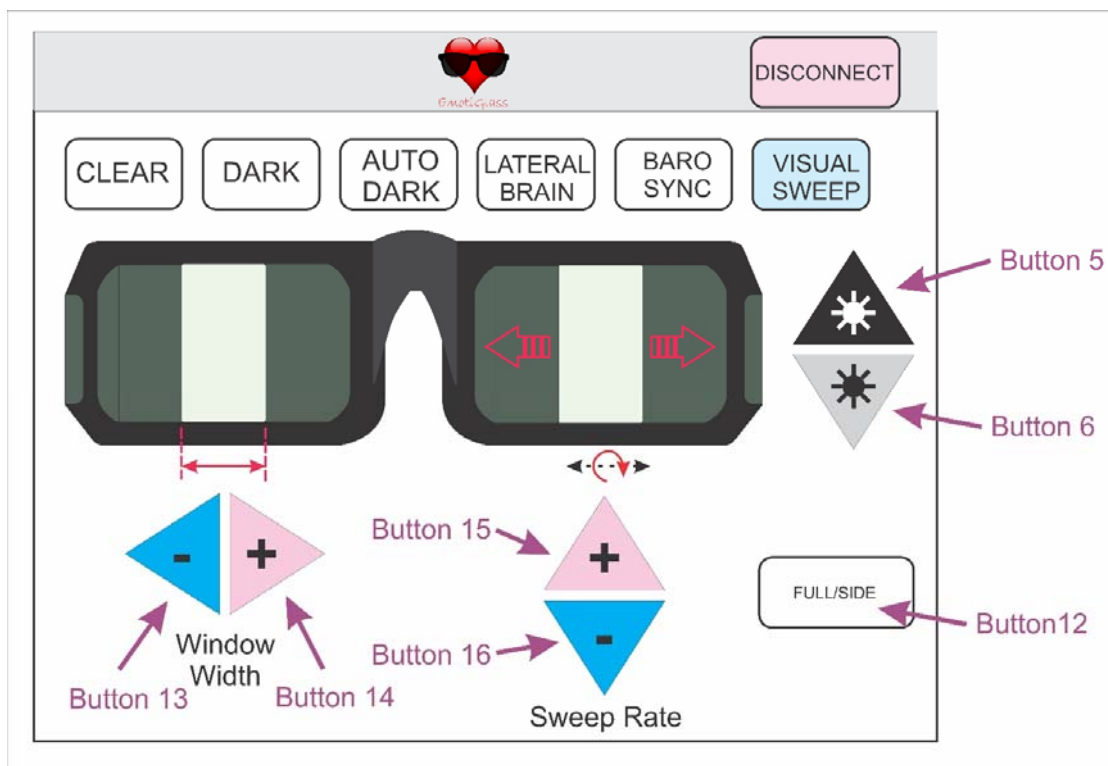


Figure 25 - EmotiGlass GUI wireframe for VISUAL-SWEEP mode

6.8 GUI Installation and Development

A GUI app that runs under Android is available at the project page. To install it, one simply has to open the file manager on any Android device that supports BLE and install the EmotiGlass.apk.

We have not yet submitted an iOS app to the Apple App Store, but this doesn't prevent running the EmotiGlass App on any iOS device without having to jailbreak. To do so, the free CGTek Viewer app needs to be installed from the App Store, and the GUI loaded through Evothings Studio. By the way, the same works under Android by downloading Evothings Viewer from the Google Store.

Evothings Studio 2.0 first needs to be installed in the computer used for app development. Windows, Mac OS X and Linux installers are available for free at: <https://evothings.com/download/>. A starter guide is available at: <https://evothings.com/doc/starter-guides/evothings-studio-starter-guide.html>.

After installing Evothings Studio, a new project named "EmotiGlass" should be started, and the unzipped contents of EmotiGlassGUI.zip copied into the project's directory.

Evothings Studio and the Evothings player then need to be connected. This is done by getting a key and sharing it with the app as shown in Figure 26. That's it! The BLE-enabled device running the client should be able to control EmotiGlass without any further setup.

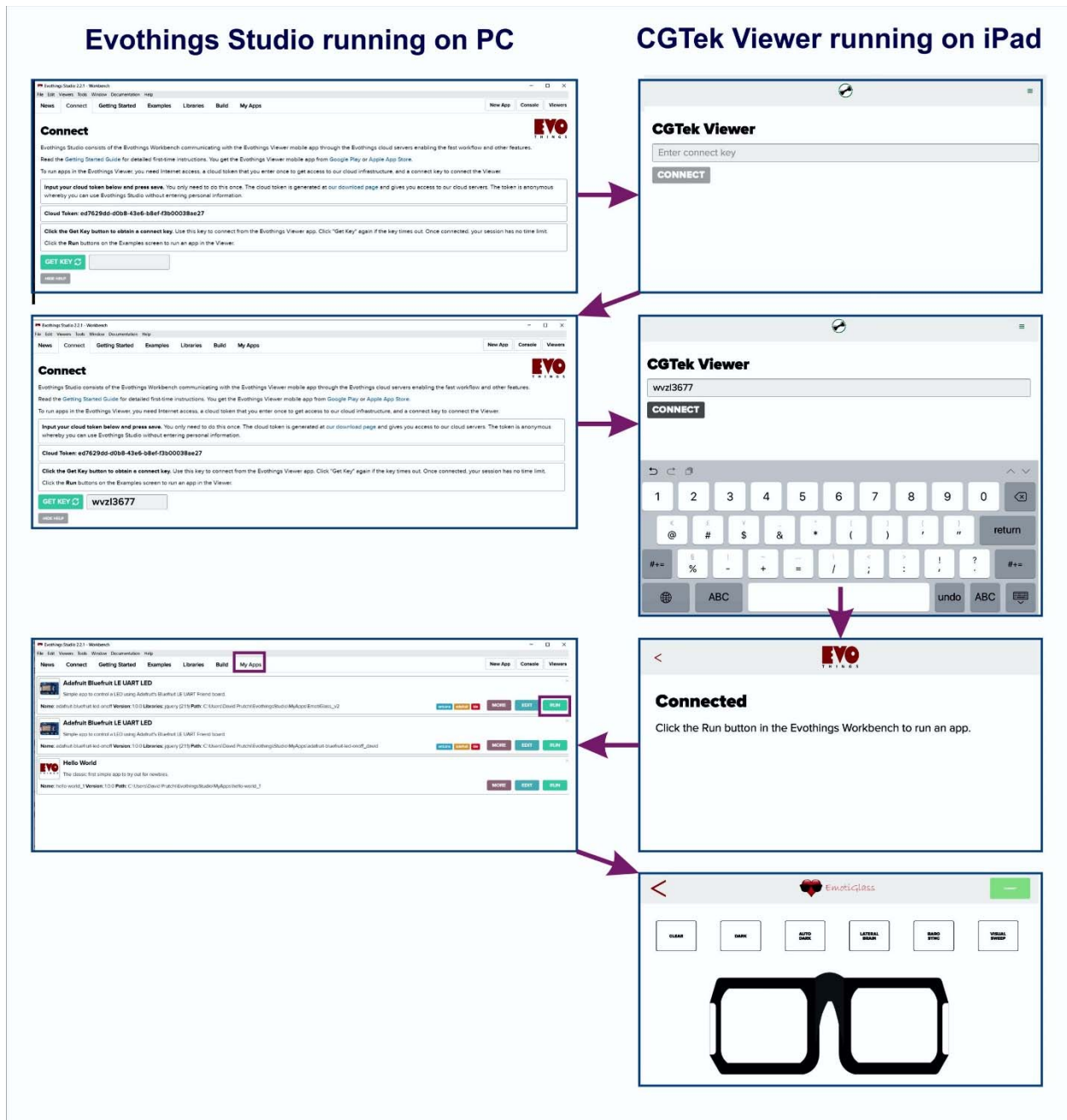


Figure 26 – Evothings Studio running on a Windows, Mac, or Linux machine is used to develop and upload the GUI into any Android or iOS device running an Evothings player app (e.g. CGTek Viewer for iOS).

For further developing the app, the GUI's development files can be modified using a smart editor (e.g. Visual Studio), and the app will be instantaneously updated into any connected Evothings player.

7 Compliance with Requirements and Final Specifications

7.1 Compliance with Requirements

Table 1 below shows the way in which the EmotiGlass wearable prototype complies with the project's objectives defined by conceptual requirements in Section 2.1.

Table 1 – EmotiGlass wearable prototype compliance with conceptual requirements

Conceptual Requirements (See Section 2.1)	EmotiGlass Wearable Prototype	Outcome / Comments
Hardware		
The EmotiGlass device shall be constructed as goggles wearable by an adult user.	EmotiGlass fits comfortably a wide range of adult heads.	Fulfills requirement.
The EmotiGlass device shall incorporate a microcontroller to control its operation such that further development can be done by reprogramming the device with no need for hardware changes.	The Adafruit Feather M0 Bluefruit LE used to control EmotiGlass is based on a NXP 32-bit Cortex-M0™ microcontroller	Fulfills requirement
The EmotiGlass device shall incorporate a sensor for detecting the wearer's heartbeat.	The EmotiGlass device incorporates a Pulse Sensor Amped plethysmography sensor.	Fulfills requirement
The EmotiGlass goggles shall be stand-alone (with exception of the GUI device) and be fully self-contained.	The EmotiGlass device incorporates all of its electronics (including battery), sensors, and light shutters into its face-worn enclosure.	Fulfills requirement
The EmotiGlass goggles shall be controlled via a wireless user interface, preferably one that can run as an app on the user's smartphone or similar portable device.	The user interface is a GUI running as an app in the user's BLE-enabled iOS or Android handheld device.	Fulfills requirement
Hardware selected for the EmotiGlass Device shall be widely available. With the exception of custom PCBs and frame, all electronic components shall be in current production and available in small quantities from easily-accessible vendors to enable experimenters to replicate the device for personal use.	All components for the EmotiGlass are widely available from multiple distributors. All parts are in current production. Files for the manufacture of PCBs and enclosure are made available online.	Fulfills requirement
Firmware		

Conceptual Requirements (See Section 2.1)	EmotiGlass Wearable Prototype	Outcome / Comments
<p>The firmware for the EmotiGlass device shall implement the following operating modes:</p> <ul style="list-style-type: none"> a) Clear b) Dark c) Auto-Dark d) Lateralized Brain Stimulation e) Occlusion synchronized to Baroreceptor Activation f) Interoceptive Awareness g) Visual Sweep 	<p>The EmotiGlass wearable prototype implements the following operating modes:</p> <ul style="list-style-type: none"> a) Clear b) Dark c) Auto-Dark d) Lateralized Brain Stimulation e) Occlusion synchronized to Baroreceptor Activation f) Interoceptive Awareness (as part of e, above) g) Visual Sweep 	<p>Fulfills requirement</p>
<p>The firmware for the EmotiGlass device shall implement the logic layer for communicating with the wireless user interface, preferably one that can run as an app on the user's smartphone or similar portable device.</p>	<p>The firmware for EmotiGlass communicates with the iOS or Android control app via BLE.</p>	<p>Fulfills requirement</p>
<p>Firmware shall be written in an easily-accessible language, and shall use only open-source modules to enable experimenters to replicate and modify the device for personal use.</p>	<p>The firmware for EmotiGlass is written as an Arduino sketch, making it easy to replicate and modify.</p>	<p>Fulfills requirement</p>
User Interface		
<p>The user interface shall be intuitive and easy to use</p>	<p>The user interface is very intuitive and easy to use.</p>	<p>Fulfills requirement</p>
<p>If possible, the user interface shall run as an app on the user's smartphone or portable device</p>	<p>The user interface is a GUI running as an app in the user's BLE-enabled iOS or Android handheld device.</p>	<p>Fulfills requirement</p>
<p>Software for the user interface Firmware shall be written in an easily-accessible language, and shall use only open-source modules to enable experimenters to replicate and modify the device for personal use.</p>	<p>The GUI for EmotiGlass is written under Evothings Studio, making it easy to replicate and modify.</p>	<p>Fulfills requirement</p>

