Camera Gimble Controller Version 1 Hardware Design

Joey Asher

***Abstract*— The purpose of this project is to design a well-tuned gimbal system capable of swinging around a mid-sized camera. This project will lay the groundwork for future iterations that will integrate camera control with position control. Eventually, this will be implemented on a remotely operated fixed-wing UAV, but this project focuses solely on the camera and gimbal systems.**

I. Introduction

As this is the initial iteration of the Camera Gimbal Controller, the project's focus remains intentionally narrow. The primary objective is to create a precise prototype capable of controlling two brushless motors while concurrently gaining experience with the ESP32-S2 microcontroller and the ICM-20948 9-axis sensor. The gimbal system will actively adjust the camera's orientation along two axes by utilizing feedback from an accelerometer, gyroscope, and magnetometer. Sensor data will be processed by an ESP32-S2 microcontroller and then translated into motor control signals to drive the brushless motor drivers. The entire system will be implemented on a compact 6-layer, 50mmx50mm circuit board manufactured by JLCPCB.

II. USB and Power Systems

A. USB-C Port

The USB-C port serves not only for data transfer to and from the system but also as the power source for the board and motors. Data transfer is facilitated by the full-speed USB 2.0 OTG controller within the ESP32-S2, simplifying the design by eliminating the need for an external IC to manage the USB connection. This design does not incorporate the USB Power Delivery standard. In this instance, the 15W that USB-C is capable of delivering is sufficient to power all components. However, in future iterations, if greater power is necessary, USB Power Delivery will need to be implemented. In future iterations, a faster USB standard will also most likly be added in order to better enable lot latency video streaming.

The layout of the board positions the USB D+ and D- pins on the ESP32-S2 directly adjacent to the USB-C connector. The Traces for the differential pair were kept short, and they were rounted on internal layers surrounded by ground planes. This was done to minimize the impedance of the trace. In addition, a L type matching section is included on both D+ and D- near the ESP32-S2.The scematic for the USB-C system is included in appendix 1. Note the PTC fuse that is included in the design. The PTC fused that was used allows up to 750mA of current before tripping, and is resetable if it does trip. In addition a 5V Zener diode is included to prevent any overvoltage from damaging the upstream device.

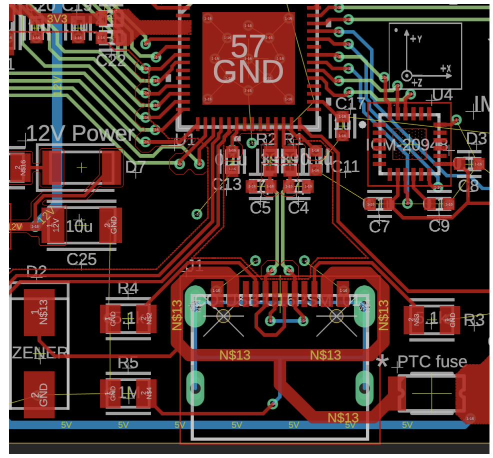

Fig. 1. USB-C Layout

B. 3.3V Power Supply

The main power supply on the board is 3.3V. It is regulated using the TPS7A4533DCQR linear regulator, which has a maximum output current of 1.5A, well above the requirements of the ICs it powers. One of the reasons for its selection is its low dropout voltage. This regulator boots up automatically whenever the board receives power, in contrast to the other power supplies that require enabling. When the 3.3V rail is operational, the 3.3V power LED will illuminate. A copper pour on layer 4 of the printed circuit board is connected to the 3.3V rail to power various ICs. Additionally, there is a 3.3V Zener diode to protect against ESD and voltage spikes. This diode is located close to the ESP32-S2.

C. 1.8V Power Supply

While it is possible to supply 1.8V from the ESP32-S2 on the VDD_SPI pin, it was decided in this case to employ a separate LDO linear regulator for providing 1.8V. The IMU is the only chip that requires 1.8V, and because it is unlikely to draw more than 40mA, future designs will probably eliminate this regulator. It is important to note that the enable pin for the 1.8V rail is connected to GPIO21 on the ESP32-S2 and is active high. When the rail is powered, the 1.8V power LED will illuminate. The ability to toggle this power supply on and off is currently its sole advantage. Otherwise, it would be more practical to utilize the embedded LDO in the microcontroller.

D. 12V Power Supply

The final power supply on the board is a boost converter to take USB voltage (5V since PD is not utilized) and create a 12V power rail for the motor drivers. This rail is created using the MIC2288YML-TR boost converter from Microchip Technology. This chip is a constant-frequency, PWM current-mode boost regulator operating at 1.2MHz. Like the 1.8V power supply, this needs to be enabled from the ESP32-S2. The enable pin on the boost converter is attached to GPIO 13 on the microcontroller. Logic high enables the regulator, while logic low shuts it down.

