Investigating Hemodynamic Responses to Color Stimuli Using an Open-Source fNIRS Headset

Abstract

This research investigates the potential of open-source functional Near-Infrared Spectroscopy (fNIRS) systems for neuroimaging applications. Leveraging advancements in low-cost, open-hardware devices, the study focuses on classifying hemodynamic responses to visual stimuli and breathing exercises. Two devices, HEGduinoV2 and DIY-fNIRS (NIRDuino), were reviewed based on accessibility, support, and technical capabilities. While the HEGduinoV2 was excluded due to lack of support, the DIY-fNIRS system and its updated version, NIRDuino, were selected for further development.

Experimental protocols were designed to classify neural responses to RGB color stimuli and validate system performance through breath-holding exercises. These protocols were informed by existing studies and adapted for compatibility with open hardware. Additionally, a classification pipeline was developed and tested on a mental arithmetic dataset, enabling integration with EZKL, a zero-knowledge proof system, to verify that classification was conducted with the specified model.

To facilitate manufacturing, components for NIRDuino PCBs were ordered, with remaining parts awaiting lead time confirmation. Collaboration with the system designers provided updated manufacturing files, with final assembly instructions forthcoming.

The literature reviewed demonstrates the practicality of open-source fNIRS devices for neuroimaging, providing a cost-effective alternative for studying neural activity. Future work will focus on assembling the device, collecting data, and validating system performance in classifying hemoglobin changes in response to stimuli. The findings aim to advance accessibility and reliability in neuroimaging research.

Intro

This research project leverages the updated version of the DIY-fNIRS system, a low-cost, open-hardware functional Near-Infrared Spectroscopy (fNIRS) headset, to investigate changes in hemoglobin absorption in the brain as participants view various visual stimuli—specifically, colors displayed on a screen. Following a formal collaboration with the designers of the original DIY-fNIRS system, updated manufacturing files and guidance for the latest system, NIRDuino, were obtained. This advanced version addresses prior inconsistencies in the programming and assembly process, ensuring improved functionality and reliability. By adapting this refined device and established fNIRS methodologies, the study will analyze hemodynamic responses to visual color stimuli and breathing exercises. The project aims to validate the performance of the updated DIY-fNIRS system in detecting neural activity associated with visual perception and assess its capabilities in decoding complex cognitive tasks.

Context

Functional Near-Infrared Spectroscopy (fNIRS) is a non-invasive neuroimaging technique that measures cerebral hemodynamic responses associated with neural activity. Traditional fNIRS systems are often expensive and inaccessible to many researchers. Open-source hardware presents an opportunity to democratize access to neuroimaging tools. This project aims to leverage open-source fNIRS technology to explore brain activation in response to visual color stimuli and breathing exercises.

Device Analysis and Selection: Review and select open-source fNIRS hardware

To identify fNIRS devices suitable for studying individuals' responses to different colors, search was conducted using Google, Google Scholar, and GitHub. The selection criteria emphasized devices with accessible hardware manufacturing files, facilitating potential hardware procurement. Upon identifying a suitable device, additional studies referencing it were located using Google Scholar. This approach led to the discovery of the OpenFNIRS website, a platform that curates open hardware fNIRS initiatives.

Table 1 provides an overview of the devices, evaluated across four dimensions: pricing, portability, complexity, and licensing. A detailed description of each device is presented below. Two devices were selected for characterization - the HEGduinoV2 and the DIY-fNIRS, due to the low complexity of assembly for the former, and the support offered by the designers for the latter.