7.2 Specifications

The final specifications for the EmotiGlass wearable prototype are as follows:

Parameter	Specification	Notes
Physical Specifications		
Dimensions	195 mm W X 57 mm H x 150 mm D	
Weight	137 g	
Frame Materials	Ultimaker green PLA + Taulman 645 nylon	
Plethysmography Sensor	In contact with skin: Transparent nylon and chrome-plated steel	
Optical Specifications		
Front optics (each eye)	128x64 pixel liquid-crystal shutter backed with 0.01" polycarbonate film for eye protection in case of breakage	
Side optics (each eye)	Single-pixel liquid-crystal shutter backed with 0.01" polycarbonate film for eye protection in case of breakage	AC drive at 500Hz
Front optical window opening (each eye)	44.5 mm x 24.8 mm	
Side optical window opening (each eye)	22mm x 29.2 mm	
Electrical Specifications		
Battery	350mAh LiPo	
Recharge	5V micro USB	
OFF-state current consumption	73 μ A	@3.7V, using Feather M0's ENABLE pin connected to ground
ON-state current consumption, not connected to BLE	12.2 mA	@3.7V, "CLEAR" mode
ON-state current consumption, connected to VLE and operating	13.7 – 18.8 mA	@3.7V, depending on mode
Operating Modes		
Clear	LCD panels and side liquid-crystal shutters as clear as possible	
Dark	LCD panels and side liquid-crystal shutters as dark as possible	
Auto-Dark	Optical density varies between clear and programmable darkness as a function of ambient light intensity	

Parameter	Specification	Notes
Lateralized Brain Stimulation	LCD panels and side liquid-crystal shutters occlude the visual field such that only the parts of the retinas that innervate the left or right brain are illuminated by the scene	
BaroSynch	Scene is occluded in synchrony with baroreceptor activation. Plethysmographic signal threshold is programmable from GUI. “BLANK/STIM” programmable from GUI: “BLANK” dampens emotional response, “STIM” enhances emotional response. “INTEROCEPTION” mode provides direct heartbeat feedback causing side panels to dim or lighten (as selected by “BLANK” or “STIM”) in synchrony with the plethysmographic signal.	Heartbeat signal detected by optical plethysmographic sensor placed on earlobe
Visual Sweep	Clear window of programmable width sweeps back-and-forth at rate programmable from GUI.	
Interface Specifications		
API transport	Bluetooth Low Energy (BLE)	
GUI Requirements		
Platform	Android 4.4 KitKat or newer	Tested on Samsung Galaxy Tab E Lite 7"; 8 GB Wifi Tablet with Android 4.4 KitKat

8 Further Development and Productizing EmotiGlass

The EmotiGlass project was developed as a proof-of-concept device. It needs further development and optimization to be turned into an actual wellness product, as well as a device suitable for conducting controlled clinical trials. One obvious starting point is replacing the expensive LCDs by custom-built multi-segment panels as shown in Figure 27. These can be produced by the same manufacturers that make custom LCDs. Although NRE is relatively high, unit price can be suitably low under volume production. Each vertical segment would be more or less 3.5mm wide, making each front shutter have 16 separately-addressable segments (instead of the 8,192 pixels of the current LCD). This has the advantage that faster

refresh rates are possible, making spatio-temporal sweeps much smoother than the prototype implementation. In addition, much higher contrast can be achieved than with a small-pixel LCD.

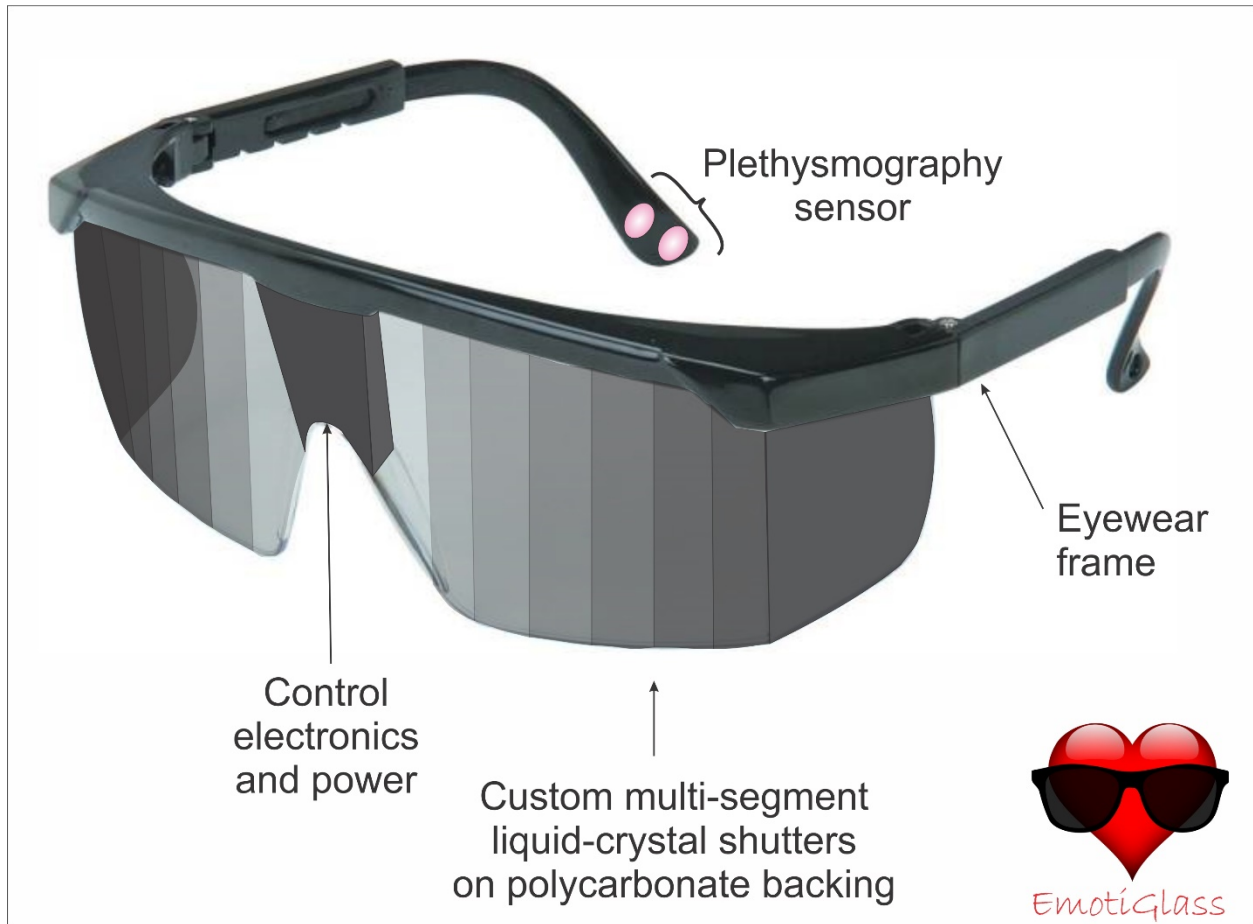


Figure 27 – Conceptual view of a productized version of EmotiGlass. A custom multi-segment liquid-crystal shutter would be used instead of the expensive LCDs for the front lenses.

8.1 Electronics

The circuit can be stripped to only the absolutely necessary components, eliminating the overhead created by the connectors and dead PCB areas. A single flexible PCB can then be used as the substrate for the complete EmotiGlass circuit.

8.2 Enclosure

Reducing the volume of the circuitry makes it possible to design a much sleeker frame that can be produced in volume through an injection-molding process.

A productized version would need to be more robust than the prototype so that it can be widely used. This could be accomplished by binding the multi-segment shutters and side shutters to a transparent impact-resistant polycarbonate backing, which would be significantly thicker than the .01" film used in the prototype.

8.3 Firmware

Firmware for the EmotiGlass prototype is written to implement basic functionality. There is quite a bit of optimization that can be done on the code that can lead to reduced component count, current consumption, display flicker, etc.

8.4 GUI

Currently, the GUI sends commands to EmotiGlass without knowing if they were received. A productized version of EmotiGlass would benefit from establishing a bidirectional BLE link with the GUI app. This would allow the graphical elements in the GUI to be updated to reflect the actual state of EmotiGlass. In addition, the plethysmography threshold and blanking period could be displayed on a real-time graph of the plethysmography signal.

Another aspect that requires attention for a productized version is Bluetooth pairing. At the moment, the EmotiGlass prototype accepts commands from any device that establishes a link. One-to-one pairing between an EmotiGlass device and its controller should be implemented as is common with Bluetooth-enabled consumer electronics.

8.5 Other

A major market for EmotiGlass would be as a device for reducing anxiety. The regulatory process for making a medical claim is much more complex and would require clinical data to support it. However, EmotiGlass could be sold as a wellness device without making claims that need to be evaluated by FDA or other regulatory agencies.

Unlike a medical device, which is intended to be used to diagnose, treat, mitigate or prevent a disease, “wellness devices” are intended only as an aid for general healthy lifestyle. According to FDA regulations, wellness devices present a minimal risk to the safety of the user and to others. Examples of wellness devices are those that don’t make specific reference to diseases or conditions and instead make general claims. These claims are typically related to weight management and physical fitness, including products intended for recreational use, relaxation or stress management, mental acuity, self-esteem, sleep management, etc. EmotiGlass would thus fit well within the category of a wellness device intended for relaxation and stress management until therapeutic claims can be made after conducting proper clinical studies.

9 Licenses

Hardware for the EmotiGlass project is licensed under the Creative Commons Attribution-ShareAlike 4.0 International License. To view a copy of this license, visit <http://creativecommons.org/licenses/by-sa/4.0/>

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The following licenses apply to libraries that are used by the software that operates EmotiGlass:

The source code for the Arduino environment is covered by the GPL, which requires any modifications to be open-sourced under the same license. It does not prevent the sale of derivative software or its inclusion in commercial products. The following libraries fall under this license:

- <Arduino.h>
- <string.h>
- <SPI.h>
- <Wire.h>

The LCD module library <dog_7565R.h> is open-source released under GNU General Public License version 2 or the GNU Lesser General Public License version 2.1, both as published by the Free Software Foundation.

The following Adafruit libraries are open source released under the BSD License:

- Adafruit BLE:
 - "Adafruit_BLE.h"
 - "Adafruit_BluefruitLE_SPI.h"
 - "Adafruit_BluefruitLE_UART.h"
 - "BluefruitConfig.h"
- <Adafruit_MCP4725.h>

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10 Disclaimer

The EmotiGlass project is presented solely for educational purposes. The authors make no medical or healthcare claims for the EmotiGlass device. The potential therapeutic applications for EmotiGlass have not been reviewed by FDA or any other regulatory agency. The authors do not suggest that the circuits and software presented herein can or should be used in place of or as an adjunct to professional medical treatment or advice. Sole responsibility for the use of these circuits and/or software or of systems incorporating these circuits and/or software lies with the reader, who must apply for any and all approvals and certifications that the law may require for their use.

Furthermore, the safe operation of these circuits requires the use of batteries, and connection to external signal acquisition/processing/monitoring equipment should be done only through signal isolators with the proper isolation ratings. Users of these devices must also be aware that flickering may cause seizures in sensitive individuals.

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11 Acknowledgements

We are very grateful to Gregory Leonberg for applying his HTML/JavaScript magic to turn our square-button EvoThings GUI into pretty graphics that match our wireframe vision.

