BCI Implementation Report

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***Abstract*—As research progresses, the original tools purchased from OpenBCI are no longer able to meet the needs of electroencephalogram (EEG) signal acquisition. There is an urgent need by our client for a low-cost EEG acquisition systems' hardware with higher amounts of channel and strong customizability. This report presents the capstone project of CSE453 of the University at Buffalo. The goal of design is to manufacture a PCB board that can support multiple channels for capturing EEG signals with lower cost. Our project only contains a PCB design and a prototype board that is built on breadboard so far for now. However, This rebuild hardware from scratch to minimize the cost of future upgrades. Currently, the prototype supports 4-Channel EEG signals acquisition, and is able to receive digital data by using Bluetooth. The source code and design diagrams are available at https://github.com/Tyson-Hu/Brain-Computer-Interface_Project.**

***Index Terms*—brain-computer interface, rapid prototyping, open-source, electroencephalogram**

I. Introduction

This project is our CSE453 capstone, designed and implemented with the topic "Brain Computer Interface". We implemented a 4-Channel EEG signal prototype with 100Hz frequency input, and designed the PCB board with 16-Channel. Our project has features of

- Low Cost. Compared to OpenBCI boards, our project product can get the same features for quarter the price.
- Higher amounts of channel. Based on our 4-Channel EEG signal prototype, the amounts of channel can be customized by following the Daisy-Chain Configuration, which the rest AD converter will transfer their digital data to the AD converter that is connecting to micro-controller, through the connection between DAISY_IN and DOUT.
- Open Source. Our resource code is based on GitHub code with GNU GENERAL PUBLIC LICENSE, so the code is free to use and change.

II. Components

The whole prototype is combined by three components, which are Analog Digital Converter, Bluetooth, and micro-controller. Through the three components, the 4-Channel EEG signal prototype can read analog signals from electrodes input, convert analog to digital, and send the digital to a peripheral device that is connected to Bluetooth.

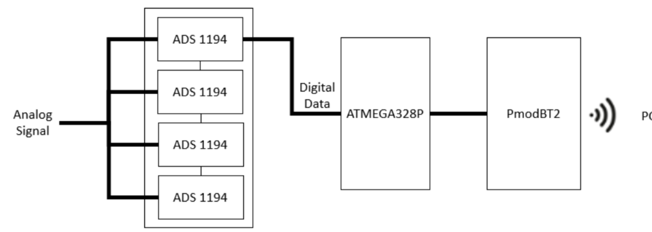

Fig. 1. Prototype-board component connection

A. Analog Digital Converter

This component will receive the input analog signal from electrodes, and convert to digital data. We chose the ADC chips from Texas Instruments with the model of ADS119X family - ADS1194. The ADS1194 used with low-power, and supported 4-Channel and 16-Bit Analog Front-End measure, so the final PCB board will be manufactured with four ADS1194 chips to configure as 16-Channel.

Once ADS1194 receives command on the DIN pin from the micro-controller through SPI communication, ADS1194 will process the data, and send data back to the micro-controller. The commands are included and follow the order below

- `RESET`: Reset to Default Setting
- `SDATAC`: STOP Read Data Continuous mode (must called after `RESET`)
- `START`: Turn ON / OFF ADS1194 to convert input
- `RDATAC`: Enable Read Data Continuous mode
- `WREG`: Overwrite ADS1194 registers
- `RREG`: Read ADS1194 registers

ADS1194 has input with 100Hz frequency by 250 SPS and Gain 1. To operate the ADS1194, we set up its Analog supply (AVDD-AVSS) to 5 V and Digital supply (DVDD-DGND) to 3 V, and connect VCAP and VREF to ground with capacitors.

B. Micro-controller

This component is mainly used to communicate with Analog Digital Converter and Bluetooth as SPI communication and UART communication. The communications are provided by the ATMEGA328P micro-controller on Arduino UNO Rev3, which has 4 SPI pins (SCK, CIPO, COPI, & SS), and 2 UART pins (TX & RX).

The ATMEGA328P is compiled by Arduino IDE. From the Arduino IDE, we send commands and set up registers to the