Name	Pricing	Portability	Complexity	Licensing
HEGduino V2	100	High	Low	MIT license

DIY-fNIRS / NIRDuino	200 / 150	High	Medium	CC0 1.0 Universal
NinjaNIRS 2022	2000+	Low	High	Not stated, will inquire
OpenNIRS 2015	800+	Medium	Medium	CC BY-NC 4.0

HEGduino V2:

The HEGduino v2 utilizes the MAX86141 pulse oximeter ADC, offering dual-channel simultaneous sensing at up to 4096 samples per second with 19-bit resolution. Its sensing array consists of two high-sensitivity BPW34S photodiodes paired with two infrared LEDs (~950 nm) and one red LED (~650 nm), enabling functional near-infrared spectroscopy (fNIRS) and hemoencephalography (HEG) measurements. Hardware features include ambient light cancellation, error detection, and integrated IIR filters to reduce noise and enhance signal quality. The device allows for configurable LED routines, power settings, and sampling rates to adapt to various applications.

The system is powered by an ESP32 microcontroller, which features a 32-bit dual-core processor running at 240 MHz, 4 MB of onboard memory, and connectivity options including Wi-Fi, Bluetooth/BLE, and USB. Its firmware, developed with Arduino and Espressif IDE compatibility, supports real-time updates and is designed to enable straightforward customization for diverse experimental needs.

The HEGduino v2 is designed as a modular system, with components that can be detached from its wearable headset for reconfiguration or replacement. In addition to monitoring cerebral blood flow, the device supports additional biofeedback capabilities, including heart rate variability, breathing patterns, and skin temperature. Its software interface is built on a cross-platform HTML5/CSS/JS framework, enabling use across devices without the need for dedicated installations.

This version incorporates improvements in sensing resolution and sampling rates compared to earlier iterations and offers enhanced flexibility through its modular design and open-source development model. These features make it suitable for a wide range of research and biofeedback applications, with potential for integration into larger brain-computer interface systems.

Published work with HEGduino V2

Two studies have been identified where the HEGduinoV2 device was reportedly used.

In “**Validating the reproducibility of a low-cost single-channel fNIRS device across hierarchical cognitive tasks**”, the HEGduino v2 was utilized as a single-channel functional near-infrared spectroscopy (fNIRS) device to monitor prefrontal cortex activity during cognitive tasks of varying complexity. Optodes were placed over the dorsolateral prefrontal cortex (dlPFC) to capture hemodynamic changes related to motor control, working memory, and creative thinking.

Participants completed three tasks: a motor task (finger-tapping), a working memory task (n-back), and a creativity task (Alternate Uses Test, AUT). Data were recorded to assess cerebral blood flow changes, with additional processing for motion artifact correction, bandpass filtering, and signal-to-noise ratio (SNR) evaluation. The results revealed distinct patterns of dlPFC activation correlating with task complexity, including increased activity during the AUT compared to rest and significant differentiation between 1-back and 2-back task conditions. These findings aligned with known hemodynamic responses, demonstrating the device's effectiveness for task-specific prefrontal cortex monitoring and validating its potential as a cost-effective tool for cognitive neuroscience research.

In the study “**Evaluation of a low-cost portable NIRS device for monitoring muscle ischemia**” the HEGduino was employed to detect tissue oxygen saturation changes during a vascular occlusion test in 19 healthy participants. Measurements were taken from the forearm, focusing on hemodynamic changes caused by blood flow interruption and subsequent reperfusion. The device used LEDs emitting red (650 nm) and infrared (950 nm) light, with a photodiode placed 3 cm apart to balance sensitivity to deeper tissue signals and minimize superficial interference.

The study followed a three-phase protocol: baseline measurements, ischemia induced via sphygmomanometer cuff inflation for 3 minutes, and reperfusion post-cuff release. Signals from the red and infrared LEDs represented changes in deoxygenated hemoglobin (HHb) and oxygenated hemoglobin ($HbO2$), respectively. The data were normalized to each participant’s baseline, enabling comparisons across phases. Results showed characteristic hemodynamic responses, with the red signal decreasing during ischemia and sharply increasing during reperfusion, while the infrared signal displayed the inverse pattern. Statistical analysis confirmed significant differences between baseline and minimum signal values for both wavelengths (red: $p < 0.014$; infrared: $p < 0.001$).

