H.A.L.O - Hall-effect Array for Live Observation

Critical Design Review - Group 18

Brogan Dougherty
Electrical Engineering

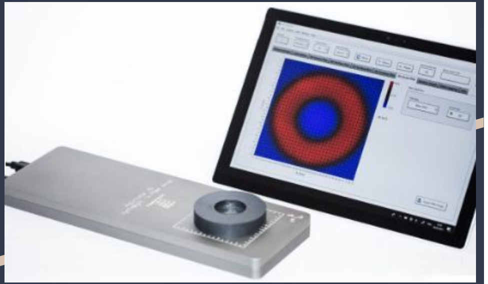
Aidan Kennedy
Electrical Engineering

Gabriel Martin
Computer Engineering

Ryan McCord
Electrical Engineering

Motivation and Background

MRI machine



Metrolab HallinSight

- H.A.L.O. utilizes hall-effect sensors to image magnetic fields.
- Magnetic field measurement technology was developed in the early 1800’s.
- Modern usages include power system monitoring, object detection, and medical applications such as MRI.
- Most of these systems are large, heavy, and unwieldy.
- Our motivation is to build a system that can image magnetic fields effectively while maintaining a size and weight that allows for better maneuverability and mobility.

Goals and Objectives

Main Goals

- Obtains a series of measurements from a magnetic field via a grid of 64 Hall-effect sensors
- Visualize the data in multiple manners that allows for intuitive analysis of the magnetic field
    - Heat Map - a grid of tiles where each tile displays a color related to the value obtained from its hall sensor, ie negative Tesla values are blue, and positive Tesla values are red with a gradient for the values in between
    - Raw Data - Each tile displays the actual value in Teslas of that region in space.

Stretch Goals

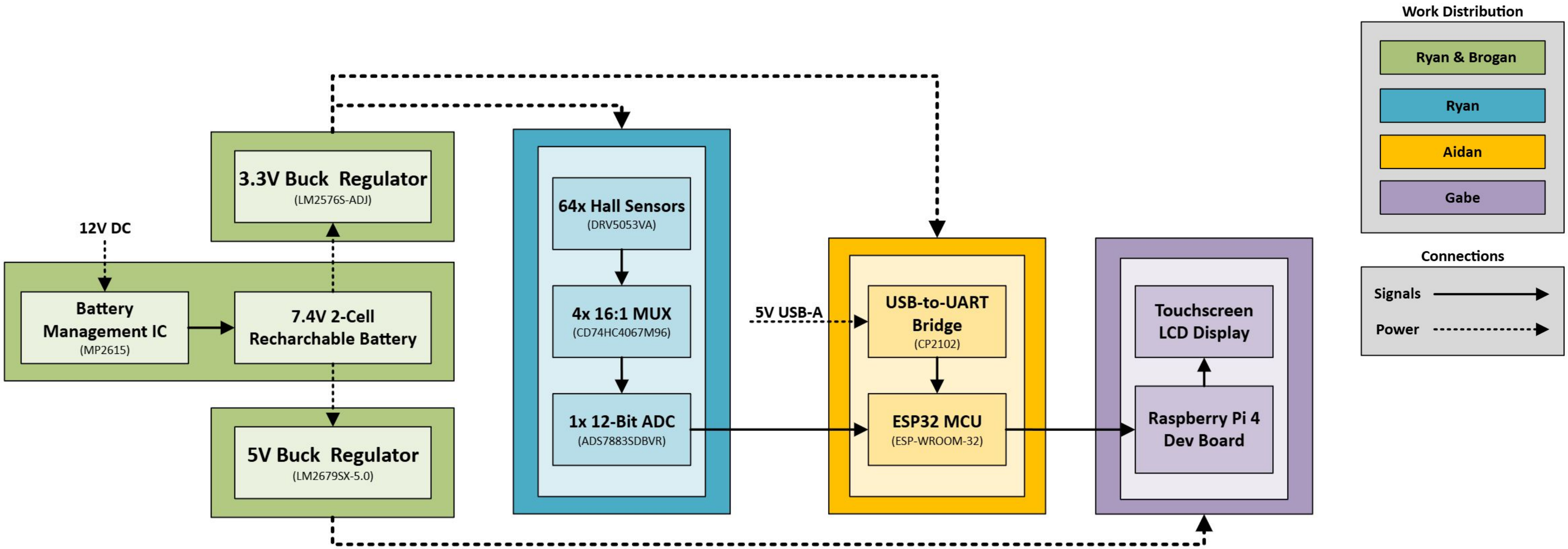
- Larger array size
- Utilization of 3-axis magnetometers for a 3-dimensional visualization mode

Engineering Specifications

Parameter	Purpose	Value
Number of Tiles in Heat Map	Magnetic field visualization	≥ 64 tiles
Field Size Detected	Magnetic field visualization	≥ 64 cm^2
Field Intensity Range Detected	Magnetic field visualization	[-8, 8] mT
Detection Distance	Accurate measurement of fields near sensor array	≤ 1 cm
Screen Refresh Rate	Expedient display of data	≥ 15 Hz
Amount of Data Saved	Value storage for analysis	≥ 30 s
Power Consumption	Small energy footprint	< 5 W

Parameter	Purpose	Value
Power Efficiency	Small energy footprint	> 75% efficiency
Operating Temperature	Convenience	< 120° F
Latency	Expedient data transmission	< 200 ms
Weight	Convenience	< 5 lbs
Size	Convenience	< 1 square foot
Cost	Affordability	< $250

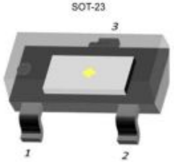
Hardware Block Diagram



Hall-effect Sensor

Technology	Resolution	Sensitivity	Size	Cost
Hall-effect Sensor	poor	poor	miniscule	cheap
Magneto-Resistive Sensor	fair	fair	fair	fair
Fluxgate Sensor	great	great	massive	expensive

Component	Sensitivity	Temperature Range	Power Consumption	Cost	Risk of EMI
DRV5053VA	± 9 mV/mT	-40°C to +125° C	Low	Moderate	Medium
DRV425RTJT	± 2 mT	-40°C to +125° C	Moderate	High	High
A1324LLHLX-T	2.5 mV/G	-40°C to +125° C	Low	Low	Low
SS495A1	3.125 mV/G	-40°C to +150° C	Low	Low	Medium



Different package sizes of the DRV5053VA

Analogue to Digital Converter

ADC Type	Max Resolution	Max Sample Rate
SAR	18 bits	10 MHz
Delta-sigma	32 bits	1 MHz
Flash	12 bits	10 GHz

ADC	Resolution	Sample Rate	Communication Protocol	Cost
ADS7883SDBVR	12 bit	3 MSPS	SPI	$4.73
AD7940BRMZ	14 bit	100 kSPS	SPI, DSP	$16.90
ADC081C021CIMKX/NOPB	8 bit	188.9 kSPS	I2C	$1.13

Comparison and Selection of Hardware

MCU Requires

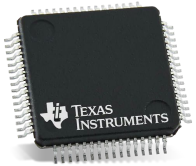
9 GPIO: S0-S3, EN0-3, CS

UART: RX, TX

SPI: MISO, SCKL

MCU

Feature	MSP430FR6989	ESP32	STM32
Architecture	16-bit MSP430	32-bit Xtensa LX6	32-bit ARM Cortex-M7
Clock Speed	16 MHz	< 240 MHz	< 550 MHz
Flash Memory	128 KB FRAM	4 MB (external)	64 KB - 2 MB
SRAM	2 KB	520 KB	16 KB - 1024 KB
GPIOs	40	34	100+
ADC Resolution	12-bit (16 channels)	12-bit (18 channels)	12 to 16-bit (24 channels)
Operating Voltage	1.8V - 3.6V	2.2V - 3.6V	1.8V - 3.6V
Wireless Capability	None	Wi-Fi, Bluetooth	None
Interfaces	I2C, UART, SPI, ADC, Timer, PWM	I2C, UART, SPI, ADC, DAC, PWM, CAN	I2C, UART, SPI, USB, CAN, Ethernet, LTDC