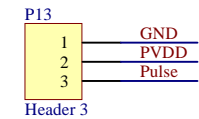
12 References

1. Azevedo RT, Garfinkel SN, Critchley HD, Tsakiris M, "Cardiac Afferent Activity Modulates the Expression of Racial Stereotypes", *Nature Communications*, 8: 13854, 2017; DOI: 10.1038/NCOMMS13854. Available online at: <https://www.nature.com/articles/ncomms13854.pdf>.
2. Buck R, U.S. Patent No. 6,141,797, "Opaque Goggles Having Openable Window", November 7, 2000. Available online at: <https://patentimages.storage.googleapis.com/6f/7f/c2/bb86033b169aea/US6141797.pdf>
3. Critchley HD, Garfinkel SN, "Interactions Between Visceral Afferent Signaling and Stimulus Processing", *Frontiers in Neuroscience*, 9, 2015; DOI: 10.3389/fnins.2015.00286. Available online at: <https://www.frontiersin.org/articles/10.3389/fnins.2015.00286/full>.
4. Critchley HD, "ADIE to Prevent Development of Anxiety Disorders in Autism", ISRCTN14848787, 2017. <https://doi.org/10.1186/ISRCTN14848787>
5. Electronic Assembly, *DOGM GRAPHIC SERIES 128x64*, 3.3V, Datasheet Issue 10.2014. Available online at: <https://www.lcd-module.com/eng/pdf/grafik/dogm128e.pdf>.

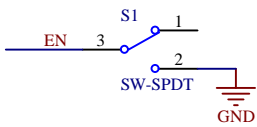
6. Electronic Assembly, *Arduino meets EA DOG-Graphic series with ST7565R controller*, unknown year of publication. Available online at: <https://www.lcd-module.com/support/application-note/arduino-meets-ea-dog.html>
7. Gray MA, Rylander K, Harrison NA, Wallin BG, Critchley HD, “Following One’s Heart: Cardiac Rhythms Gate Central Initiation of Sympathetic Reflexes”, *J. Neurosci*, 29(6), 1817–1825, 2009; DOI:10.1523/JNEUROSCI.3363-08.2009. Available online at: <http://www.jneurosci.org/content/29/6/1817>.
8. Gray MA, Rylander K, Harrison NA, Wallin BG, Critchley HD, “Cardiac Rhythms Gate Central Initiation of Sympathetic Reflexes”, *J Neurosci.*, 29(6), 1817–1825, 2009; doi:10.1523/JNEUROSCI.3363-08.2009
9. Gray MA, Beacher FD, Minati L, Nagai Y, Kemp AH, Harrison NA, Critchley H, “Emotional Appraisal Is Influenced by Cardiac Afferent Information”, *Emotion D.*, 2011; DOI: 10.1037/a0025083
10. Schaefer M, Egloff B, Gerlach AL, Witthöft M, “Improving heartbeat perception in patients with medically unexplained symptoms reduces symptom distress”, *Biol Psychol.*, 101, 69-76, 2014; DOI: 10.1016/j.biopsycho.2014.05.012.
11. Schiffer F, *Of Two Minds: The Revolutionary Science of Dual-Brain Psychology*, Free Press, 1998
12. Schiffer F, U.S. Patent No. 5,963,294, “Method for using therapeutic glasses for stimulating a change in the psychological state of a subject”, October 5, 1999. Available online at: <https://patentimages.storage.googleapis.com/2f/6c/60/8d6cedc5f07f36/US5963294.pdf>
13. Shapiro F, *Eye Movement Desensitization and Reprocessing (EMDR) Therapy, Third Edition: Basic Principles, Protocols, and Procedures*, The Guilford Press; Third Edition, 2017.

Appendices

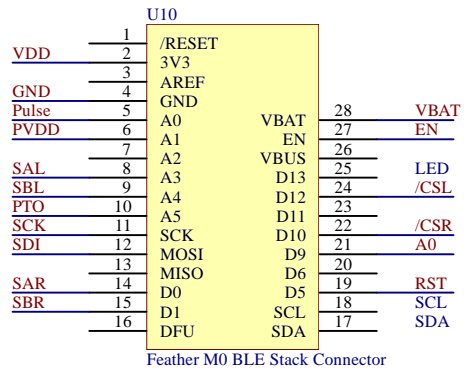
A. EmotiGlass Wearable Prototype Schematics



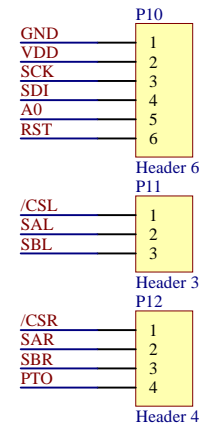
Pulse Sensor



JST Connector tail for Battery - Watch Polarity

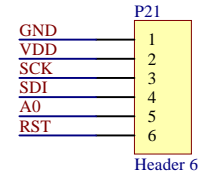
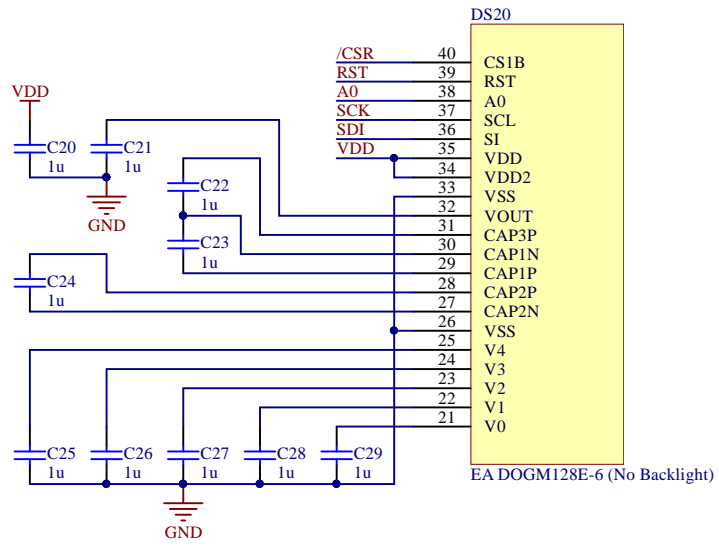
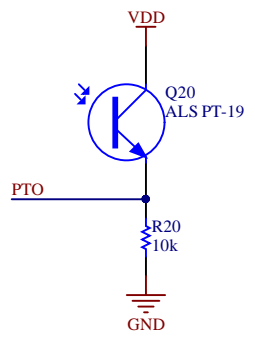
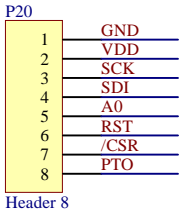


IO Assignment changes from Breadboard:
PVDD Moved
A1-4 Removed



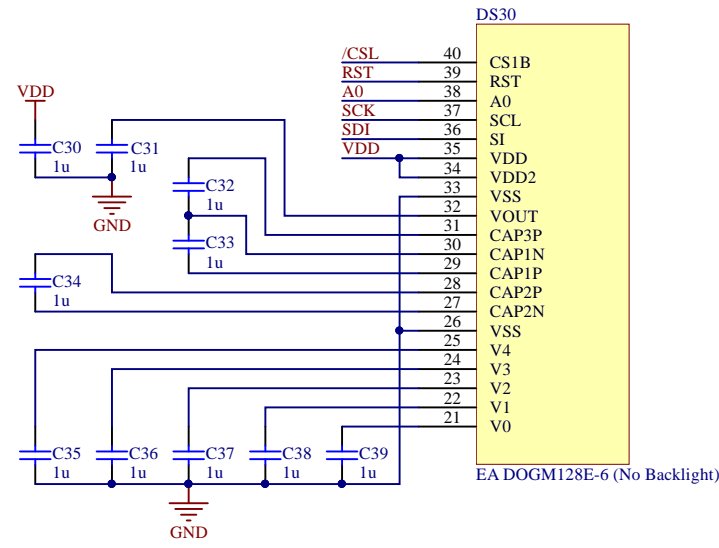
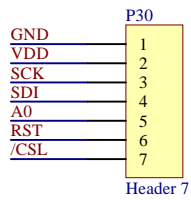
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Title: Right Side PCB	
Project: EmotiGlass Prototype	Rev: 1.1
Designed By: David Prutchi, Jason Meyers	Date: 20181007
File: right side.SchDoc	Size: A
	Sheet 1 of 4



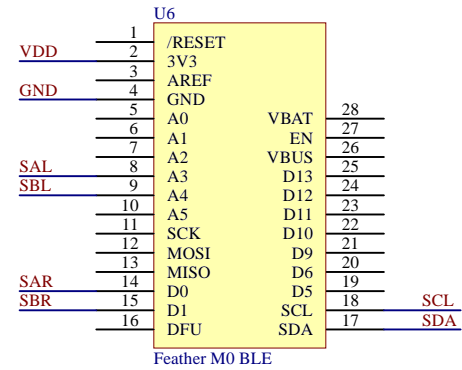
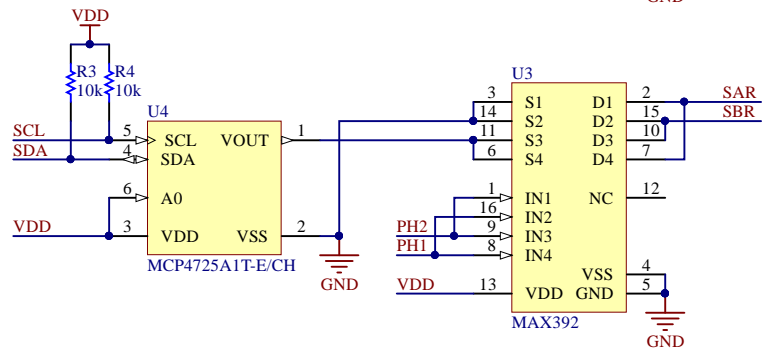
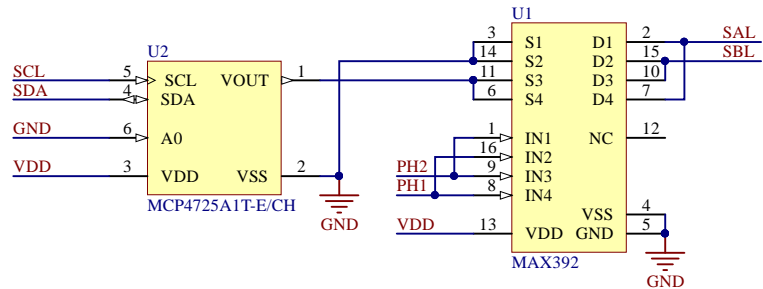
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Title: Right Front PCB	
Project: EmotiGlass Prototype	Rev: 1.1
Designed By: David Prutchi, Jason Meyers	Date: 20181007
File: right front.SchDoc	Size: A
	Sheet 2 of 4

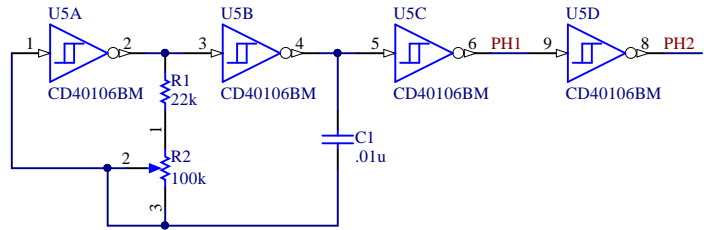


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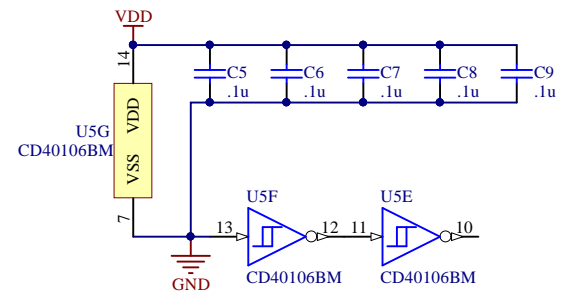
Title: Left Front PCB	
Project: EmotiGlass Prototype	Rev: 1.1
Designed By: David Prutchi, Jason Meyers	Date: 20180107
File: left front.SchDoc	Size: A
	Sheet 3 of 4



A3,A4,D0,D1 must be set as inputs when HW shutter drive is used



Liquid Crystal Shutter Drivers



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Title: Right Side Development PCB	
Project: EmotiGlass Prototype	Rev: 1.2
Designed By: David Prutchi, Jason Meyers	Date: 20181016
File: right side dev.SchDoc	Size: A
	Sheet 4 of 4

PCB Prints and Assembly Notes

Appendix B

EmotiGlass Prototype Revision 1.1
 Jason Meyers, David Prutchi 20181009

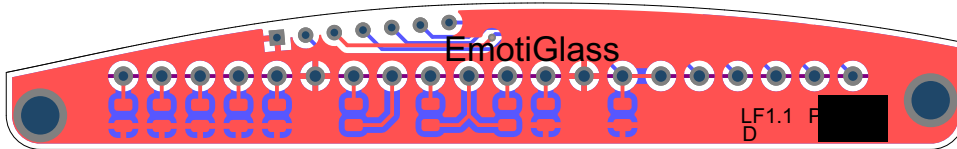
PCBs here are shown looking at outside of glasses (wearer is looking at you).
 Left and Right are as worn. Through hole components on top layer (red) unless noted.