The study also evaluated potential noise contributors, including ambient light and motion artifacts. Ambient light showed minimal correlation with signal variation, as indicated by low R-squared values (red: 0.08; infrared: 0.105). Motion artifacts and acceleration similarly had negligible effects, suggesting robust signal integrity under experimental conditions. These findings underscore the HEGduino’s capacity to reliably monitor physiological changes in muscle oxygenation during ischemia-reperfusion.

This study provided evidence for the HEGduino’s utility in NIRS monitoring for muscle oxygen saturation research.

DIY-fNIRS

The DIY functional near-infrared spectroscopy (fNIRS) device is a low-cost, wearable neuroimaging system developed to facilitate accessible and portable functional neuroimaging. The system employs a dual-wavelength light source at 740 nm and 850 nm and a set of four silicon photodiode detectors spaced at 5 mm, 10 mm, 23 mm, and 28 mm from the source. This layout enables both shallow and deeper cortical imaging, supporting the correction of superficial physiological noise through short-channel subtraction.

The device's control system is built around multiple microcontrollers, including a Texas Instruments MSP430F5438A for data acquisition, MSP430FG6626 for LED intensity control, and MSP430F2001 for timing and synchronization. The system employs a 12-bit successive-approximation-register (SAR) analog-to-digital converter (ADC) for precise signal capture, while wireless data transmission is facilitated by a Bluetooth 2.1 module. The hardware design enables a modular structure, allowing for scalability to multi-channel configurations and integration with additional sensors.

To reduce external interference, the sensors are encased in a silicone polymer mold designed to block ambient light and provide a stable optode-skin interface. The headband's cloth and Velcro enclosure further enhances comfort and usability, ensuring secure placement during data acquisition. The device broadcasts data at a sampling rate of 10 Hz, powered by a rechargeable 400 mAh lithium-polymer battery, with a continuous runtime of up to 5 hours.

Published work with DIY-fNIRS

The paper in which the device was presented also included a validation study (Tsow, Kumar, Hosseini & Bowden, 2021). Their fNIRS device is designed for cost-effective neuroimaging in naturalistic settings. Researchers assessed its performance through breath-holding and arithmetic tasks, as well as resting-state measurements.

During a breath-holding test, a participant alternated between 30 seconds of normal breathing and 20 seconds of breath-holding over 10 cycles. The data showed characteristic decreases in oxyhemoglobin concentrations during breath-holding and recovery upon resuming normal breathing. Longer source-detector separations captured cortical signals, while shorter separations reflected superficial activity, facilitating artifact correction. In an arithmetic task involving 20 cycles of relaxation and problem-solving, oxyhemoglobin concentrations increased during problem-solving, consistent with cognitive load studies. Short-channel correction, achieved by subtracting signals from the shortest detector from the longest, effectively reduced motion artifacts and non-cortical noise.

Resting-state measurements conducted over 10 and 30 minutes demonstrated stable hemodynamic signals with minimal drift. The system's design allowed real-time data acquisition at 10 Hz with wireless transmission via Android and MATLAB applications.

The results confirmed the device's ability to reliably measure cortical activity during physiological and cognitive tasks, matching established patterns in commercial systems. Its artifact resistance and consistent performance highlight its potential as a cost-effective tool for neuroimaging in diverse research environments. Future developments will aim to enhance multi-channel configurations and refine artifact correction methods.

Methodology Development: Conduct literature reviews and create experimental protocols.

To create an experimental protocol for decoding perceived colors, studies investigating the decoding of visual imagery from fNIRS data were researched.

Three studies where visual imagery was decoded fNIRS devices were selected.

First study description

Study Description

A study by Nissen (2020) examined the neural and emotional impact of blue-colored ecommerce websites using functional near-infrared spectroscopy (fNIRS). Twenty-four participants (75% male, mean age 26.33) viewed websites in four color schemes (blue, green, orange, and black). Neural activity in the prefrontal cortex (PFC) was recorded to explore blue's role in cognitive and emotional processing, hypothesizing reduced cognitive effort and enhanced positive emotional responses to blue.