Development Board

Feature	STM32H735G-DK	STM32H747I-DISCO	Raspberry Pi 4B
MCU	STM32H735IGK6	STM32H747XIH6 (Dual-core: Cortex-M7 + M4)	Broadcom BCM2711
Core(s)	Cortex-M7 @ 550 MHz	Cortex-M7 @ 480 MHz + Cortex-M4 @ 240 MHz	Quad core Cortex-A72 (ARM v8) 64-bit SoC @ 1.8GHz
Flash/RAM	1 MB Flash / 564 KB RAM	2 MB Flash / 1 MB RAM	Micro SD card slot for loading operating system and data storage / 8GB LPDDR4-3200 SDRAM
Display	4.3" 480x272 TFT LCD (with capacitive touch)	4.3" 480x272 TFT LCD (with capacitive touch)	3.5” 480x320 TFT LCD (with resistive touch)
Connectivity	USB OTG HS (micro-B), Ethernet, microSD	USB OTG HS (micro-B), Ethernet, microSD, Wi-Fi expansion	2 USB 3.0 ports; 2 USB 2.0 ports. Raspberry Pi standard 40 pin GPIO header, 2 × micro-HDMI®

Display

Display Type	RGB LED	LCD - IPS	LCD - TFT
Resolution	Low	High	Moderate
Refresh Rate	High (120 Hz)	Moderate-High (60-120 Hz)	Low - Moderate (30-60 Hz)
Power Consumption	High	Moderate	Low

Display	Waveshare 3.5” TFT LCD	Kuman 3.5" TFT LCD	Elegoo 2.8" TFT LCD
Resolution	480x320	480x320	320x240
Refresh Rate	~30 Hz	~5 Hz	~45 Hz
Interface	SPI	SPI	RGB888
Cost	$25	$20	$15

Comparison and Selection of Software

Communication protocols required

SPI: For ADC to ESP

UART: For ESP to Pi

SPI: For Pi to Screen

Communication Protocol

Spec	I2C	SPI	UART
Speed	Slow	Fast	Slow
Distance	Long	Short	Short
Clock	Synchronous	Synchronous	Asynchronous
Configuration	Half duplex	Full duplex	Simplex, Half Duplex, or Full Duplex
Connectable devices	Multi	Multi	Single
Lines	2	4	2

Comparison and Selection of Software

Bare-Metal vs. Operating System

Platform	Approach	Pros	Cons
ESP32	Bare-Metal	- Fast startup - Low memory usage - Tight timing	- Manual scheduling - Slower development
ESP32	FreeRTOS	- Task prioritization - Abstraction drivers	- More complexity - Steeper learning curve
Raspberry Pi	Bare-Metal	- Fast Startup - Full control	- Extreme development difficulty - No display / touch drivers
Raspberry Pi	Raspbian, FreeRTOS	- Easy driver support - High level programming	- Slower boot - Higher latency

Comparison and Selection of Software

Operating System Options for Raspberry Pi

Feature	Raspberry Pi OS (Linux)	FreeRTOS
Display Driver Support	Drivers for framebuffers and SPI LCD interface	Manual configuration
Touchscreen Support	Drivers and calibration tools	Manual configuration
Package & Library Support	Linux pip (easy installation)	Less commonly used, lacking support
Development Tools	IDEs, ssh, file systems, near-complete stacks	Lower-level programming, limited abstraction

Comparison and Selection of Software

GUI Development Frameworks

Framework	Language	Capability	Ease of Use
Tkinter	Python	Basic widgets and raster graphics	Easy
PyQt	Python	Full Qt GUI Toolkit	Moderate
GTK	C / Python	High-quality Linux-native UI	Steep learning curve

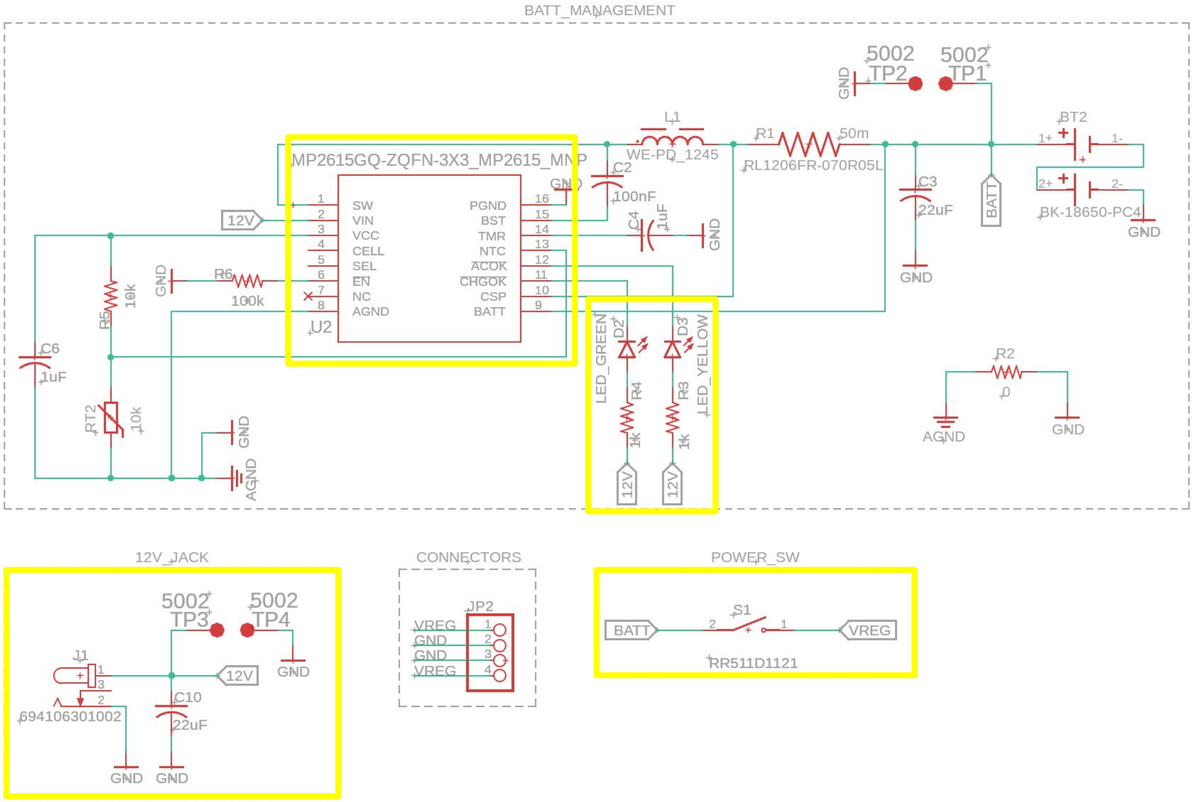
Power Requirements

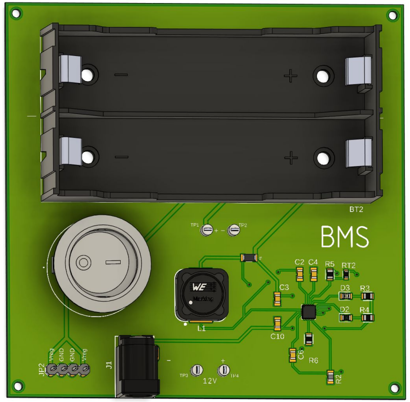
- Important to consider current draw across system components
  - System components operate on either 3.3V or 5V
  - CP2102 requires 5V supplied via USB-A
  - A separate 12V input required for battery charging (Mp2615)
- Selected a two-cell (7.4V) Li-io battery pack with 5000mAh
- Buck regulators step down voltage to 3.3V and 5V