III. Microcontroller

As previously stated, the microcontroller running everything in this system is the ESP32-S2. This chip is common in IoT applications and was mostly chosen in this case to gain knowledge and experience with Espressif's ESP family of microcontrollers. Not only does it have a built-in USB 2.0 peripheral as discussed in section II, but it has an array of other peripherals, including a built-in WiFi system that will allow the device to be extra versatile when it comes to creating and writing firmware. This chip has 4MB of embedded flash and 2MB of embedded PSRAM, which means that external ICs for flash and RAM are not needed.

In future versions of this project, the microcontroller will likely be upgraded to a microprocessor like an ARM®Cortex®-A72. A more advanced computer will be needed to support Gigabit-speed Ethernet and USB 3.0. The extra processing power and high-speed communications will be important for taking in image data from the camera and relaying it with low latency. But once again, version 1 is intended to test the subsystems and to provide a platform to develop the control algorithm.

A. GPIO

This chip has just about the perfect number of GPIO pins for this design. In fact, only 3 GPIO pins are not used. Table 1 lists the GPIO pins on the ESP32-S2, the net name associated with that pin, and a brief description of the function of that pin. All of the GPIO signals are routed on the 3rd layer of the PCB, in between two ground planes.

TABLE I
ESP32-S2 GPIO Pin Specifications

ESP32-S2 GPIO Pin	Net Name	Description
0	BRK2	Motor 2 Brake
1	HA2	Hall Sensor 2 - Pin A
2	HB2	Hall Sensor 2 - Pin B
3	HC2	Hall Sensor 2 - Pin C
4	N/A	Not Used
5	N/A	Not Used
6	HC1	Hall Sensor 1 - Pin C
7	HB1	Hall Sensor 1 - Pin B
8	HA1	Hall Sensor 1 - Pin A
9	BRK1	Motor 1 Brake
10	S1	Motor 1 Speed
11	EN1	Motor 1 Enable
12	DIR1	Motor 1 Direction
13	12VEN	12V Regulator Enable
14	BUZZ	Buzzer
19	USB_N	USB D-
20	USB_P	USB D+
21	1V8EN	1.8V Regulator Enable
33	N/A	Not Used
34	IMUINT	IMU Interrupt
35	IMUSTAT	IMU Status LED
36	S2	Motor 2 Speed
37	EN2	Motor 2 Enable
38	DIR2	Motor 2 Direction
45	HS2	Hall Limit Switch 2
46	HS1	Hall Limit Switch 1

B. Clock

The clock used by the Microcontroller is a 40Mhz oscillator attached to pins 52 (XTAL_N) and 53 (XTAL_P). the oscillator that was chosen for this application has a frequency stability of $\pm 10ppm$. A second oscillator for the RTC can be added to the ESP32-S2, but in this case since size was a constraint, one was not added. In future iterations it might make sense to include a RTC to add extra data to the video that is being captured.

C. Reset

Besides the power-on reset, the microcontroller can also be reset with the small reset button on the board. Pressing this button will drive the CHIP_PU pin to fall to ground. Notice that there is a small RC time delay on this pin. The PU pin needs to be driven high at least $50\mu s$ after the power on the VDD pins have stabilized. And the button needs to be held for $50\mu s$ to initiate a reset.

IV. 9-Axis Sensor

An important part of the overall system is the orientation feedback that is gathered from the inertial measurement unit (IMU). The IMU chosen for this project is the ICM-20948 from InvenSense. This chip incorporates a 3 axis accelerometer, a 3 axis gyroscope, a 3 axis compass, a thermometer, and programable digital filters all in one small package. The IMU communicateas with the microcontroller using serial periphreal interface or SPI.

A. SPI

There are a few important details about the SPI communication that are worth discussing. First, the data is latched on the rising edge of the clock, and the data is transmitted on the falling edge of the clock. The maximum clock speed that the IMU and microcontroller together can support is 7MHz. This is limited by the electrical characteristics of the IMU.

As for the composition of the messages sent from the microcontroller to the IMU, it is important to keep in mind that the leading bit designates whether the microcontroller is reading or writing to the IMU, and the following 7 bits specify which register the user is reading or writing to. The following byte or bytes of data are sent most significant bit first.