Experimental Structure

- **Stimuli**: Participants viewed each website for 4 seconds, with a 2-second question prompt and a fixation cross.
- **Ratings**: Simplicity, Diversity, Colorfulness, and Purchase Intention were rated on a 5-point Likert scale.
- **fNIRS Setup**: The NIRSport device recorded oxygenated and deoxygenated hemoglobin changes in the PFC.

Data Collection and Analysis

- **Preprocessing**: Bandpass filtering (0.01–0.2 Hz), short-separation regression, and hemoglobin value calculations were applied.
- **Statistical Analysis**: ANOVA and t-tests (FDR-corrected) identified neural activity differences between colors.

Results

- Blue websites were rated significantly higher in Simplicity, Diversity, and Colorfulness compared to orange.
- Neural activity showed:

    - **Increased activation** in areas processing pleasant stimuli (dlPFC).
    - **Decreased activation** in regions linked to cognitive effort and negative emotional processing (dmPFC, vmPFC).

Findings

Blue websites reduced cognitive effort and evoked positive emotional responses, supporting their preference in ecommerce. These findings highlight blue's effectiveness in enhancing trust and aesthetic appeal, though further studies are needed to validate results in interactive settings.

Second Study Description

A study by Shi, Tu, Wang, Zhu & Zhang (2022) investigated the impact of color saturation on visual discomfort, using both subjective questionnaires and objective fNIRS measurements of cortical hemodynamic response. The OctaMon+ device was used, collecting data from participants (N=16, 10 males and 6 females, mean age 24.69) that viewed three high-saturation images (Parrot, People, Flower) displayed at three saturation levels—low (0.13 of NTSC), mid (0.73 of NTSC), and high (0.92 of NTSC). Images were calibrated for consistent luminance, and participants rated image quality, visual comfort, and preference on a 5-point scale. Visual stimuli were presented for 16 seconds in objective trials (to measure hemodynamic response) and 5 seconds in subjective trials (for questionnaire responses), with randomized order and sufficient intervals to prevent fatigue.

Experimental Structure

1. **Block Design:**
    - Each session consisted of multiple blocks, with each block corresponding to a specific image and saturation level combination.
    - In the **objective sessions**, participants viewed a single image at all three saturation levels (low, mid, high) in randomized order, repeated across eight trials for each condition to ensure reliability of the fNIRS data. Each block included:
        - A 1-second fixation cross.
        - A 16-second image presentation (to allow the hemodynamic response to reach its peak).
        - An inter-stimulus interval (ISI) of 27–36 seconds (gray field) for the hemodynamic response to return to baseline.
2. **Subjective Session:**
    - This session evaluated participants' ratings of visual comfort, image quality, and preference.
    - Each block included:
        - A 1-second fixation cross.

        - A 5-second image display (sufficient for subjective evaluations).
        - A questionnaire displayed on a gray background immediately after the image, where participants rated the image using a keyboard.
3. **Between-Block Intervals:**
    - To prevent fatigue and ensure accurate data collection, the experiment was divided into three objective sessions (24 minutes each) with at least a one-day interval between sessions.
    - Subjective and objective parts of the experiment were separated by at least seven days to mitigate learning effects.

Data Collection and Analysis

- fNIRS was used in the objective sessions to capture cortical hemodynamic responses. Signals were processed to extract peak HbO2 amplitudes as indicators of neural activity related to visual discomfort.
- Questionnaire data from the subjective session provided complementary insights into participant perceptions of visual quality, comfort, and preference.