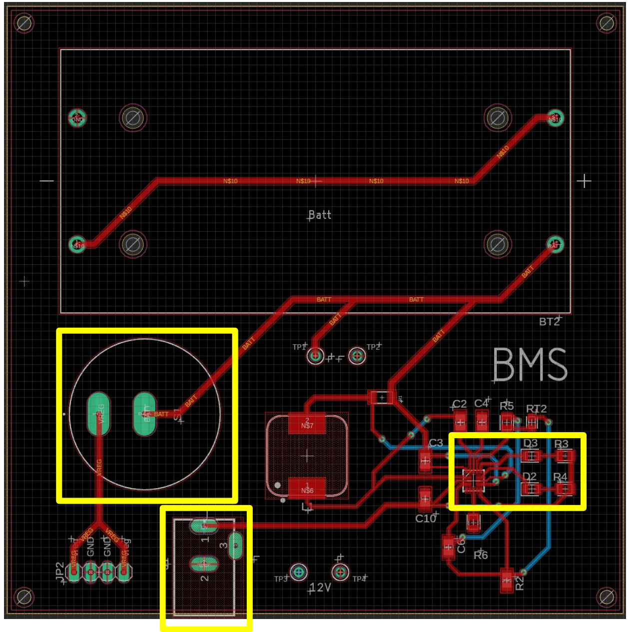
	Voltage Requirement	**Current Requirement**
Hall Sensor (64x)	3.3 V	230.4 mA
Multiplexer (4x)	3.3 V	32 uA
ADC	3.3 V	3 mA
ESP32	3.3 V	240 mA
Raspberry Pi w/ LCD	5 V	3 A
Totals	3.3 - 5 V	~ 3.5 A

	Voltage Requirement	**Current Requirement**
CP2102 (USB-A)	5V	20mA
MP2615 (12V Jack)	12V	2A