SPI Address format

MSB							LSB
R/W	A6	A5	A4	A3	A2	A1	A0

SPI Data format

MSB							LSB
D7	D6	D5	D4	D3	D2	D1	D0

Fig. 2. SPI Message Composition

B. Digital Motion Processor

The IMU has a system called the digital motion processor that offloads some of the computation of motion processing algorithms from the microcontroller. This can reduce the overall latency of the system by allowing the microcontroller to quickly find the orientation of the board.

V. Brushless Motor Drivers

This board is designed to control two brushless motors using two A4915METTR-T motor drivers. These drivers receive inputs from the ESP32 microcontroller, including PWM signals for speed control, direction commands, and brake signals for stopping the motors. Furthermore, the motor drivers incorporate hall sensors embedded within the motors, enabling precise timing adjustments during motor operation. It's important to note that the A4915METTR-T motor drivers don't directly power the motors. Instead, they serve as input signals for controlling the gate signals of six external MOSFETs. In this setup, N-Channel 50V 220mA MOSFETs, typically in an SOT-23 package, are employed for the external MOSFETs. However, the design is flexible and allows for the use of any suitable N-Channel FET in the same package, making it adaptable to various motor control applications. Fig. 3 shows the pinout for both of the motors. It is worth noting that the connectors being used are 8-pin Micro-Lock PLUS 505565 made by Molex.

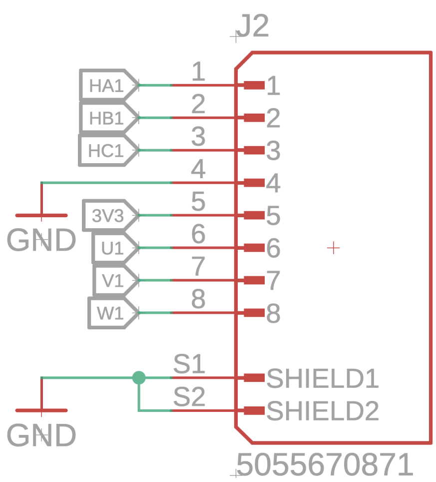

Fig. 3. Motor Pinout

VI. Limit Inputs

In order for the controller to know its own orientation in space, it first needs to find a zero or home position that is consistent between power cycles. This is achieved using two hall sensors, one for each axis. Both of these sensors connect to the same input on the board, using the same Micro-Lock connector. At start up, the motors will drive themselvs towards the hall sensors till they sense the small trigger magnets. Once it gets here, the system will then use the hall inputs on the motors to acuratly drive the motors to orient the camera.

VII. Final Notes

All of the hardware in this project has been designed using Fusion 360's integrated Electronics Design platform. The components for the project were purchased from Digikey, and the associated Bill of Materials is included in Appendix 2. The software, in particular the feedback position controller, will be disucssed in further reports.