Data recorded at a 50 Hz sampling rate was preprocessed using bandpass filtering, baseline correction, and artifact removal. Hemodynamic responses were quantified as peak amplitude (PA) of oxygenated hemoglobin (HbO2), analyzed using ANOVA and post hoc tests. Results showed a significant effect of saturation on PA, with mid saturation eliciting the lowest hemodynamic response and highest visual comfort, while high saturation induced the greatest PA and visual discomfort. Image quality and preference scores increased with higher saturation, indicating that visual discomfort and aesthetic preferences are distinct perceptual dimensions.

The findings highlight mid saturation as an optimal balance point, combining improved image quality and preference with minimal discomfort. The study indicated that hemodynamic response is more sensitive to discomfort than subjective evaluations. balance vividness with viewer comfort. Further research with expanded datasets and variable conditions is recommended to generalize these results.

Third Study Description

A study by Liu & Hong (2017) investigated the detection of primary RGB colors (red, green, and blue) by analyzing hemodynamic responses (HRs) in the visual cortex using functional near-infrared spectroscopy (fNIRS). The NIRSport device was employed to measure oxygenated (HbO) and deoxygenated hemoglobin (HbR) levels in 14 participants (10 males, 4 females, aged 22–34 years) with no history of neurological disorders. Participants viewed primary RGB color stimuli projected onto a screen by a beam projector. Each stimulus was presented in a controlled environment, with randomized trials to ensure unbiased responses and sufficient rest intervals to avoid fatigue.

Experimental Structure

Block Design

- **Objective Session**:
    - Participants viewed each RGB color stimulus for 10 seconds, followed by a 25-second rest period to allow the hemodynamic response to return to baseline.
    - Each session comprised nine blocks, with three repetitions of each color stimulus (red, green, and blue) in randomized order. The total experiment time was approximately 16 minutes.
    - Each block included:
        - A 10-second color stimulus display.
        - A 25-second rest interval with a gray background to prevent carry-over effects.

Data Recording

- fNIRS recorded signals from the visual cortex using a 15-source and 15-detector optode configuration. Channels were mapped to the International 10-20 system, focusing on occipital regions.
- The visual cortex's HR was assessed by analyzing five features of HbO signals: mean, peak, slope, skewness, and kurtosis.

Data Collection and Analysis

Signal Preprocessing:

- Data was filtered to remove noise (e.g., respiration at 0.033 Hz and cardiac signals at ~1 Hz) using a low-pass filter with a 0.15 Hz cut-off.
- Baseline correction and detrending techniques removed signal drift, and normalization scaled the signals to a 0–1 range.
- Activation maps were generated using t-values to visualize cortical responses for each RGB color.

Feature Analysis:

- HbO signals were analyzed using the five features, and a Linear Discriminant Analysis (LDA) classifier was used to distinguish between RGB stimuli.
- The analysis focused on a 2–7 second window within the 10-second stimulus period, where HR peaked.

Results:

- Activation maps showed distinct spatial patterns for each color:
    - Red activated the upper-right visual cortex.
    - Green activated bilateral regions with a rightward bias.
    - Blue activated the lower-left visual cortex.

- Peak HbO values varied across colors: green elicited the highest response (0.1816), followed by red (0.1642) and blue (0.1405).

Classification Accuracy:

- LDA achieved an average accuracy of 55.29% across subjects, significantly above the chance level (33.33%), with the best two-feature combination being peak and skewness.
- Individual accuracy peaked at 74.07% for one subject using the slope-skewness combination.

Findings and Implications

The study demonstrated the feasibility of using fNIRS to detect RGB colors based on hemodynamic responses in the visual cortex. While the accuracy varied between individuals, the results consistently surpassed the chance level, indicating reliable differentiation of RGB stimuli. The findings also highlighted distinct spatial and temporal activation patterns for each color, with green eliciting the strongest response. Limitations included noise from hair and eye movements, which could be addressed with instructions and participant selection. The study provides insights for using fNIRS in color detection.