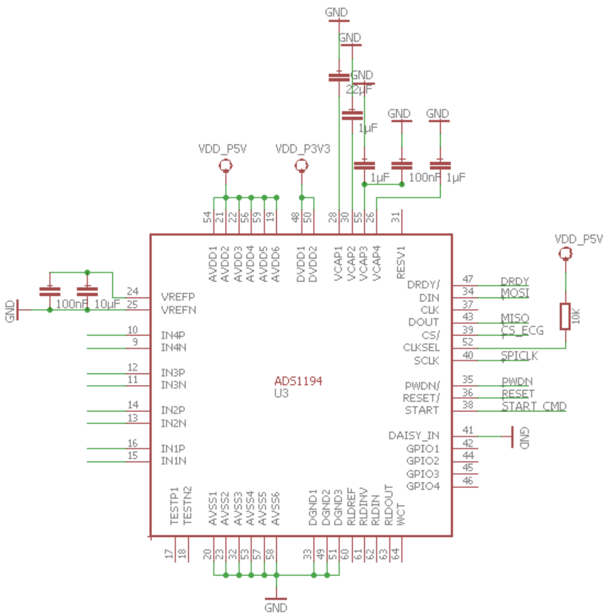

Fig. 2. ADS1194 Schematic

ADS1194 chip by SPI communication, and also send digital data to the Bluetooth module by UART communication. To set up the registers of ADS1194, we called the `WREG` function in Arduino IDE to send `WREG` commands with the register addresses and data,

TABLE I
REGISTER CONFIGURATION

Address	0x1	0x2	0x3	0x5 - 0x8
Register	Config1	Config2	Config3	CHnSET
Bit 7	0	0	1	0
Bit 6	0	0	1	0
Bit 5	0	1	1	0
Bit 4	0	0	0	1
Bit 3	0	0	1	0
Bit 2	1	0	1	0
Bit 1	0	0	0	0
Bit 0	1	0	0	1

*For more information, check ADS119X User Manual [1].

the registers will be set as Table I above with settings of

1) `Config1`
   a) Daisy Chain Model [Bit6]
   b) Oscillator clock output disabled [Bit5]
   c) 250SPS [Bits2-0]
2) `Config2`
   a) Test signals are driven externally [Bit4]
   b) –1 × (VREFP – VREFN)/2.4mV [Bit2]
   c) Pulsed at Pulsed at $f_{clk}/2^{21}$ [Bits1-0]
3) `Config3`
   a) Enable internal reference buffer [Bit7]
   b) VREFP is set to 4V [Bit5]
   c) Open [Bit4]
   d) RLDREF signal (AVDD – AVSS)/2 [Bit3]
   e) RLD buffer is enabled [Bit2]
   f) RLD sense is disabled [Bit1]
   g) RLD is connected [Bit0]
4) `CHnSET`
   a) Normal operation [Bit7]
   b) 1 PGA gain [Bits6-4]
   c) Normal electrode input [Bits2-0]

To communicate with both ADS1194 and Bluetooth, we set the SPI baud rate to typical 1MHz, and UART baud rate with 115200 bps. Then we follow the step below to interact with the two components

1) Power-Up oscillator by active $\overline{PWDN}$ to high
2) Send `RESET` and `SDATAC` commands to reset ADS1194
3) Send `START` command to start ADS1194 conversion
4) Send `RDATAC` command to read and convert analog data
5) Receive Digital Data from ADS1194 from CIPO pin
6) Transfer Digital Data to Bluetooth through TX pin

C. Bluetooth

This component supports data transmission, even without cable connection between the peripheral device and our board. The component is developed by Digilent that is called PmodBT2, and its UART interface takes a default baud rate of 115200 bps to transfer 8 data bits. Hence, we also set 115200 bps UART baud rate on ATMEGA328P micro-controller to synchronize PmodBT2. When ATMEGA328P receives digital data from ADS1194, ATMEGA328P will transfer data through TX pin to PmodBT2 RXD pin by UART serial communication, and automatic display on Serial Terminal.

III. PCB DESIGN

The final PCB design is a 2 layer board with a size of 3.1 X 3.3 inches. The design contains the 4 ADCs surrounding the microprocessor and Bluetooth module. Placing the 4 ADCs on the outer edges leads to the pin headers being on either side of the board, which is not an efficient design. This was chosen to simplify the routing and reduce the layers of the board.

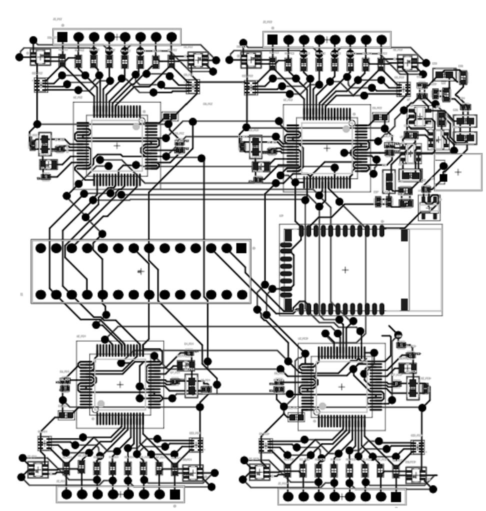

Fig. 3. Final PCB Layout

IV. Testing

All tests with improvement should be place here...