Right Front

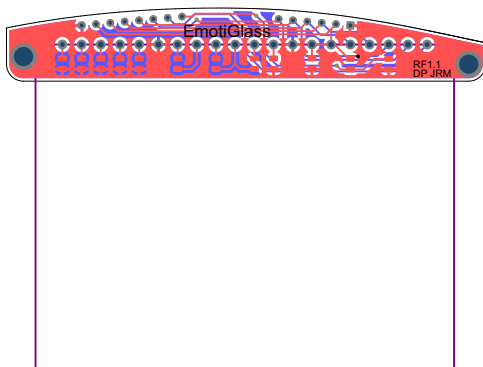


Q20 dot indicates collector. Unlabeled footprints are C20-C29.
 Display mounts to bottom.

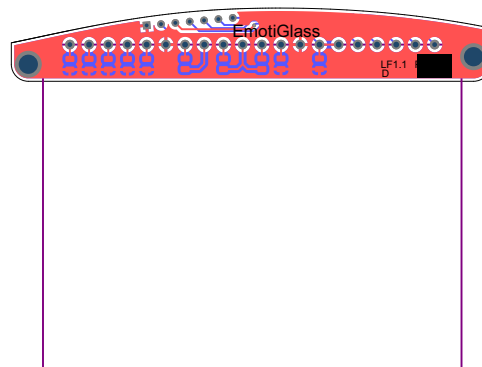
Left Front



Unlabeled footprints are C30-C39. Display mounts to bottom.

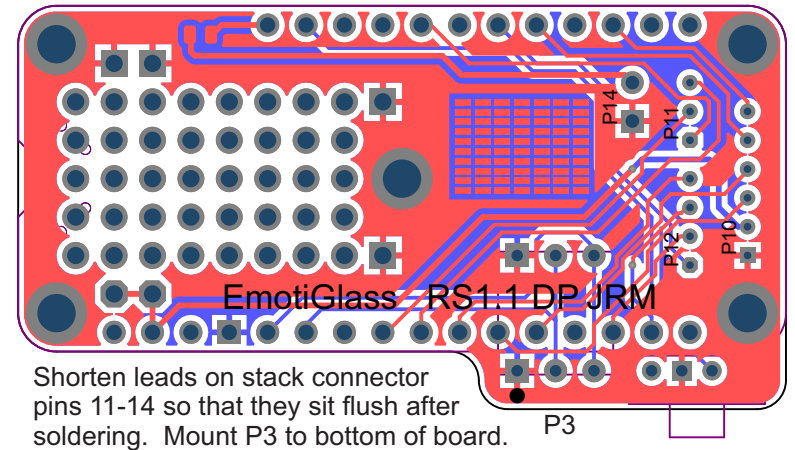


Right Front (Actual Size)



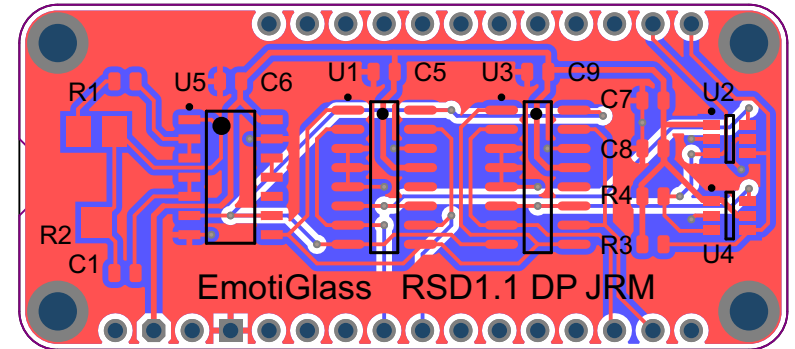
Left Front (Actual Size)

F30 Right Side

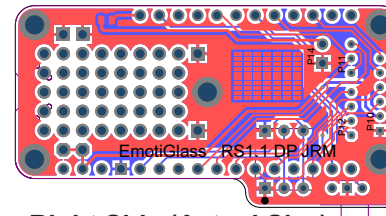


Shorten leads on stack connector pins 11-14 so that they sit flush after soldering. Mount P3 to bottom of board.

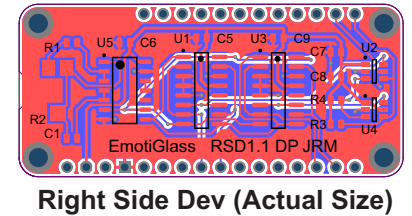
Right Side Dev



Install stack connector on bottom.



Right Side (Actual Size)



Right Side Dev (Actual Size)

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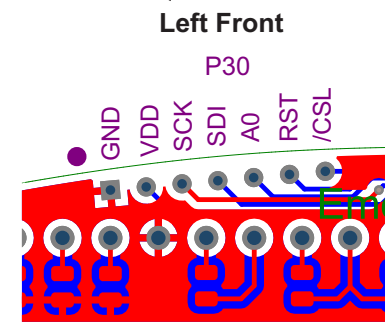
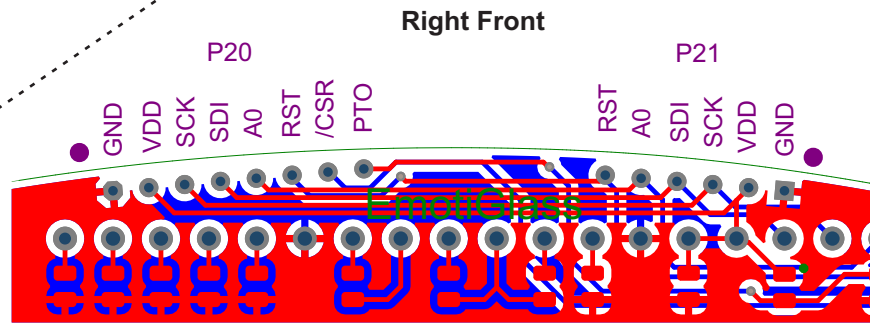
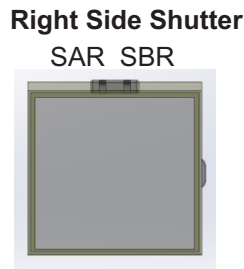
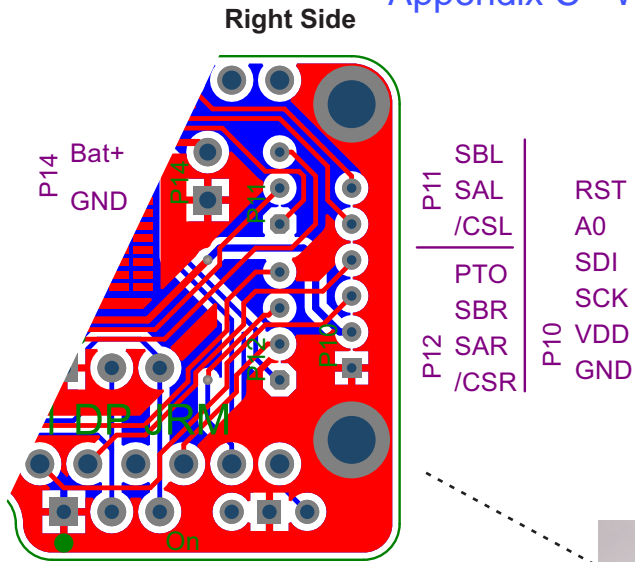
PCB Wire to Board Header Pinouts

EmotiGlass Prototype Revision 1.2
 Jason Meyers, David Prutchi 20181017

PCBs here are shown looking at outside of glasses (wearer is looking at you).
 Left and Right are as worn.

Wire wrap wire (30AWG) with kynar or teflon insulation is recommended
 for connections. Battery connections and ground wiring should either be
 doubled or use 26 AWG wire.

All signals are wired from the Right Side PCB directly to their corresponding
 header or attachment point, with the exception of pins 1-6 of P30 which are wired
 to P21. Battery pigtail ground should be wired to P14.



Appendix D

Emotiglass Bill of Materials

Revision 1.2 20181016

David Prutchi, Jason Meyers

Electronic Components

Standalone Components

Quantity		Comment	Value		MFGR	MFGR PN	Digikey PN
1		Feather M0 BLE			Adafruit	2995	1528-1562-ND
28 pos		Feather Stack Connector			Mill-Max	311-93-164-41-001000	ED1064-ND
2		LCD Shutter			Adafruit	3627	1528-2516-ND
1		Pulse Sensor			Pulsesensor.com	Pulsesensor	1568-1247-ND
1		Pulse Sensor Connector			Harwin	M20-1060300	952-2228-ND
1		Lipo Battery	350mAh		Adafruit	2750	1528-1858-ND
1		JST-PH male connector			JST	455-1704-ND	B2B-PH-K-S(LF)(SN)

Right Side PCB Assembly

Quantity	Designator	Comment	Value	Asm type	MFGR	MFGR PN	Digikey PN
1		Right Side PCB (unpopulated)					
1	F30	Fuse	375ma	SMD	AVX Corporation	F0603E0R37FSTR	478-2859-1-ND
1	S1	SW-SPDT	CSS-1210MC	TH	copal	CSS-1210MC	563-1090-ND
1	P13	Header 3		TH		M20-7890346	1528-1782-ND
28 pos	U10	Feather M0 BLE Stack Connector		TH	Mill-Max	801-93-064-10-002000	ED10964-64-ND
0	P10, P11, P12, P14	Header - direct wire		dnp			

Right Front PCB Assembly

Quantity	Designator	Comment	Value	Asm type	MFGR	MFGR PN	Digikey PN
1		Right Front PCB (unpopulated)					
10	C20, C21, C22, C23, C24, C25, C26, C27, C28, C29	C	1u	SMD	Murata	GRT188R61E105KE13D	490-12321-1-ND
1	R20	R	10k	SMD	Panasonic	ERJ-3EKF1002V	P10.0KHTR-ND
1	Q20	ALS PT-19	ALS PT-19	SMD	Everlight	ALS-PT19-315C/L177/TR8	1080-1244-1-ND
1	DS20	EA DOGM128E-6 (No Backlight)	EA DOGM128E-6	TH	EA	EA DOGM128E-6	1481-1065-ND
0	P20,P21	Header - direct wire		dnp			

Left Front PCB Assembly

Quantity	Designator	Comment	Value	Asm type	MFGR	MFGR PN	Digikey PN
1		Left Front PCB (unpopulated)					
10	C30, C31, C32, C33, C34, C35, C36, C37, C38, C39	C	1u	SMD	Murata	GRT188R61E105KE13D	490-12321-1-ND
1	DS30	EA DOGM128E-6 (No Backlight)	EA DOGM128E-6	TH	EA	EA DOGM128E-6	1481-1065-ND
0	P30	Header - direct wire		dnp			