Current study

Experimental Protocol for Classifying Visual Imagery and HbO/HbR concentrations Using fNIRS

Objective

The current work aims to classify RGB color stimuli (Red, Green, Blue) viewed by participants using fNIRS data collected from the visual and prefrontal cortices. The goal is to determine if neural activity patterns in these regions can be used to distinguish between the three colors.

Setup and Participants

- **Participants**:
  - Recruit adults with no neurological or vision disorders.
  - Ensure participants have very short hair or shaved heads to reduce noise from hair interference.
- **fNIRS Setup**:
  - Place optodes on the **visual cortex** (occipital region) and **prefrontal cortex**.

    - Align optodes to the 10-20 International System for consistent positioning. Use a rectangular probe array at each region.
- **Environment**:
    - Conduct the experiment in a quiet, dimly lit room.
    - Use noise-cancelling headphones if ambient noise is present.

Experimental Design - Color Decoding

Stimulus Presentation:

Each trial includes:

1. **10-second pre-stimulus rest**: Black screen for baseline activity.
2. **10-second color stimulus**: Display red, green, or blue color.
    a. **15-second post-stimulus rest**: Black screen for hemodynamic recovery.
3. **Repetitions: 27 trials per participant**. Three repetitions per color across nine sessions.

Participant Instructions:

- Instruct participants to fixate on a cross in the center of the screen and remain still during trials.

Data Collection:

- Record fNIRS data simultaneously from the visual and prefrontal cortices.
- Use a camera to capture optode positions before, during, and after the session.

Experimental Design - Breathing Test

Stimulus Presentation:

Each trial includes:

1. **10-second pre-breath-holding rest:** Participants breathe normally to establish baseline hemodynamic activity.
2. **20-second breath-holding period:** Participants are instructed to hold their breath after a deep inhalation.
3. **30-second post-breath-holding recovery:** Participants resume normal breathing for hemodynamic recovery.
4. **Repetitions:** A total of 10 trials are conducted for each participant.

Participant Instructions:

- Instruct participants to take a deep breath before each breath-holding period and to exhale normally once the period ends.

- Ensure participants remain seated comfortably and keep their head as still as possible throughout the session.

Data Collection:

- Record fNIRS data simultaneously from the visual and prefrontal cortices.
- Use a camera to capture optode positions before, during, and after the session.

Data Analysis

- **Preprocessing**:
    - Convert optical density to HbO/HbR concentrations using the Beer-Lambert law and extinction coefficients of HbO and HbR for the respective wavelengths, sourced from literature. Corroborate coefficients with system designers.
    - Remove motion artifacts and apply bandpass filtering to reduce noise.
- **Feature Extraction**:
    - Extract features (mean, peak, slope, skewness, kurtosis) from a time window during color presentation.
- **Classification**:
    - Use a Linear Discriminant Analysis (LDA) classifier (scikit.learn) to differentiate between Red, Green, and Blue stimuli, respectively.
    - Compare classification accuracy between visual cortex and prefrontal cortex data.
    - Use a classifier to differentiate between normal breathing, breath-holding, and post-breath-holding recovery periods.
- **Visualization**:
    - Generate activation maps and overlay them on a 2D head template for spatial analysis.

Outcome
This design aims to demonstrate the feasibility of classifying RGB color perception based on neural activity patterns in the visual and prefrontal cortices. The breathing test serves as a validation method to assess the system's ability to classify HbO and HbR concentrations using fNIRS data. The primary objective is to evaluate the system's effectiveness in replicating a published methodology for classifying neural responses to visual stimuli.

Pipeline Replication: Replicate data preprocessing and analysis pipelines using openly accessible fNIRS datasets.

No open datasets specifically designed for RGB classification were identified. However, the current study addresses a classification problem, making it possible to utilize equivalent datasets. For a list of open fNIRS datasets, see: https://github.com/hubandad/fnirs-dataset

As part of this work, a replication and retraining pipeline was implemented using a mental arithmetic dataset. An existing Python-based model was retrained on this dataset in order to be exported as an Open Neural Network Exchange (ONNX) file, ensuring compatibility with EZKL, a zero-knowledge proof system. EZKL allows for the generation of proofs to verify that inference was performed using a specific model.