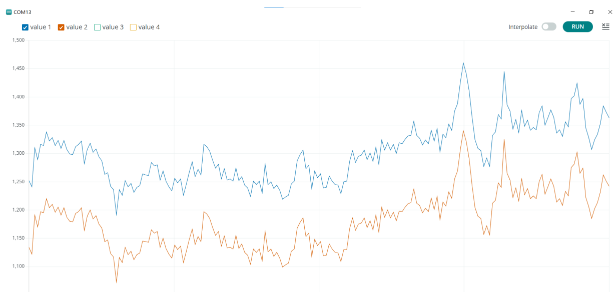

Fig. 4. Initial Test Result

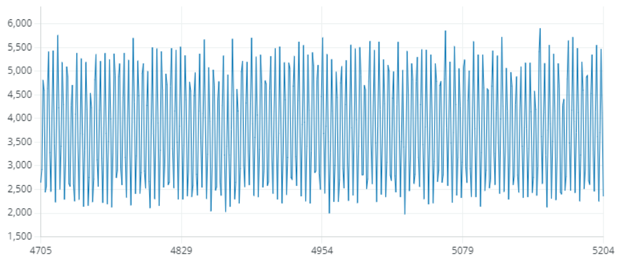

Fig. 5. Test Result after resolution

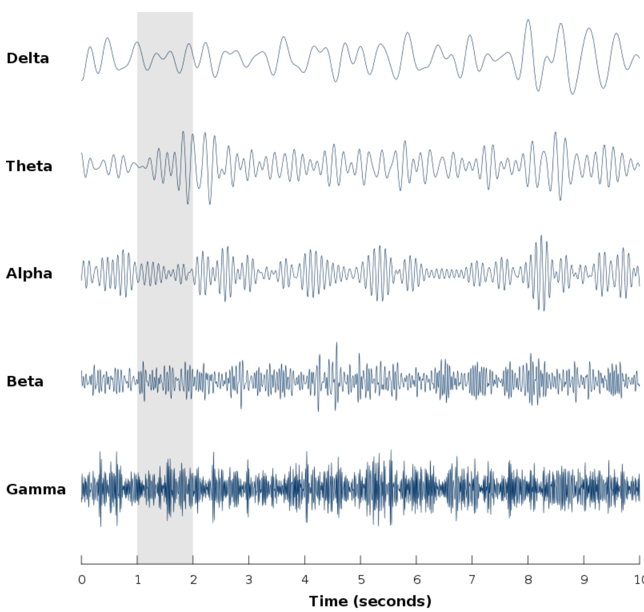

Fig. 6. Normal Brian-wave Looks

The figure above from Wikipedia [2] shows several types of brainwave based on the different frequency of the wave. Since our prototypes focus on the EEG signal with 100 Hz frequency, the brainwave will be a high Gamma wave that is between 70–150 Hz. Based on the Gamma wave look, we knew that a high Gamma wave will have fast frequencies and high amplitude Spike, which in Figure 5, our result also achieves all the features of a high Gamma wave.

V. Future

There are still far away from the initial design, and it could be done in the future with following updates:

- Extended 4 channel to 16 channel
- USB connection (Power & Data transfer)
- SD card storage
- WiFi module

A. Daisy-chain Mode

To extend the input of the board from 4 channels to 16 channels, a new data handle mode called Daisy-chain mode is required since microprocessor needs to communicate with 4 ADS1194 at the same time.

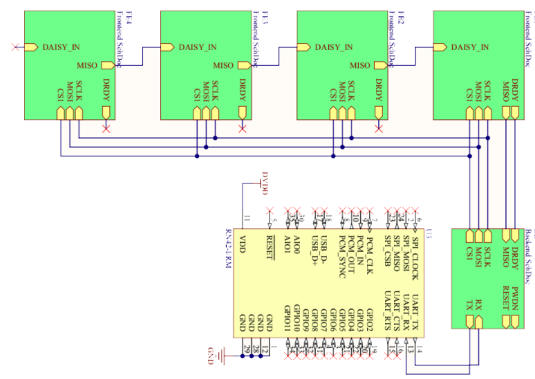

Fig. 7. Daisy-chain Mode

TODO: How does daisy-chain mode work and connects with the microprocessor based on the figure provide above, and a simple implementation discussion about how to enable this mode...

B. USB connection

TODO: Why we need this update?

C. SD card storage

TODO: benefits with SD card

D. WiFi module

TODO: benefits using WiFi module (fast speed & durable transmission)

References

[1] None. (April 2010). Low-Power, 8-Channel, 16-Bit Analog Front-End for Biopotential Measurements. Texas Instruments. Retrieved from https://www.ti.com/lit/ds/symlink/ads1194.pdf

[2] None. (April 2023). Neural oscillation. Wikipedia. Retrieved from https://en.wikipedia.org/wiki/Neural_oscillation