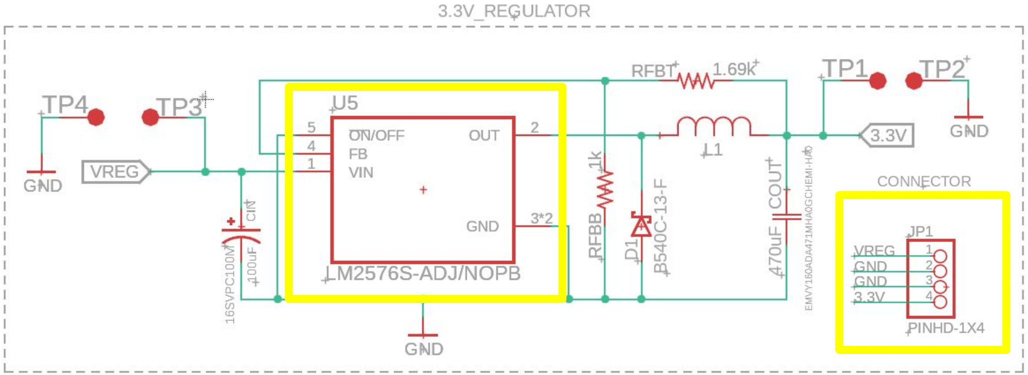
BMS Schematic/PCB

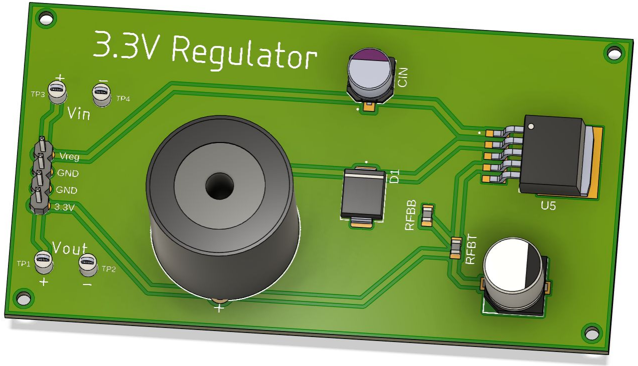


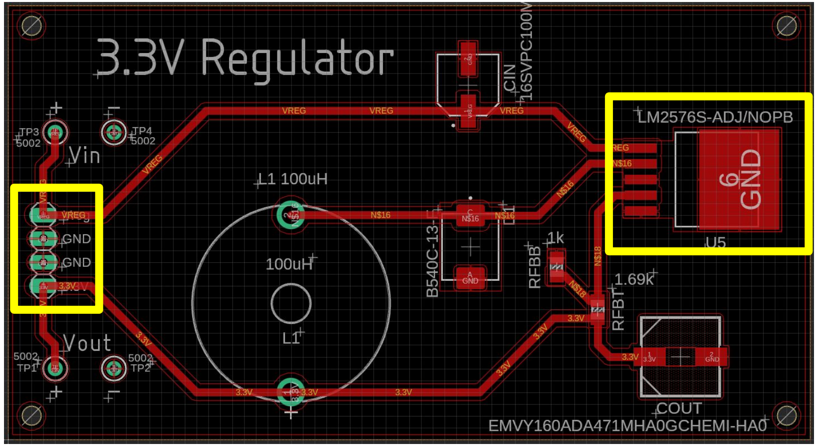




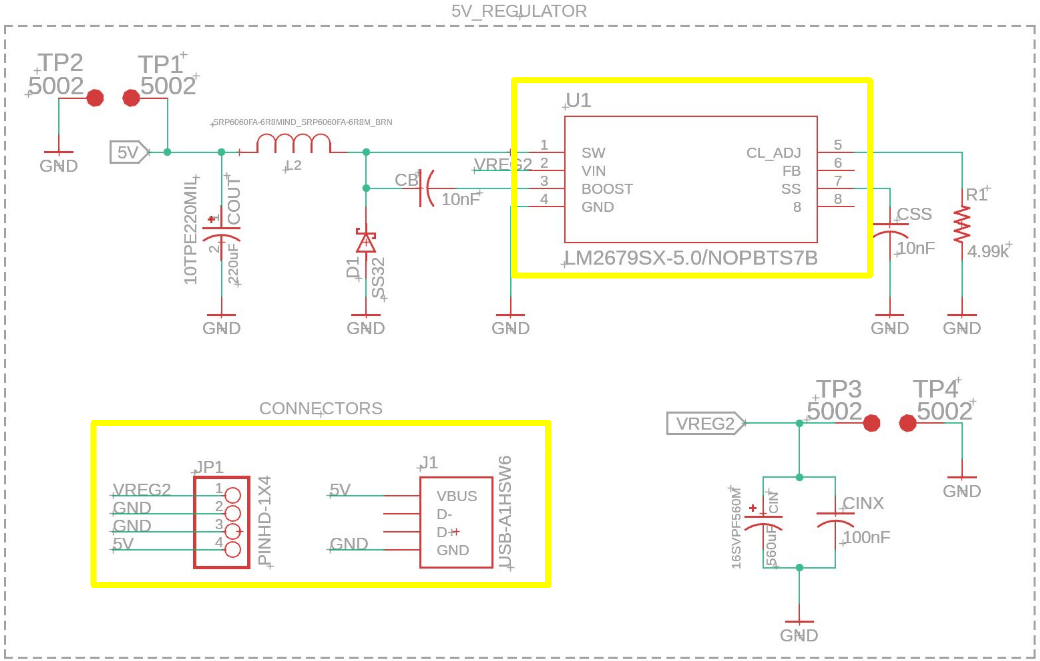
3.3V Regulator Schematic/PCB

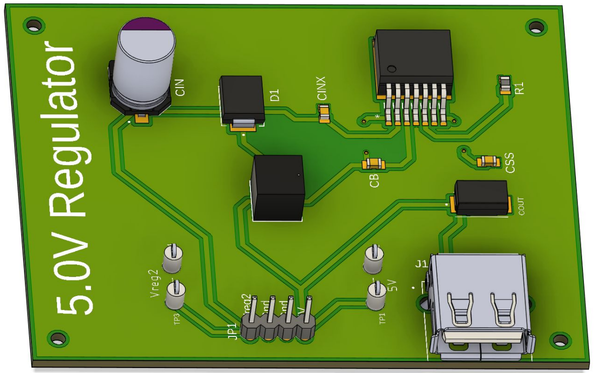


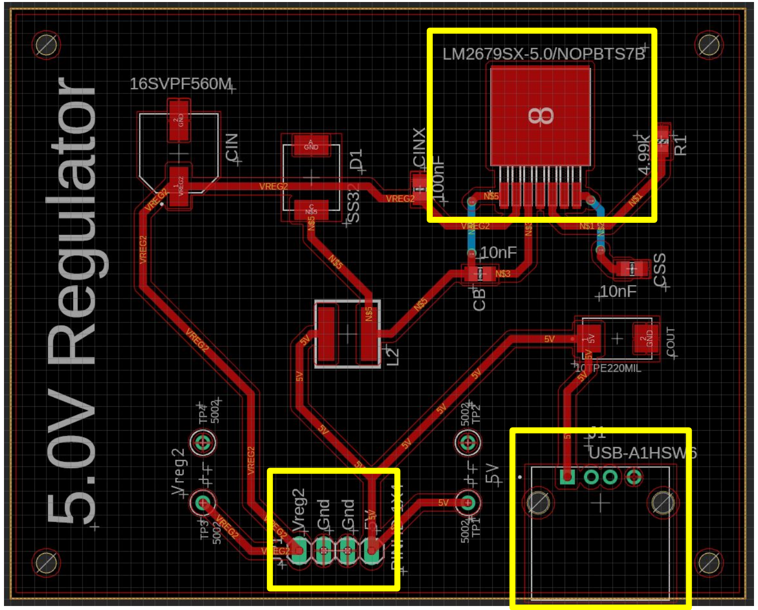




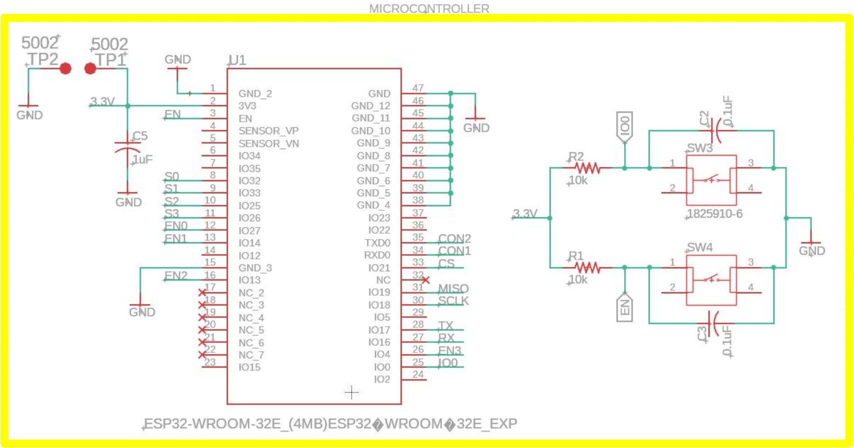
5V Regulator Schematic/PCB

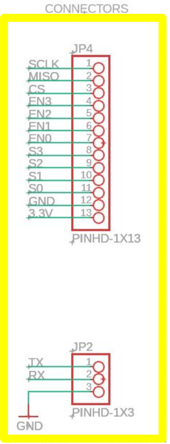