Right Side Dev PCB Assembly

Quantity	Designator	Comment	Value	Asm type	MFGR	MFGR PN	Digikey PN
1		Right Side Dev PCB (unpopulated)					
1	C1	C	.01u	SMD	Murata	GRM188R71H103KA01D	490-1512-1-ND
5	C5, C6, C7, C8, C9	C	.1u	SMD	Murata	GRM188R71H104KA93D	490-1519-1-ND
1	R1	R	22k	SMD	Panasonic	ERJ-3EKF2202V	P22.0KHCT-ND
2	R3, R4	R	10k	SMD	Panasonic	ERJ-3EKF1002V	P10.0KHCT-ND
1	R2	RPot	100k	SMD	Copal	ST4ETB104	ST4ETB104CT-ND
2	U1, U3	MAX392	MAX392	SMD	Maxim	MAX392CSE+	MAX392CSE+-ND
2	U2, U4	MCP4725A0T-E/CH	MCP4725A1T-E/CH	SMD	Microchip	MCP4725A1T-E/CH	MCP4725A1T-E/CHCT-ND
1	U5	CD40106BM	CD40106BM	SMD	Texas Instruments	CD40106BM96	296-14081-1-ND
28 pos	U6	Feather M0 BLE Stack Connector			Mill-Max	350-10-164-00-001000	ED3864-64-ND

Mechanical Components

Quantity	Part	Mcmaster Part #	Substitute Option
10	Screw, 2-56x1/4"	91772A077	M2x6
2	Screw, 2-56x7/8"	91772A085	M2x22
2 pieces	Polycarbonate film, .01"	85585K103	

3D Printed Parts

Quantity	Part
1	Frame
1	Left Side
1	Right Side
1	Key
6	Spacer

Supplies

Quantity	Supply	Details
	Wire, 30 awg wire wrap	Red, black, and one other color
	Heatshrink tubing	1/16" and 1/4"
	Kapton Tape	1/4"

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Appendix E

EmotiGlass Build Instructions

Jason Meyers, David Prutchi

Revision: 1.0 20181017

Documents Referenced

- Bill of Materials Rev 1.2
 - Contains listing of all components needed to build one EmotiGlass prototype
- PCB Drawings and Assembly Notes Rev 1.1
 - Contains diagrams and notes needed to assemble the EmotiGlass PCBs
- Wiring Info 1.2
 - Contains pinouts needed to wire together all components of the EmotiGlass prototype

This document contains instructions to build an EmotiGlass wearable prototype. Photos of most steps are included. Please gather the documents referenced above before proceeding.

All files and documentation can be found at <https://hackaday.io/project/160615-emotiglass>

Steps

Collect and Prepare Components	2
Order electronic components	2
Order PCBs	2
Gather tools and supplies	3
Assemble PCBs	3
3D Print frame components.....	4
Install Firmware and GUI	5
Install Firmware	5
Install GUI.....	6
Wearable Prototype Assembly	7
Pre-assemble Frame.....	7
Prepare Front Displays.....	8
Complete front PCB assembly.....	9
Pre-wiring.....	9
Install components in frame	10
Wiring.....	11
Complete frame	13
PCB Stack assembly.....	13
Power on	14
Assemble Pulse Sensor.....	16
Complete EmotiGlass	17

Collect and Prepare Components



Order electronic components

All electronic components used are readily available from a number of retailers. For convenience, the BOM includes DigiKey part numbers – all components were in stock at the time of writing. Passive component values are not critical, so similar parts may be substituted.

Order PCBs

The PCBs were designed to be fabricated on a standard 1/16" (1.6mm) 2-layer process and were designed to meet typical design rules. They can be ordered from Osh Park or most other PCB fabricators. A zip file containing the Gerbers can be found on the project page. This file contains 4 zip files, each of which may be directly uploaded to the fabricator.

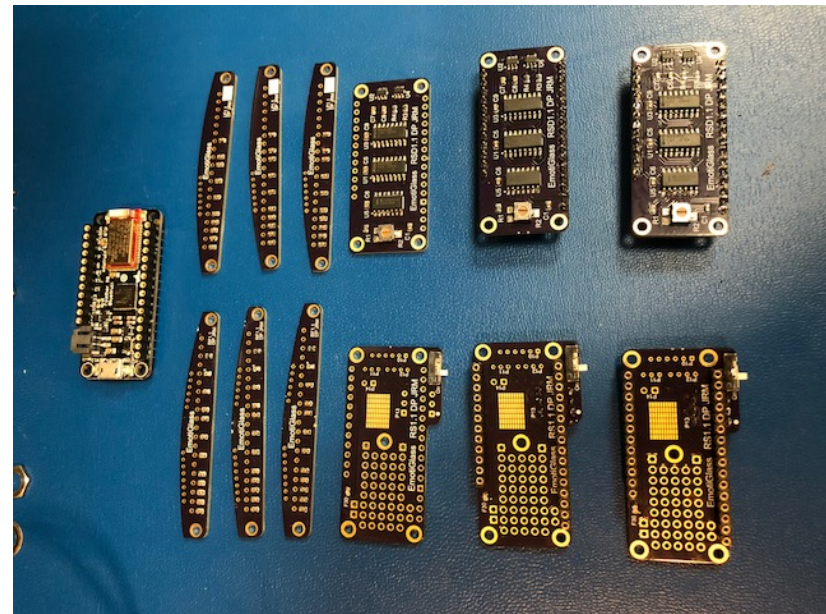
Gather tools and supplies

In addition to the components, some tools and supplies will be needed. These include:

- Safety Equipment
 - Safety glasses
- Supplies
 - Wire wrap wire (red, black, and one additional color preferably)
 - 30AWG with Kynar (PVDF) insulation is recommended (ex. DigiKey K394-ND)
 - Heatshrink – 1/16" for wires and (optional) 1/4" for
 - Kapton tape
 - Used to fix damaged wire insulation and for temporarily holding components
 - Hot Glue
- General assembly tools
 - Pliers,
 - Tweezers
 - Screwdrivers
 - Small Philips and flat head
 - Dental pick, wire director, or similar
 - Scissors
- Electronic assembly tools and supplies
 - Wire cutters and strippers
 - Soldering iron
 - Solder, flux, flux remover, solder wick
 - Solder paste (optional)
- 3D Print finishing tools
 - Xacto knife
 - Flush cutters
 - Sandpaper (180-320 grit works best)

Assemble PCBs

Refer to the "PCB Drawings and Assembly Notes" document for the details needed to assemble the PCBs. Components can be mounted using a standard soldering iron. If available, solder paste and a reflow oven may speed the process. The displays should not be mounted to the front left and front right PCBs until later in the process, but all other components should be installed. Photo below shows the assembled boards.



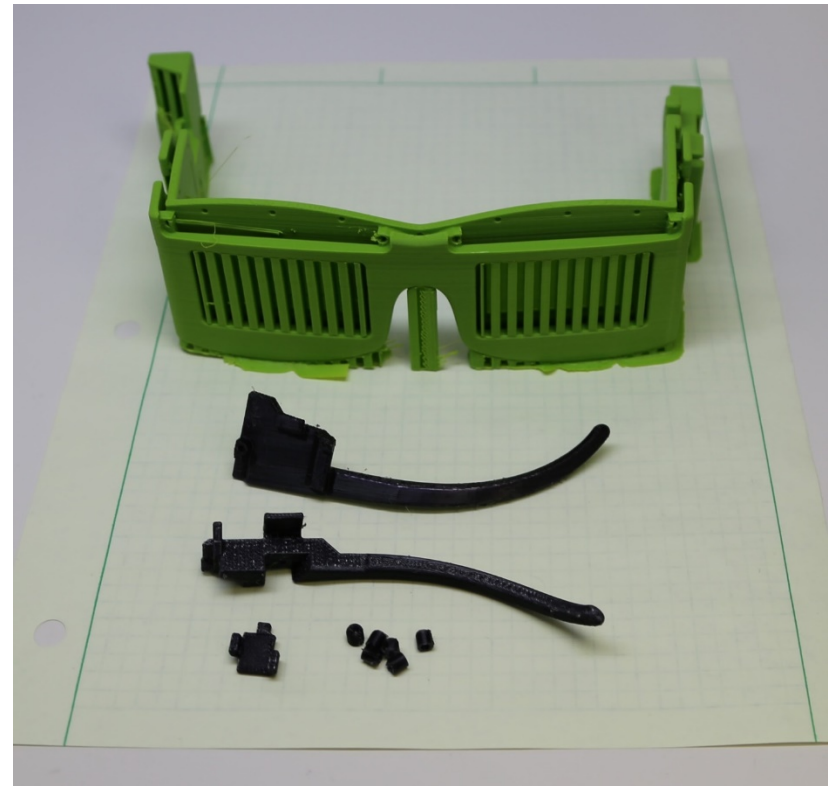
3D Print frame components

There are 5 unique 3D Printed parts in the EmotiGlass design. Most filament extrusion-type 3D printers with a common .4mm nozzle should be able to print these without issue.

The frame is the largest piece, and should be printed from a stiff material such as PLA so that it can protect the glass components. The prototype in the pictures was printed in green Ultimaker PLA on an Ultimaker 2+. It is necessary to print with support material, and we suggest using a .4mm nozzle so that the support material can reasonably be removed. The prototype shown used .15mm layers, which work well for this part, although .1mm will give slightly smoother curves if print time is not critical.

The two side pieces should be printed from a less stiff plastic. The prototype shown used Taulman 645 nylon printed by a Cetus MK2, using a .4mm nozzle and .15mm layers. Other nylons or comparable materials should also work. Note that nylon must be dried before use for good print results.

The key and spacers can be printed from any convenient material. The ones shown below were printed in the same batch as the side pieces. I suggest printing extra spacers as they are tiny and easily lost.



The next step is to remove support material, strings, and brims/rafts from the printed parts. All of the parts other than the frame will require minimal cleanup. The frame will have a rough surface on the bottom curves, which can be cleaned up with a knife and some sandpaper. It is critical to remove all support material from the display grooves to prevent assembly problems.



Install Firmware and GUI

In order to test and control the EmotiGlass prototype, the Adafruit Feather will need to have the firmware installed, and the GUI will need to be installed on a phone or tablet. The firmware must be installed on the Feather before final electronic assembly.

Install Firmware

Firmware for EmotiGlass is loaded via the Arduino IDE. Besides the standard libraries available to the Arduino v1.8.2 IDE, support libraries for the Adafruit Feather M0 Bluefruit LE need to be installed. Detailed instructions are available at: <https://cdn-learn.adafruit.com/downloads/pdf/adafruit-feather-m0-bluefruit-le.pdf>

The driver library for the LCDs also needs to be installed. Download and unzip the package from: <https://www.lcd-module.com/fileadmin/downloads/development%20service/Arduino/Arduino%20meets%20EA%20DOGM132-5%20DOGM128-6%20DOGL128-6.zip>. After that, follow the instructions available at: [Arduino meets EA DOGM132-5 DOGM128-6 DOGL128-6\Documentation\ReadMe.pdf](#).

After that, install the source files for EmotiGlass from <https://hackaday.io/project/160615-emotiglass> and compile/verify. Make sure that the board selected under the Arduino IDE's "Tools" is "Adafruit Feather M0." Select the serial port assigned to your board and upload the compiled firmware.

Install GUI

The GUI files may be downloaded from the project page. For Android only, a compiled application may be installed. For Android or iOS, the GUI may be installed via Evothings Studio

Android App Install

Open the file manager on any Android device that supports BLE and install the EmotiGlass.apk.

