Critical Assessment Document
fNIRS BCI
Functional Near Infrared Spectroscopy Brain-Computer Interface

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Abstract

Brain-Computer Interfaces are a growing method for controlling external systems such as robotics and adaptive game controllers. The main method for capturing brain signals is the Electroencephalogram (EEG), but functional Near-Infrared Spectroscopy (fNIRS) offers benefits such as higher spatial resolution, portability, and tolerance to user movement. fNIRS captures brain signals by using near-infrared light to measure changes in oxygenated and deoxygenated hemoglobin (HbO, HbR) due to neurovascular coupling. This allows fNIRS BCI systems to translate brain signals into actions or controls, often requiring training to activate specific areas of the brain consistently.

Test One | Single-Channel Prototype

Before utilizing fNIRS to sense brain signals, a simple single-channel prototype must be designed which can detect blood flow from the brain at a single point. Additionally, to maintain ease of testing, the prototype is designed to accommodate any microcontroller or development board by providing the necessary control and output signals at a standardized header.

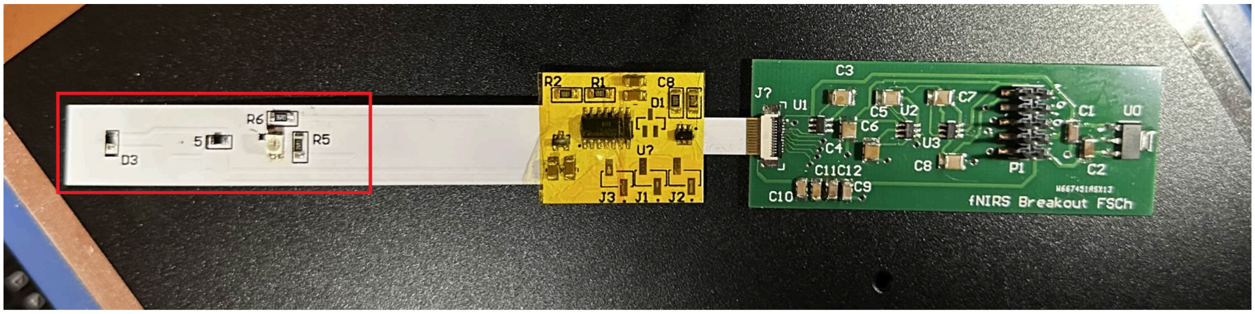

Figure 1. Single Channel (Channel outlined in red) board.

The prototype must be then tested to ensure two objectives:

1) A flexible PCB is a viable platform for an fNIRS system
2) The core circuit functions as expected

By creating a simple test program utilizing an ESP32 and its respective IDE, the output of the single-channel implementation can be analyzed.

Figure 2. Single Channel Output When Placed on Finger

One test to identify whether the fNIRS device is working properly is to place the source and detector on a finger to analyze the output of the detector circuit. As observed from Figure 2, this system is operating as expected given the clean waveform produced by the transimpedance amplifier.

Test Two | Serial Communication and Software Output
If the system is used on a patient to analyze the behavior of their brain, it is crucial to ensure that the data the system collects is accurate and no improper data is included in the readings. One part of ensuring this is to test the error rate of the communication channel in the system.

To test the error rate of the software, a test must be designed to detect the number of errors within the serial communication system. The communication system can be verified by transmitting a predetermined set of data from the MCU and analyzing the data at the receiver. If the data does not match, then an error must have occurred during transmission. The error rate must be under 5% at a baudrate of 921600 using UART. At this speed, transmission errors can occur due to electromagnetic interference. The system must be capable of handling errors and recovering proper functionality to ensure minimal data is lost.

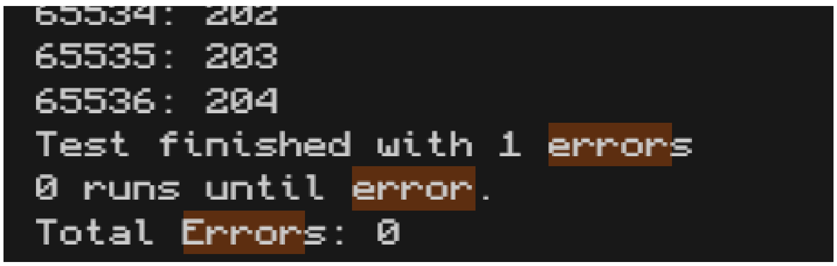

Figure 3. Communication Test

After designing a python script to test the UART communication between the host PC and the STM32 MCU, it is verified that there are no errors at 921600 baud. This allows for the possibility of potentially increasing the baud rate which also increases the data output of the sensor.

Test Three | Power Consumption
To ensure the circuit does not consume more than 100mW, the source/detector circuit should be run with all sources turned on and all channels reading. This gives the worst-case scenario for this circuit design.

Figure 4. Power Test
When testing the circuit under these conditions, the power consumption becomes 50mW which passes the 100mW requirement.

Conclusion

Overall, the current state of the design accomplishes the project objectives and meets the necessary requirements for a functioning system. Test one, verifies the theory of fNIRS and its capability to be used as a BCI system. Test two, ensures that the system is robust and produces accurate and reliable data. Test three, ensures that the system is low-power and can be powered by a battery, allowing for the possibility of a wireless system.

Additionally, the current prototype allows for the system to be analyzed on a smaller scale before scaling up and introducing a much more complex fNIRS BCI system. The prototype ensures that the project can be scaled to implement a complete, stand alone system which houses all of the necessary sources, detectors, amplifiers, MCU, and power circuitry for a portable and user-friendly version of the product.