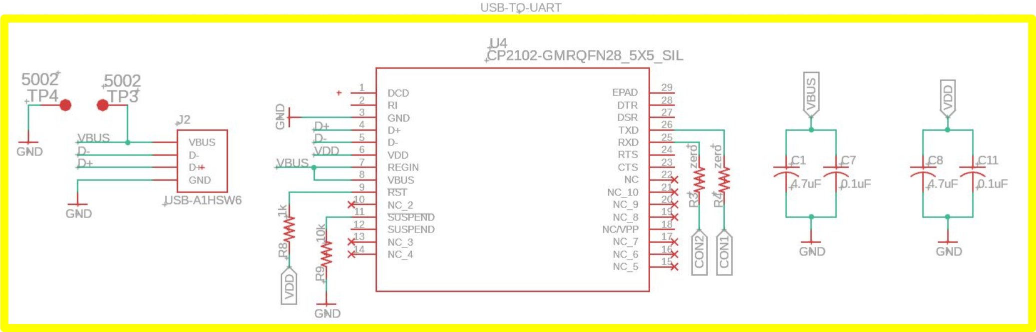


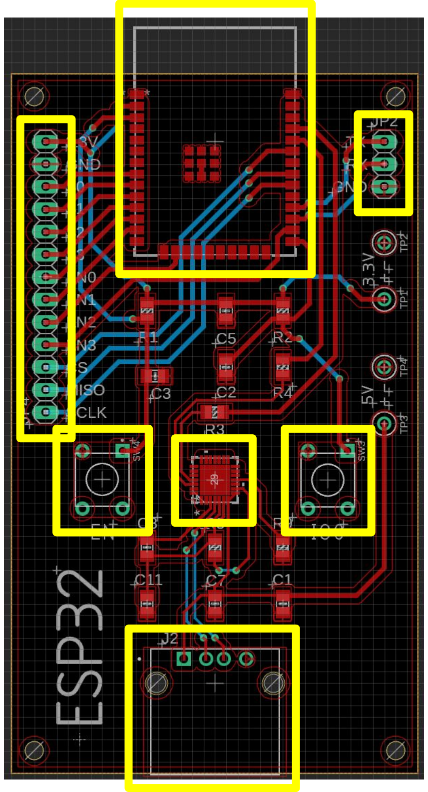


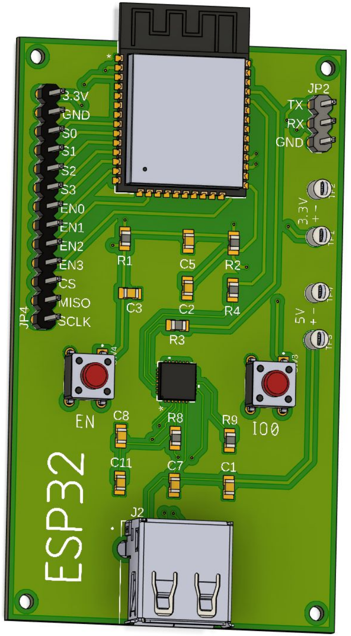
Microcontroller Schematic/PCB





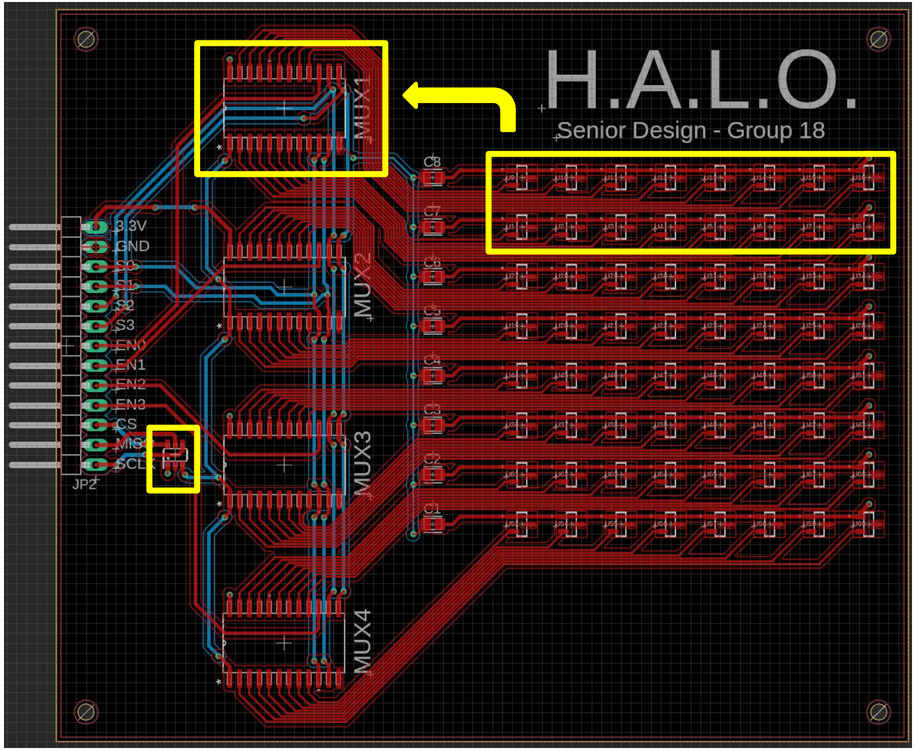




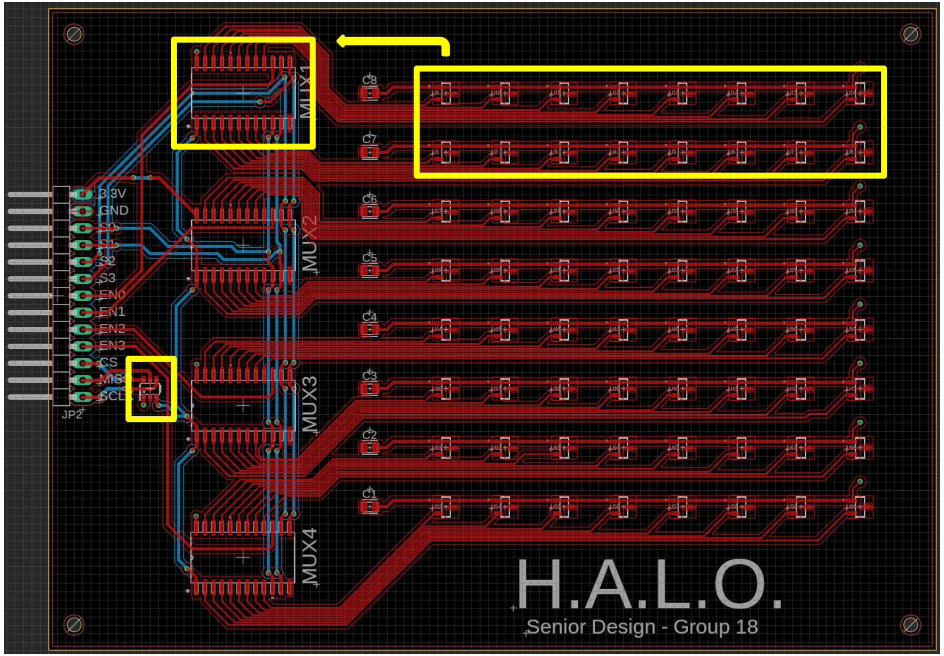


Sensor Array Schematic

Sensor Array PCBs

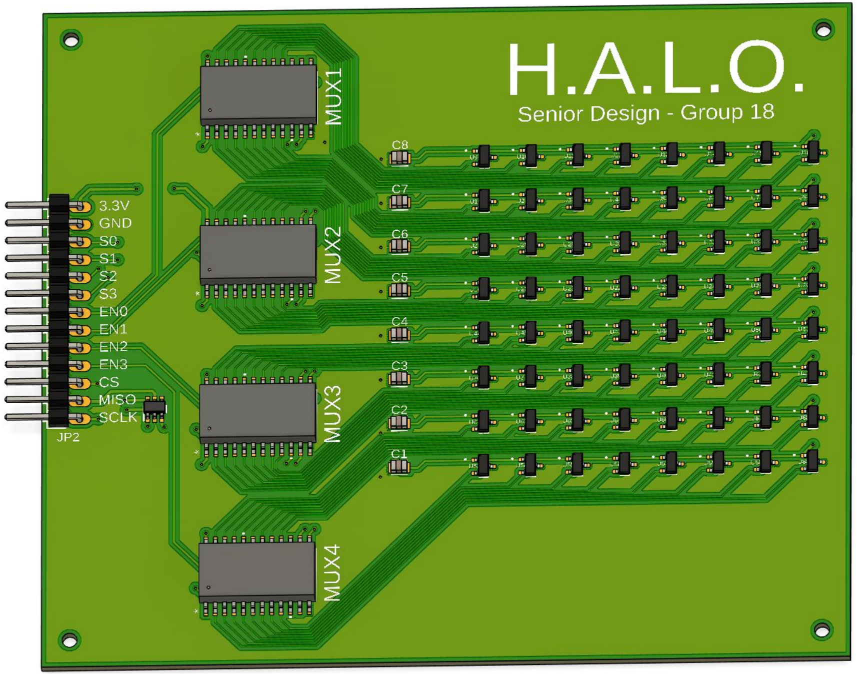


(Compact Layout)

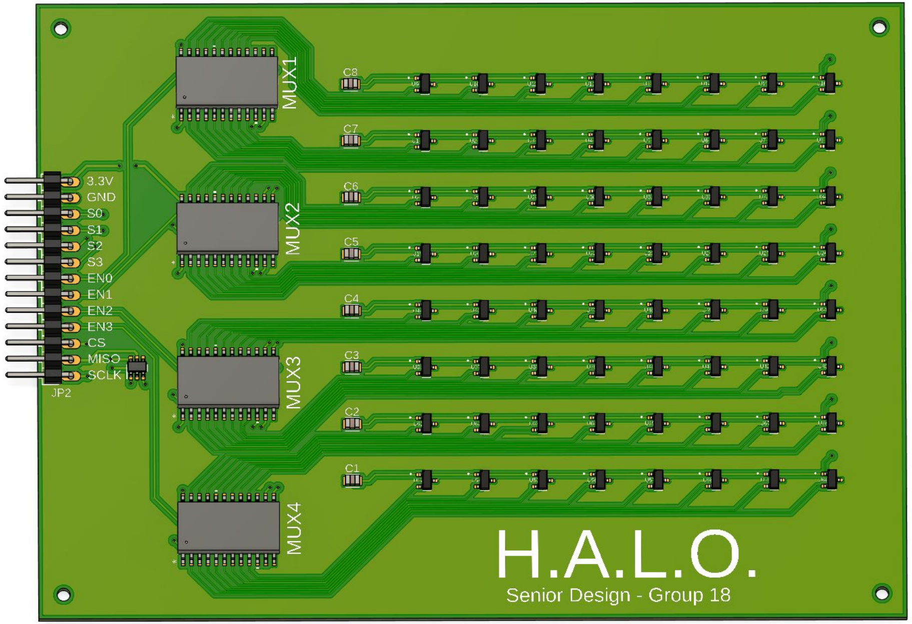


(Expanded Layout)