Evothings Studio PC Install

Evothings Studio 2.0 needs to be installed on a computer used if using an iOS device or developing the APP. Windows, Mac OS X and Linux installers are available for free at: <https://evothings.com/download/>. A starter guide is available at: <https://evothings.com/doc/starter-guides/evothings-studio-starter-guide.html>.

After installing Evothings Studio, a new project named “EmotiGlass” should be started, and the unzipped contents of EmotiGlassGUI.zip copied into the project’s directory.

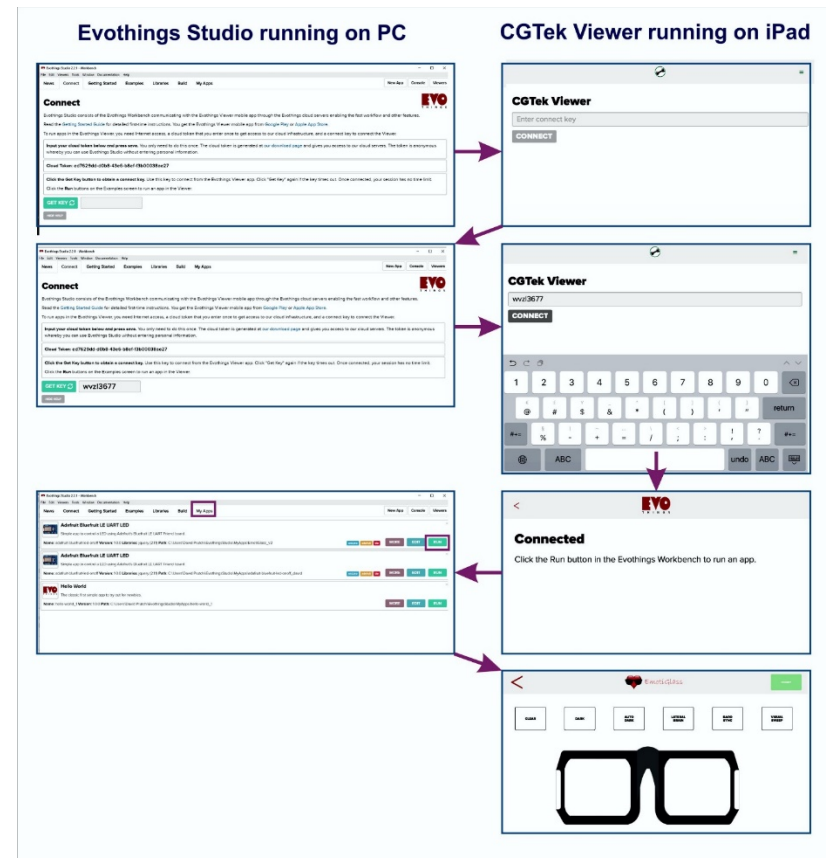
Evothings Studio and the Evothings player then need to be connected. This is done by getting a key and sharing it with the app as shown in the following imade. The BLE-enabled device running the client should be able to control EmotiGlass without any further setup.

Evothings Studio iOS Install

Install the free CGTek Viewer app from the App Store, and load the GUI through Evothings Studio.

Evothings Studio Android Install

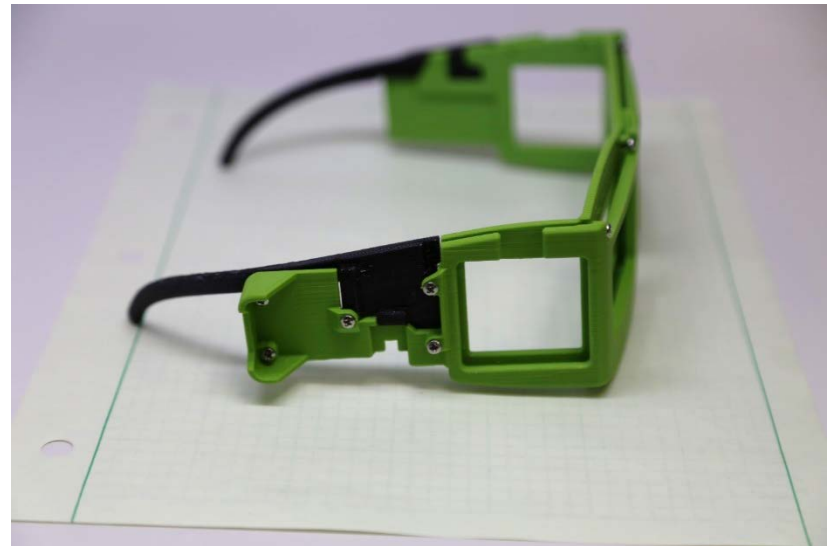
Download and install Evothings Viewer from the Google Store



Wearable Prototype Assembly

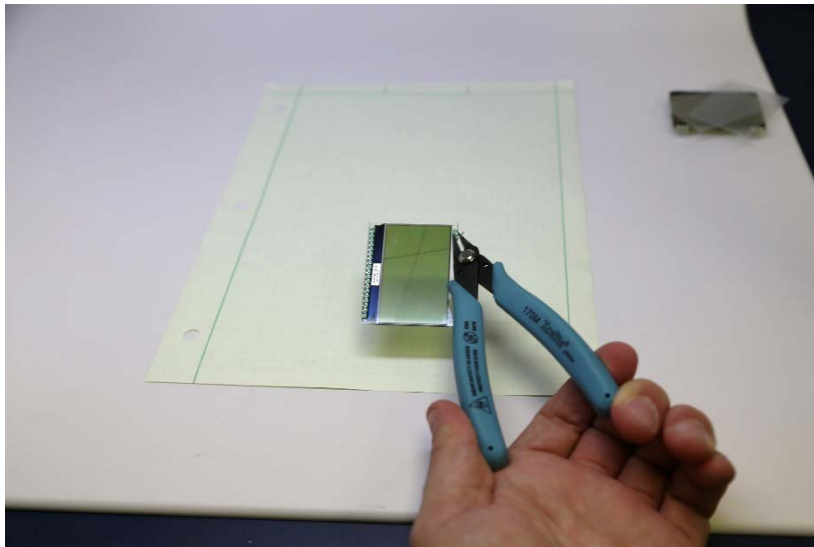
Pre-assembly Frame

After the 3D printed parts have been finished, the threads need to be cut for the screws, which should be done before any electronics are installed. In these parts, it is sufficient to simply let the screws cut their own threads when initially installing them. Unless specified, use either #2-56x1/4" or M2x6 screws. Be careful to keep the screws straight during the initial installation. This is also a good time to check the fit of the side pieces into the frame. After this is complete, remove all screws.

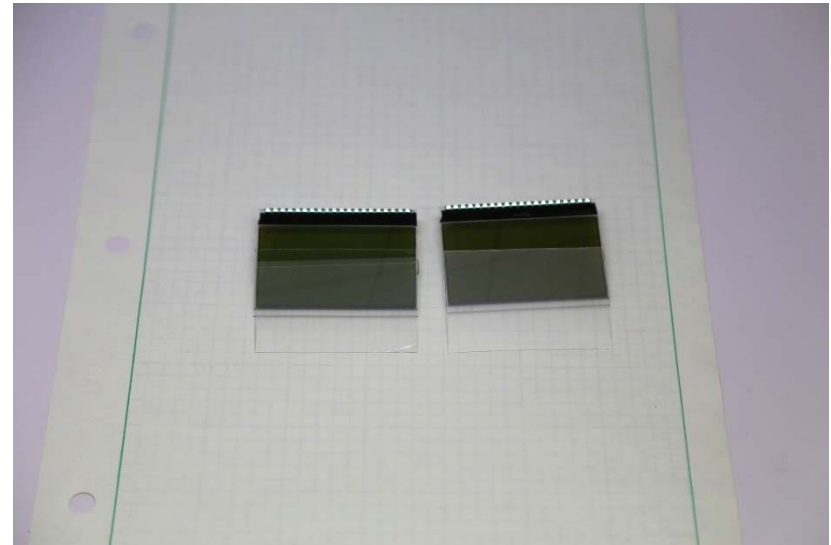


Prepare Front Displays

Some of the pins on the LCD Displays need to be removed (pins 1-3 and 18-20). These pins were installed by the manufacturer by crimping them onto the base glass and then putting some potting compound over them. To remove, they can be bent away from the display and then any excess potting compound can be scraped off. A wire cutter can be used for this. One of the cutting edges is inserted under edge of the metal pin, and the cutter is closed only enough to keep it in place as the cutter is rotated to bend the pin away from the glass. Be careful!



After the displays have had the bottom pins removed, cut pieces of polycarbonate film to match the size of these displays. Also cut pieces to match the side LCD shutters (not shown in photo). This film is intended to provide extra protection to the wearer in case the displays are somehow broken while the device is being worn.



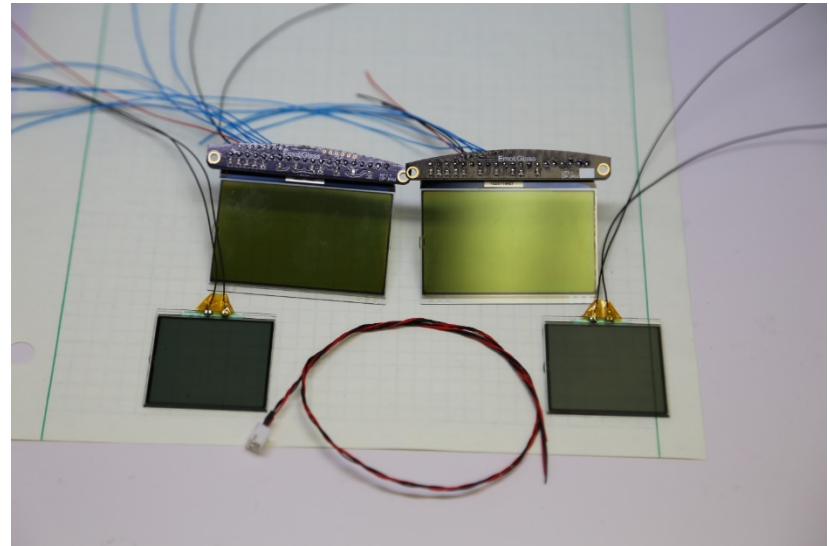
Complete front PCB assembly

Next, install the displays and the polycarbonate film into the frame. The film should be on the inside (wearer side) of the displays. The front PCBs can then be installed and screwed into place. Once the front PCBs are secured, the display can be soldered into the board. The spacing between the PCB and display is critical, so it must be assembled in place. Once the displays are soldered to the PCBs, remove the complete assemblies from the frame.



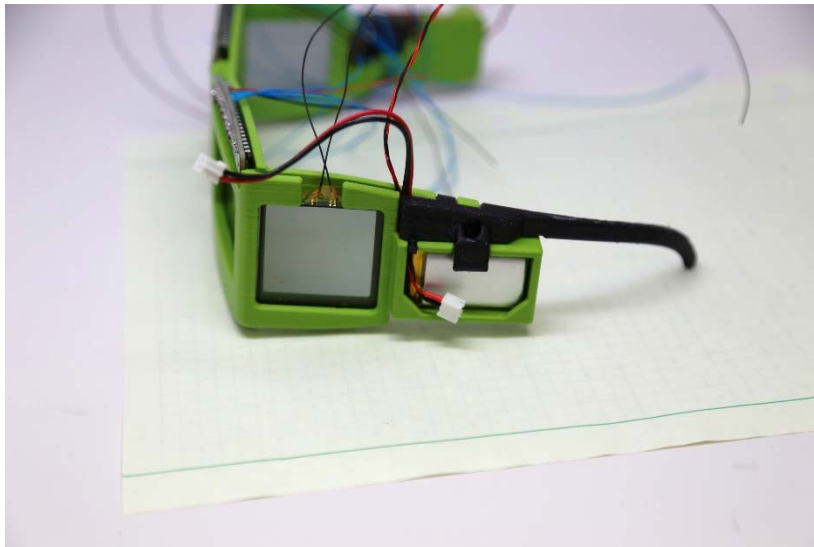
Pre-wiring

Next, attach wires to the side shutters and to the headers which send wires towards the right side (P20 and P30). The wires should exit the rear of the PCBs as shown. Be sure that the insulation comes close enough to the boards to prevent shorts. You may want to put some Kapton tape on the connections for the side shutters. The battery pigtail can also be assembled at this time by attaching wires to the male JST connector. Be sure to leave a lot of extra length on the wires. The battery connections and board to board ground connections should be doubled or use thicker wire. The battery pigtail should be twisted together.