APPENDIX I
BOARD LAYOUT AND SCHEMATIC

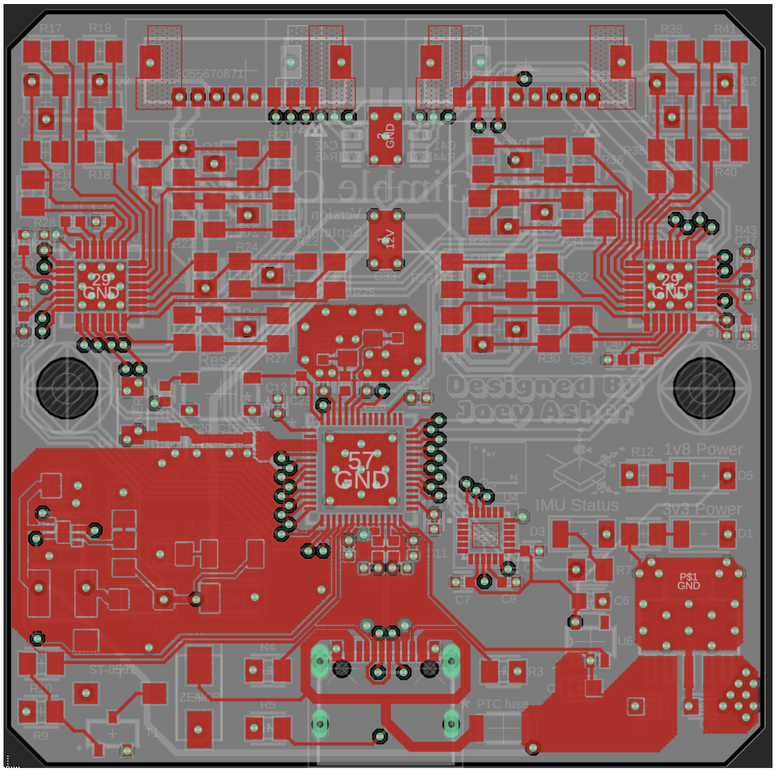

Fig. 4. Layout Top Layer

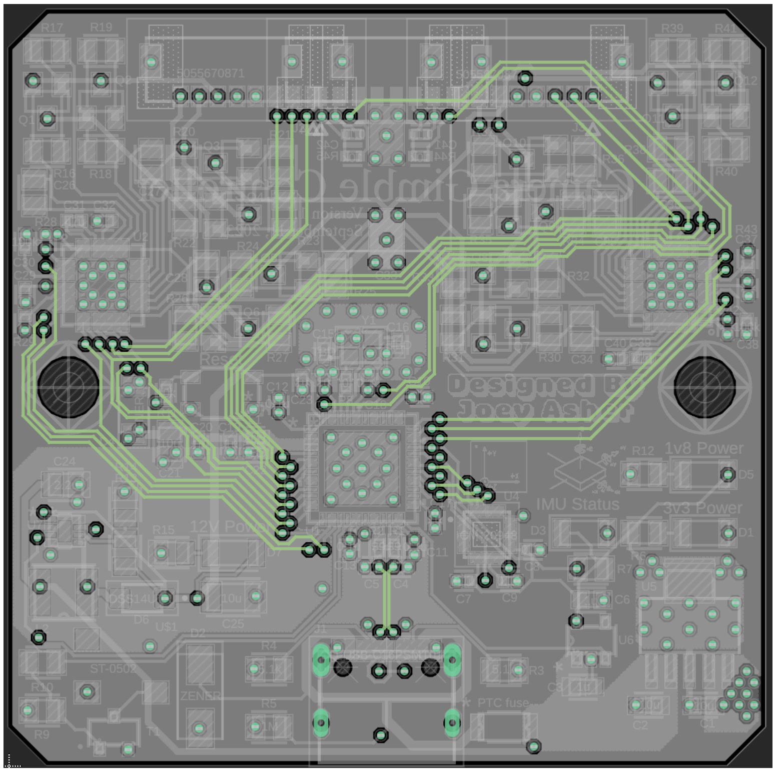

Fig. 5. Layout Layer 3

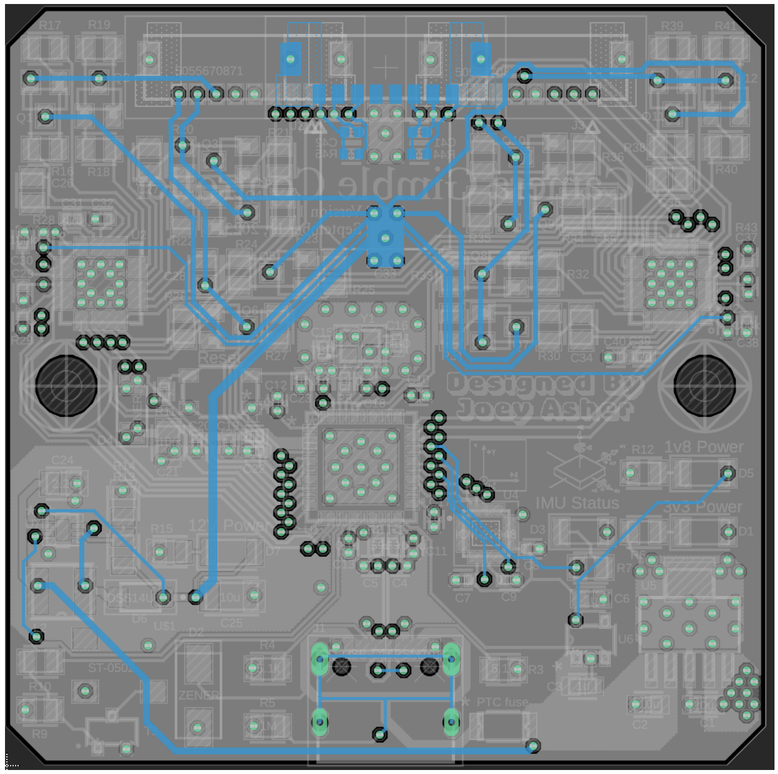