Sensor Array Models

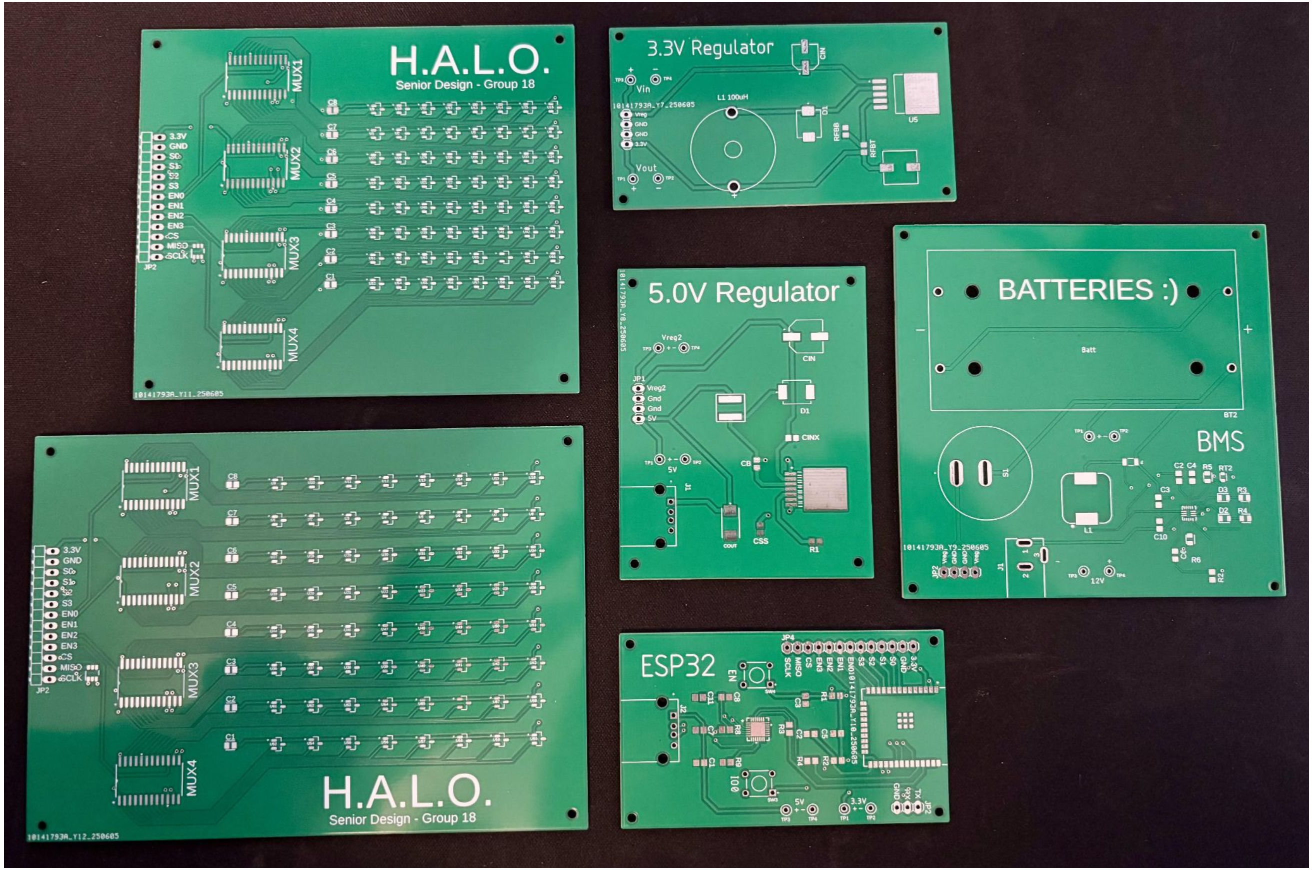


(Compact Layout)

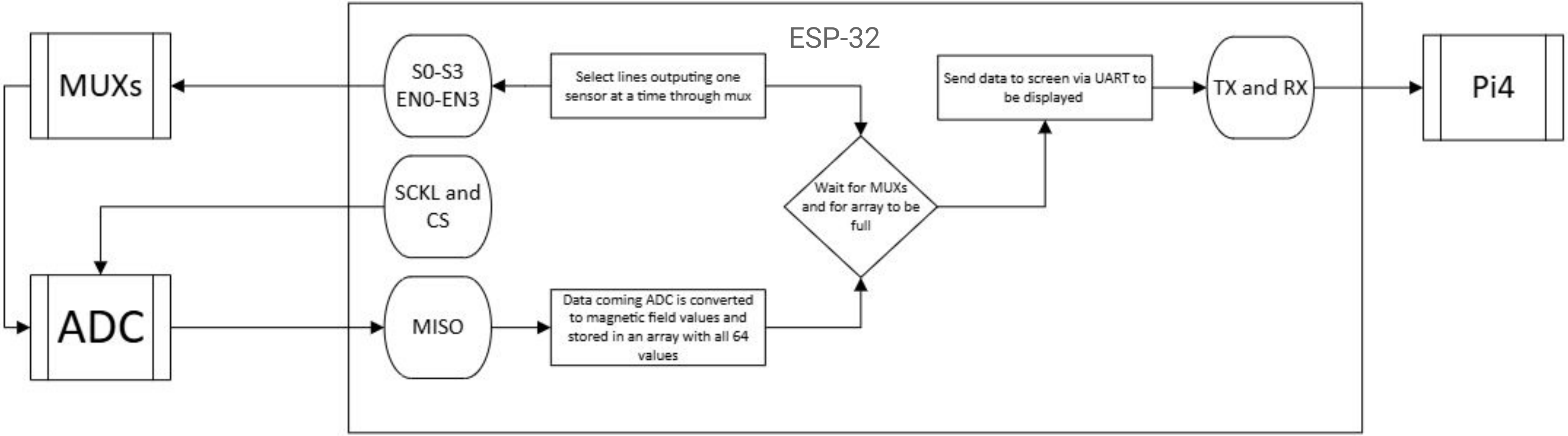


(Expanded Layout)