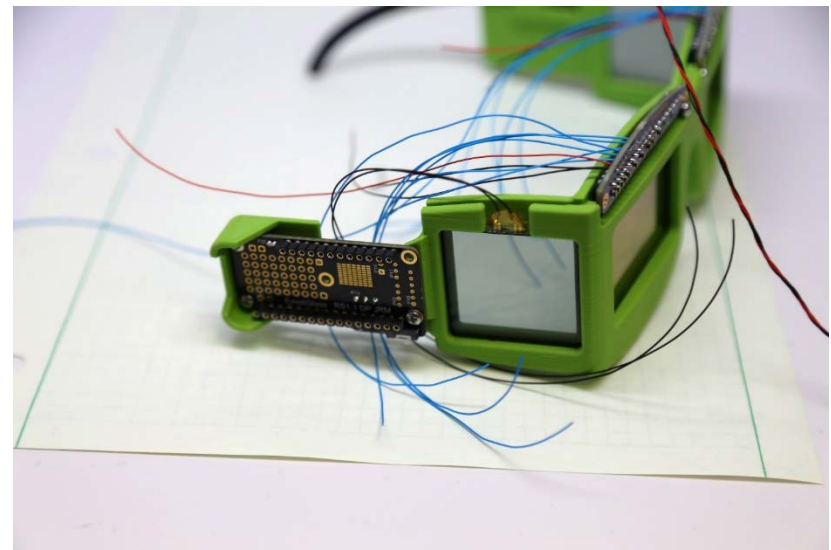
Install components in frame

The battery should be installed with the lead proceeding up the channel provided in the frame. Install the left side piece, being careful not to pinch the battery wire. The pigtail can also be routed down this channel to place the connection point in front of the battery. Do not plug in the battery yet. (Note: the frame was designed for the battery to be hard wired, but we are leaving it connectorized until thorough testing is complete so we can easily unplug it if we have any issues.)

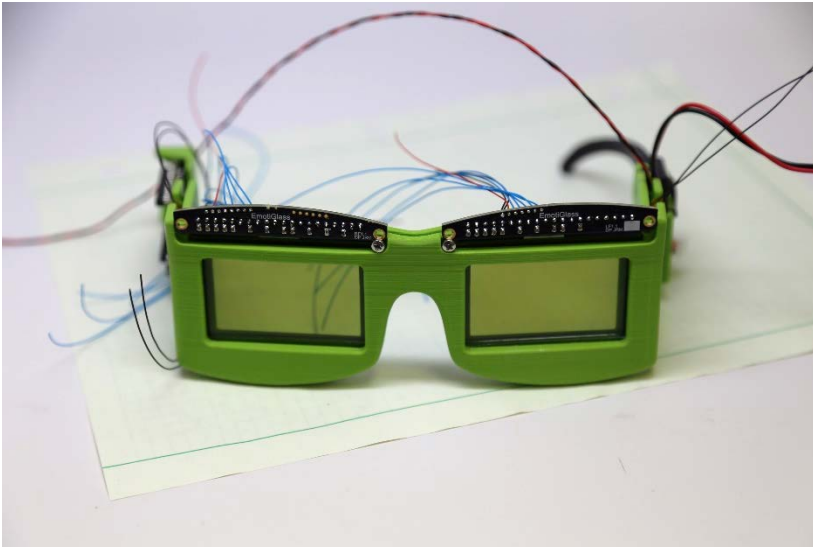


The side shutters now can be installed. The protective film on the shutters and on the polycarbonate film will need to be removed before they are installed. Be sure to clean the faces of the shutter and film that touch each other as they will not be accessible after assembly. It is helpful to use a screwdriver to pull the edge of the frame locking tabs forward slightly during the installation.

The right side PCB can also be installed. It should be installed with 3 screws as shown. Once wiring begins, this PCB should not ever be removed from the frame. The frame provides access for wiring when the right side piece is not installed.

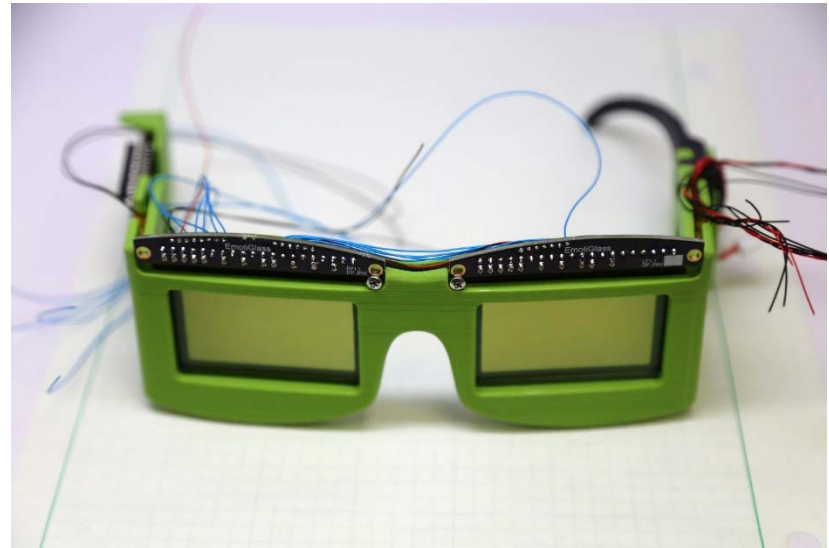


The front displays should be installed, but should remain slightly above their nominal positions. They can be rested on a screw placed in one of the mounting holes (this can be tightened to hold these PCBs in place if needed)

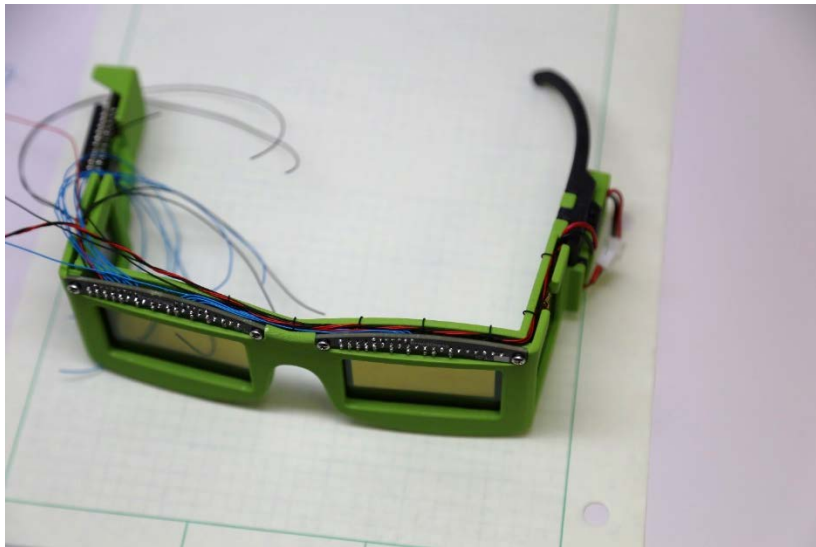


Wiring

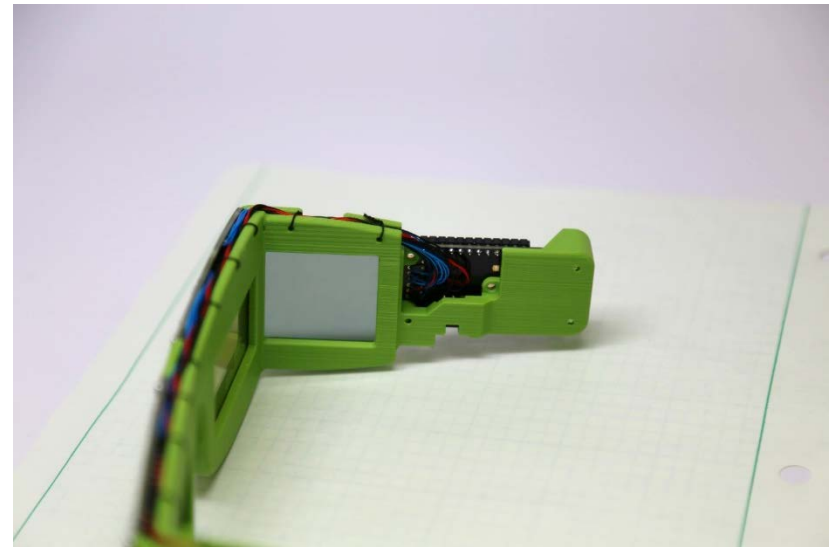
Begin wiring by making the connections between the two front PCBs. Reference the wiring info diagram for connection info.



Once these connections are complete, the front PCBs may be dropped into their final positions and secured with their mounting screws. Next, dressing of the wires can begin. A number of holes are provided through which a tie can be installed. The prototype used offcuts of wire wrap wire for the ties, but thread of twine would probably work even better. Starting from the end with the battery, dress the wires into the groove and secure. A tool such as a wire director or dental pick or similar (a bent tiny screwdriver could also work) is extremely helpful for manipulating the wires. We suggest not tying around all wires, but rather letting some wires remain below the tied bundle and only tying around the battery lead and a few additional wires as needed.

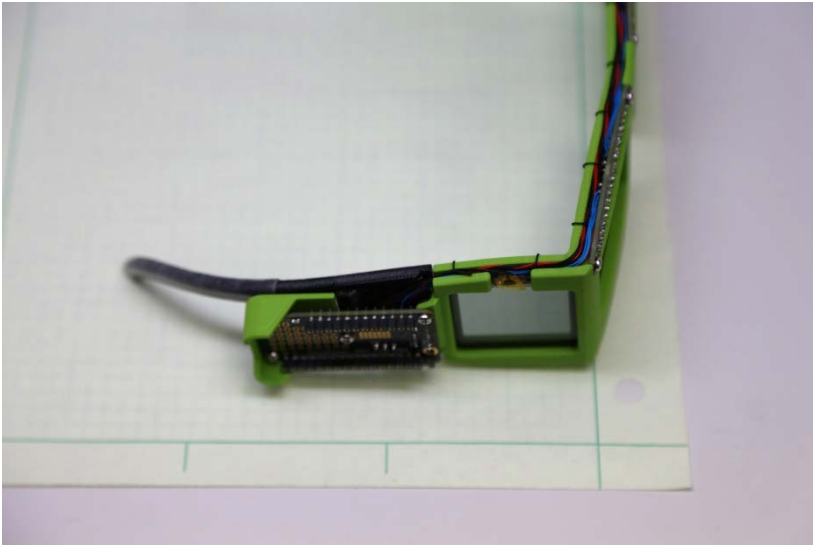


Finish the wiring by trimming all of the wires and soldering them into the headers in the right side PCB. After that, finish dressing the wires.