This work can be found at https://github.com/rainbowpuffpuff/ez_think2earn/tree/master

Manufacturing Setup: Compile acquisition list, contact manufacturers, and order PCB production.

The purpose of this study is to identify, select, and contract the manufacturing of open hardware devices. To ensure successful manufacturing, the original designers were contacted in order to receive updated files, to clarify the manufacturing process, the way firmware is flashed onto the devices, and how the data is interpreted from the PCBs. Two systems were shortlisted, due to their low complexity and cost.

Acquisition list HEGduino V2:

The designers were contacted via the Discord of Brains@Play regarding the HEGduinoV2 system. However, queries related to the HEGduinoV2 went unanswered, likely because the system's designer had left the Discord server. Due to the lack of support for this system and the absence of optodes and detectors for the FreeEEG32 system from the designers, the HEGduinoV2 system was excluded.

For the HEGduino V2 parts, see:

https://github.com/joshbrew/HEG_ESP32_Delobotomizer/blob/main/Designs/MAX86141HEG/breakout/CAMOutputs/Assembly/MAX86141_HEG_MINI.txt

Acquisition list DIY-fNIRS and NIRDuino

The designers of the DIY-fNIRS systems were contacted to clarify manufacturing instructions. Their publication indicated that some components of the board must be programmed prior to soldering, but there was an inconsistency regarding how one of the pre-solder components should be programmed. Specifically, the paper stated that U1 and U8 must be programmed before soldering, but the firmware guide included no instructions for U1. Additionally, the Bluetooth interface guide was outdated. After contacting the authors, updated manufacturing files were obtained, and a formal collaboration has been initiated to receive files for a new DIY-fNIRS system (NIRDuino) prior to preprint submission and public release. Using the bill of materials, components for manufacturing three PCBs have been ordered from JLCPCB. However, some items were not available in the manufacturer's stock, and a quote and lead time indicator are currently awaited (48 hours - 3 December).

For the DIY-fNIRS parts, see:

https://osf.io/ag46p/

The NIRDuino bill of materials has been sent through email by one of the designers, and should soon be on an osf.io repository.

Materials Sourcing: Acquire necessary materials for headset assembly (e.g. straps, silicone).

Currently, no instructions have been received regarding the contract assembly process for the enclosure of the PCB, as the designer of the NIRDuino system is still finalizing the instructions document. These instructions are crucial for minimizing engineering costs when designing the system's enclosure to limit external light interference with the optodes, which can affect the quality of the collected data.

Conclusion

This research focuses on using open-source functional Near-Infrared Spectroscopy (fNIRS) systems for practical applications in visual and cognitive neuroscience. Two devices, HEGduinoV2 and DIY-fNIRS (NIRDuino), were identified for their accessibility and potential. Due to lack of support for HEGduinoV2, the focus shifted to the DIY-fNIRS system, and the new system from the same designers, the NIRDuino. Manufacturing files for NIRDuino were obtained through collaboration with the designers, preparing the project for device assembly once the instructions document is finalized.

Experimental protocols for RGB color classification and a breathing exercise were developed based on prior studies. Open-source datasets were reviewed to replicate classification pipelines. Although no RGB-specific datasets were found, a classification pipeline on a mental arithmetic dataset was leveraged. A model was retrained and adapted for compatibility with EZKL, enabling cryptographic proofs to verify data classification is done using the constructed model.

Most components for the NIRDuino system have been ordered from JLCPCB, with several items awaiting quotes and lead times. This positions the project to begin manufacturing when the assembly documentation is released.

By building on existing studies and open-source tools, this project advances neuroimaging research efforts by focusing on validating the capabilities of open hardware. Future milestones include completing device assembly, recruiting participants, collecting data, and classifying hemoglobin changes in response to stimuli.

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