PCB Fabrication



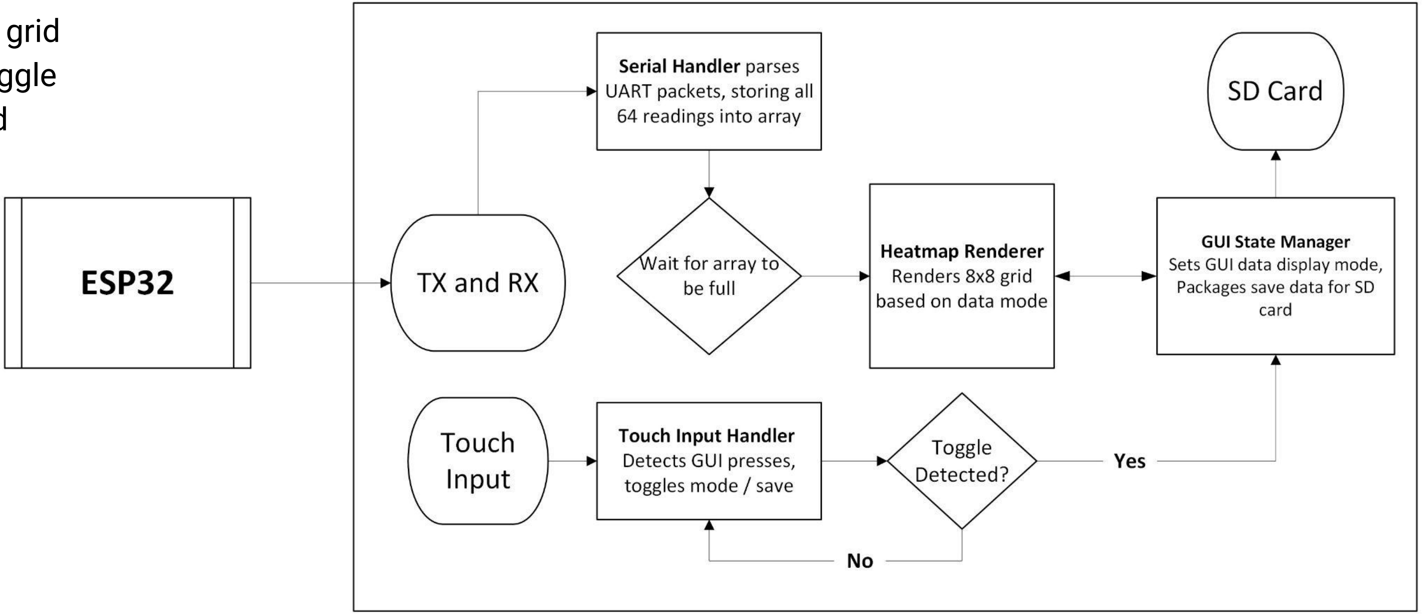
Software Design - ESP-32



Software Design - Raspberry Pi 4

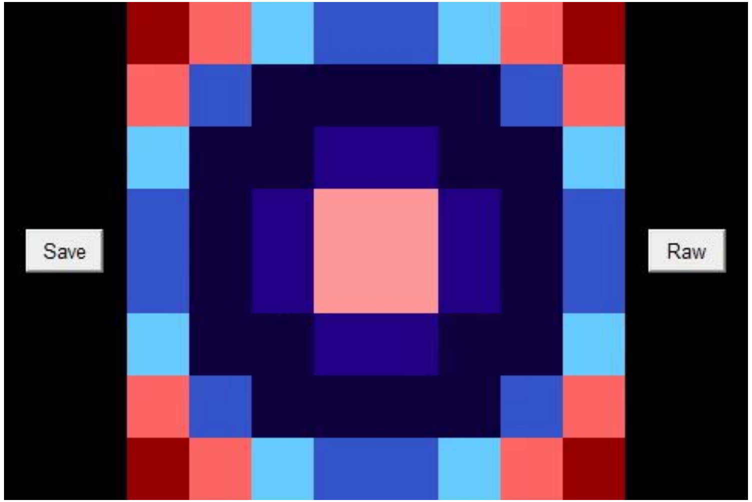
- Receive and parse UART data packets from ESP32
- Render heatmap and raw sensor values on an 8x8 grid
- Handle touch input to toggle between GUI modes, and save data to SD card

Raspberry Pi 4B



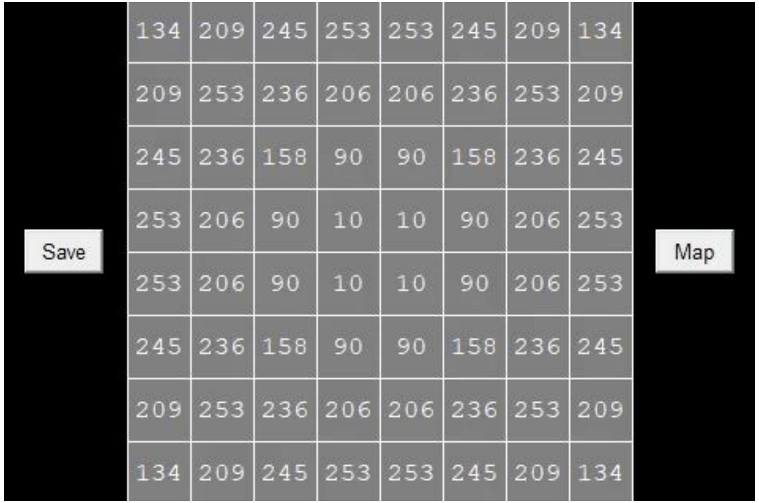
Software Design - Display GUI

Heatmap GUI



- Field intensity displayed with color mapping
- Distributed into 16 bins (colors)
- Mode switch Button
- Save Data Button

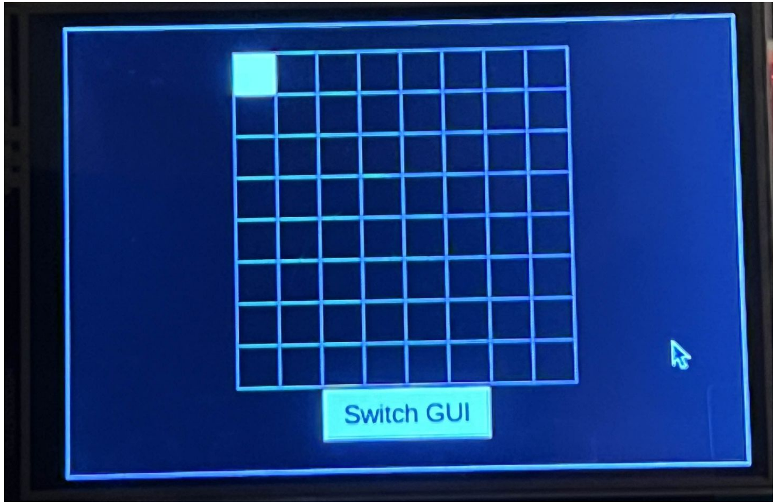
Raw Value GUI



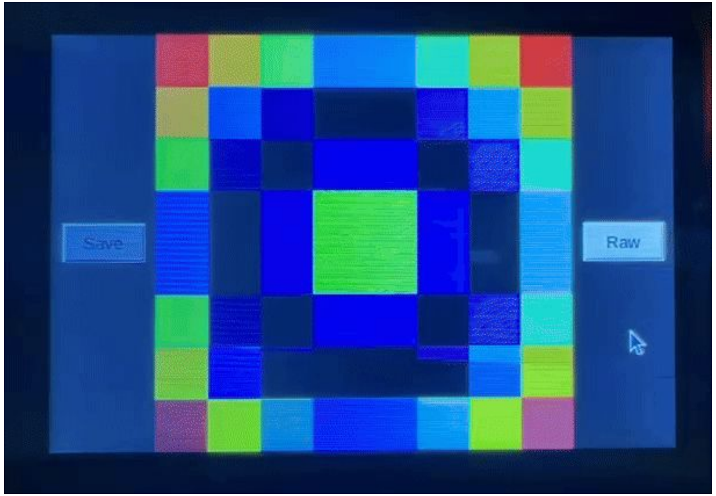
- Displays field intensity values numerically
- Cells contain readings from each sensor
- Mode switch Button
- Save Data Button