Complete frame

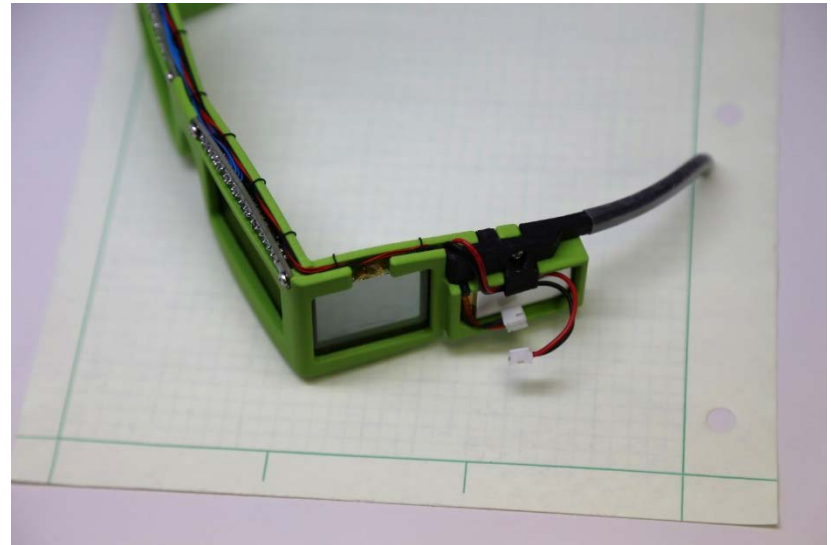
Next, the right side piece can be installed. Be careful not to pinch any wires. The right side piece is secured by two screws. After installing the side piece, remove the screws in the top left and bottom right positions.



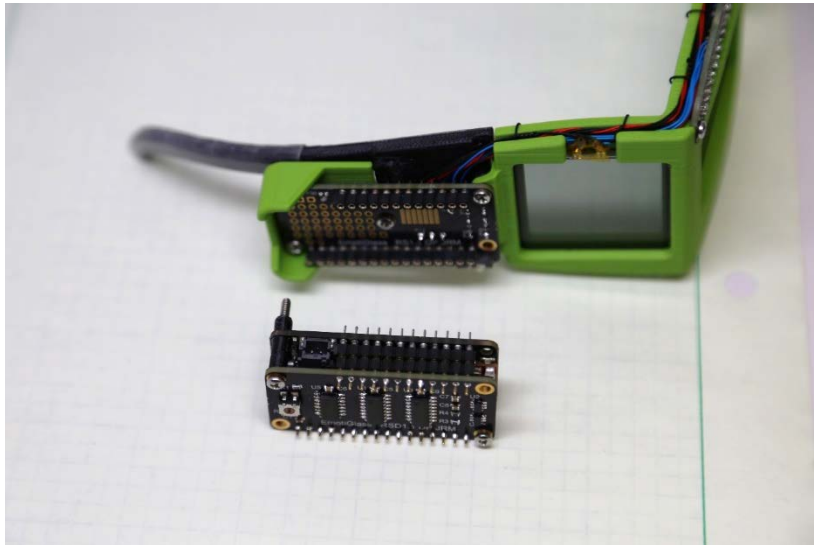
PCB Stack assembly

Before proceeding ensure that:

1. The Feather has been flashed with EmotiGlass firmware
2. The battery is still unplugged

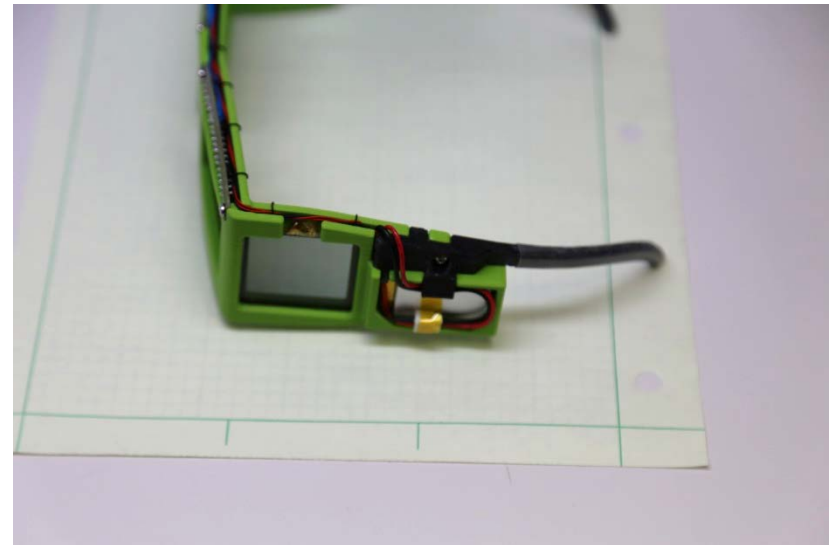


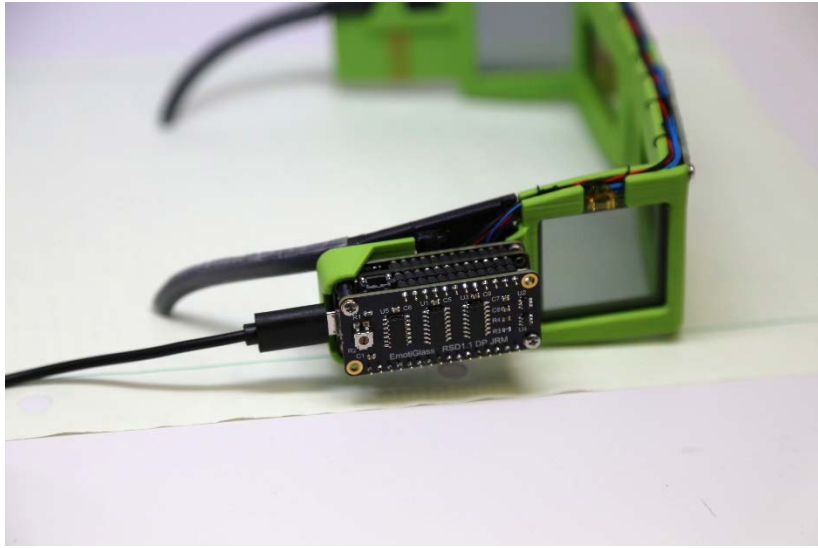
The Right Side Dev PCB stacks onto the Feather, which stacks onto the Right Side PCB. Initially, these can be plugged together for testing. Once complete, 2 #2-56x7/8" secure the stack. 2 of the 3D printed spacers go between the top two boards, and 1 goes between the lower two boards (on each screw).



Power on

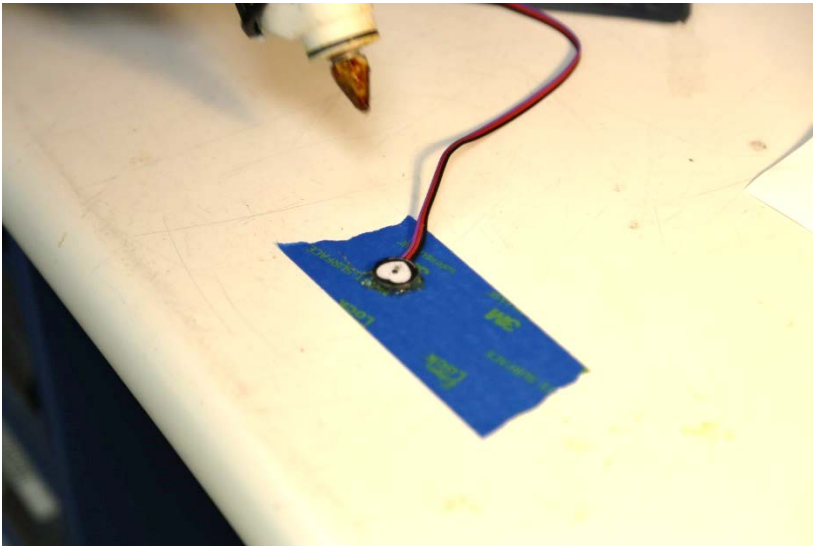
Before powering on, measure the resistance between the two terminals of the battery connector to ensure there is no short. EmotiGlass can be powered via a USB connection or from the battery (USB power will charge the battery when both are connected). If a current-limited power supply is available, it is best to initially power the device from that. This is a good point to test basic functionality (connect the GUI via Bluetooth and click 'Dark' and 'Clear'). The battery connector can be held to the battery with a piece of tape as shown.



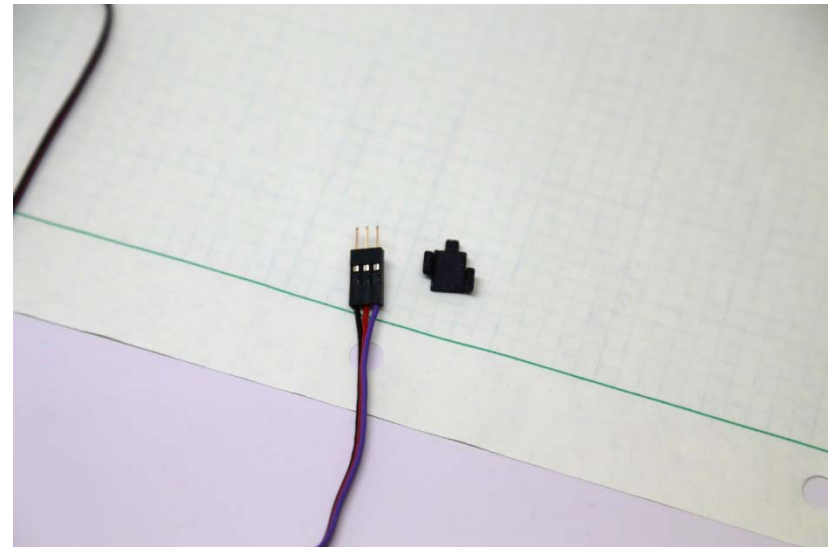


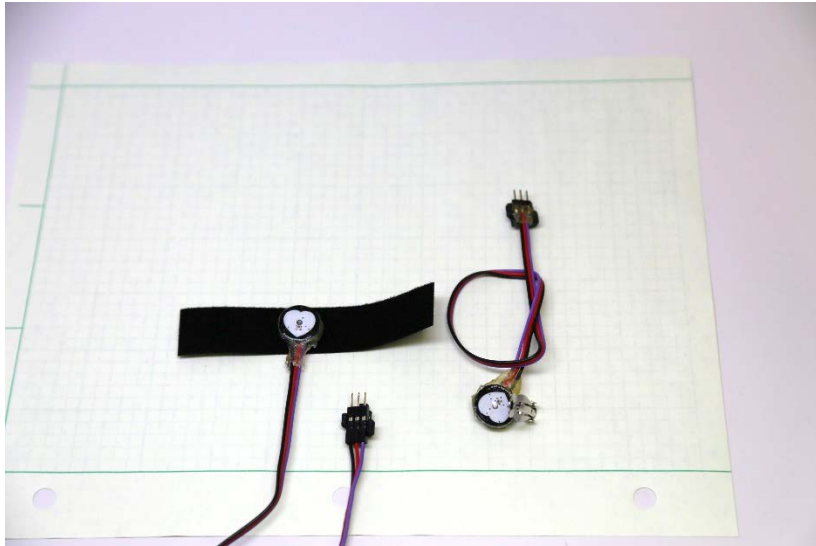
Assemble Pulse Sensor

EmotiGlass uses an open-source plethysmography sensor from pulsesensor.com (see site for more information). This sensor can be hot glued to an ear clip, Velcro finger strap, or other mounting arrangement. Following the suggestions of the manufacturer, the sensor is encapsulated in hot glue as part of the mounting.



Lastly, a 3D printed key is added to the connector to prevent the sensor from being inserted backwards, which may damage the circuitry. Remove the three single pin connector housings, and replace with the 3 position connector housing (pins in same order as cable, black is pin 1). Then, with pin 1 (black) to the left, glue the key piece underneath the connector (see photos). The front face of the key should sit flush or slightly behind the front of the connector housing. If you desire to trim the cable and don't have the crimp on pins available, the wire can be soldered to 3 positions of a standard header strip, which can then be glued to the key. Both options are shown in following photos.





Complete EmotiGlass

Plug the pulse sensor in and the EmotiGlass wearable prototype build is complete.