Prototyping and Testing - Display Driver & GUI

Initial Proof of Concept GUI on static display



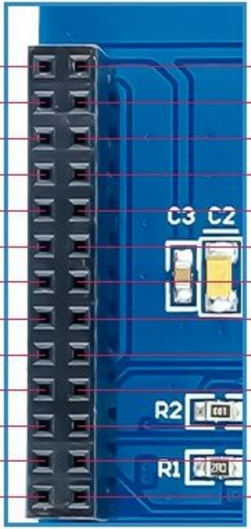
GUI Simulation running on early driver Implementation



Prototyping and Testing – Display Hardware Integration

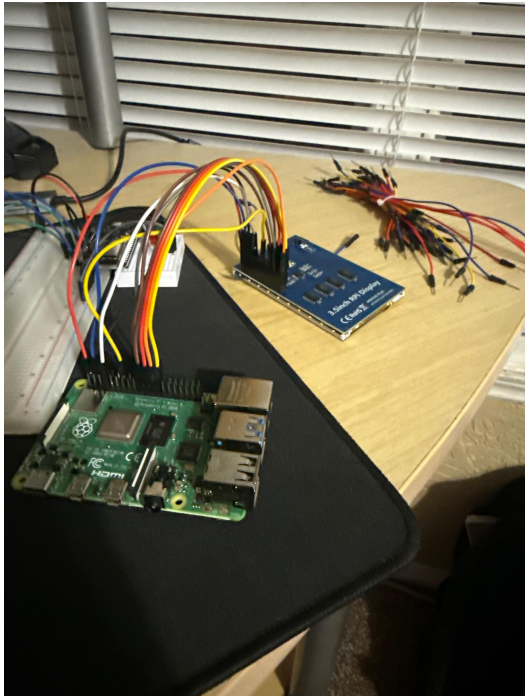
Interfaces & Description

Description	Pin	NO.		NO.	Pin	Description
Power input(5V)	5V	2		1	3.3V	NC
Power input(5V)	5V	4		3	SDA	NC
Power GND	GND	6		5	SCL	NC
NC	TX	8		7	P7	NC
NC	RX	10		9	GND	Power GND
NC	P1	12		11	PO	NC
Pwoer GND	GND	14		13	P2	NC
NC	P4	16		15	P3	NC
NC	P5	18		17	3.3V	NC
Power GND	GND	20		19	MI	TP SPI Bus input(MOSI)
TP Interrupt	IRQ	22		21	MO	TP SPI Bus output(MISO)
NC	CEO	24		23	SCK	TP SPI Bus Clock(SCLK)
TP Chip Sellect	TCS	26		25	GND	Power GND



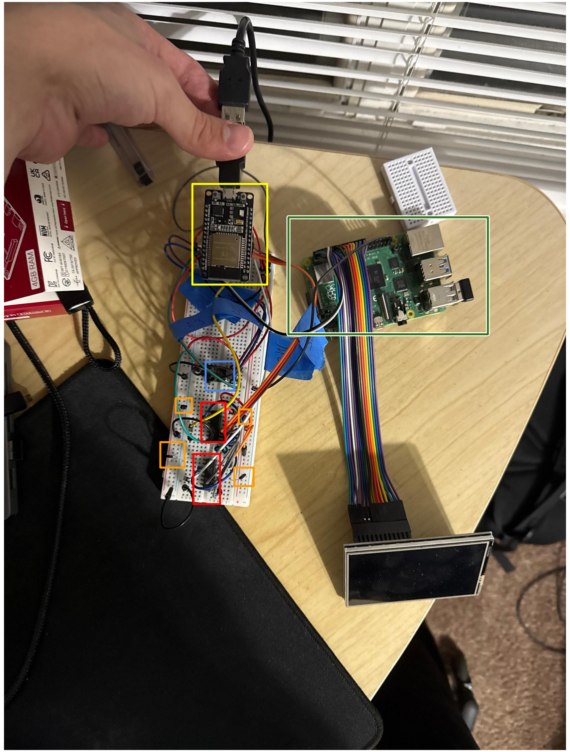
Prototyping and Testing – Screen Integration

Failed Connection Attempt

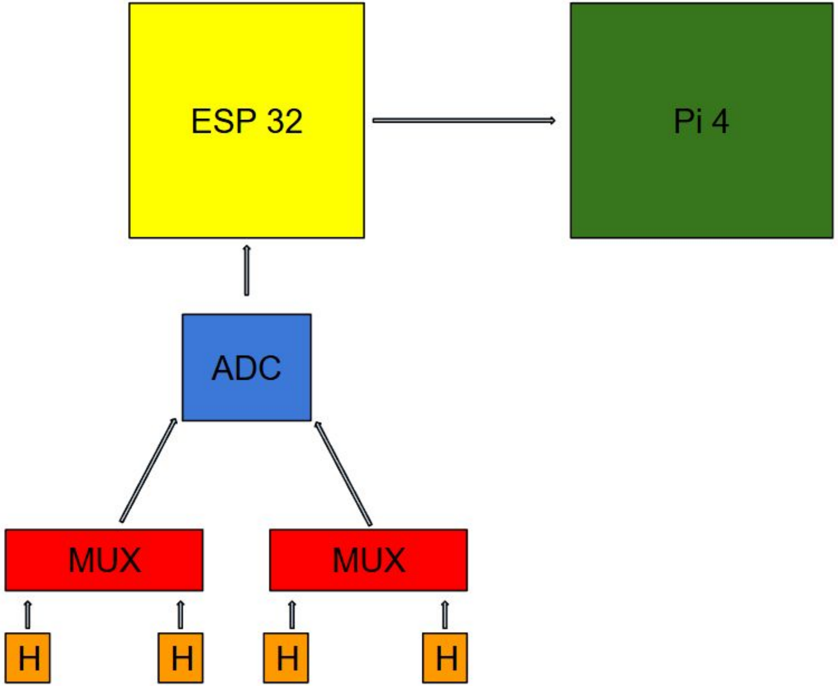


Successful Connection Attempt

Prototyping and Testing - Breadboard Testing



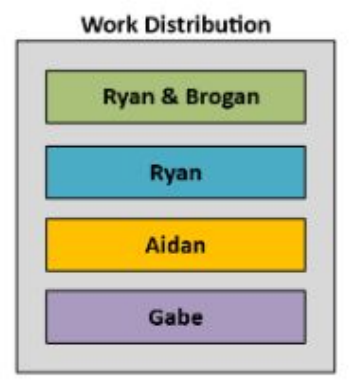
Data Flow Diagram



Administrative Content

Quantity	Component	Cost
64	Hall-effect sensor	$24.44
1	ADC	$4.73
4	MUX	$2.32
2	Raspberry Pi	$180
1	3.3 V regulator	$4.32
1	5 V regulator	$6.60
1	Battery management chip	$3.19
	Miscellaneous components	$90.94
	Obsolete Parts	$129.38
	Extras	$44.41
	Shipping, taxes, and tariffs	$38.20
Total		$528.53

Progress and Plan for Completion



Items Accomplished

- PCB’s have been designed, ordered, and have arrived
- Embedded and GUI development
- Simple integration testing

Items Left

- PCB assembly
- PCB testing
  - individual
  - integration
- Housing fabrication for system
- Sensor Calibration
- Continued GUI development
- SD card functionality
- Software and Hardware Integration