Fig. 6. Layout Bottom Layer

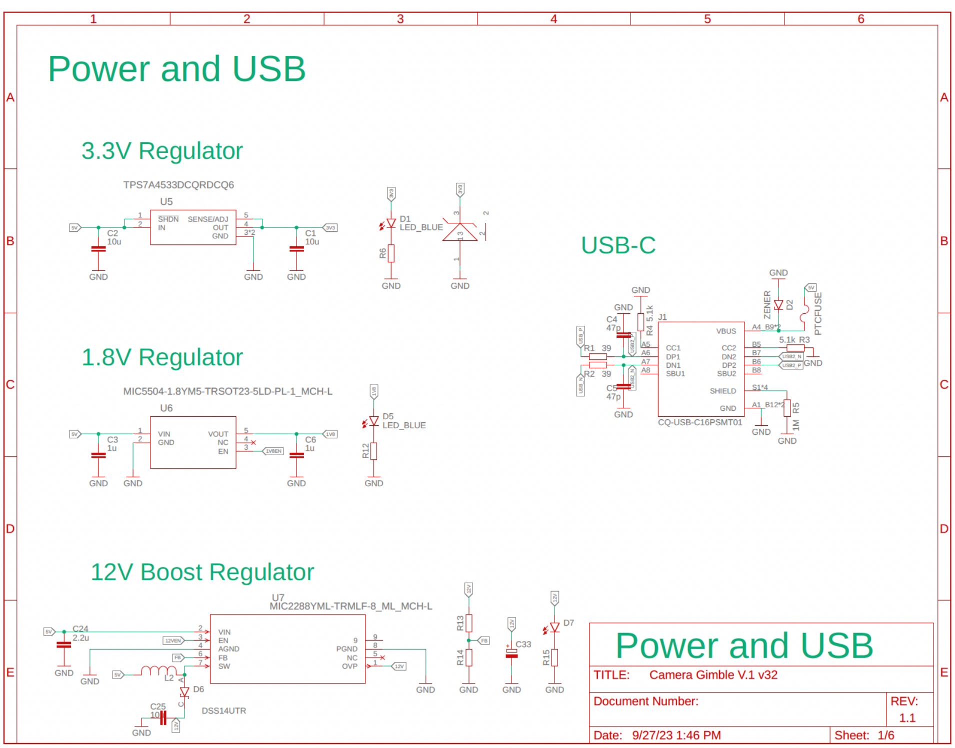

Fig. 7. Version 1.1 Power and USB Schematic

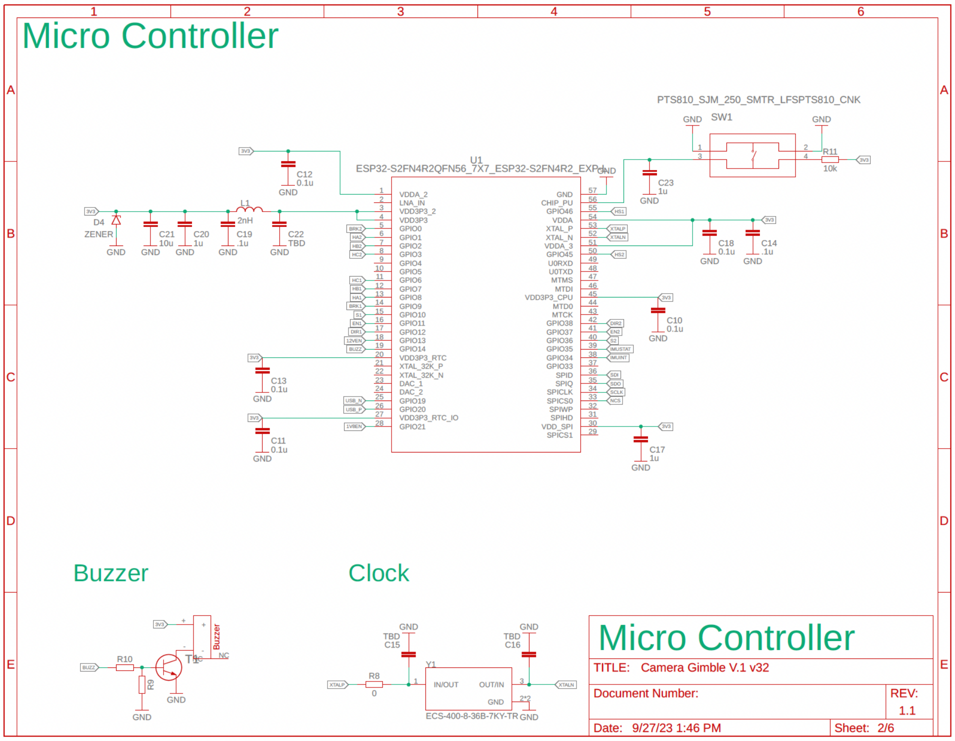

Fig. 8. Version 1.1 Microcontroller Schematic

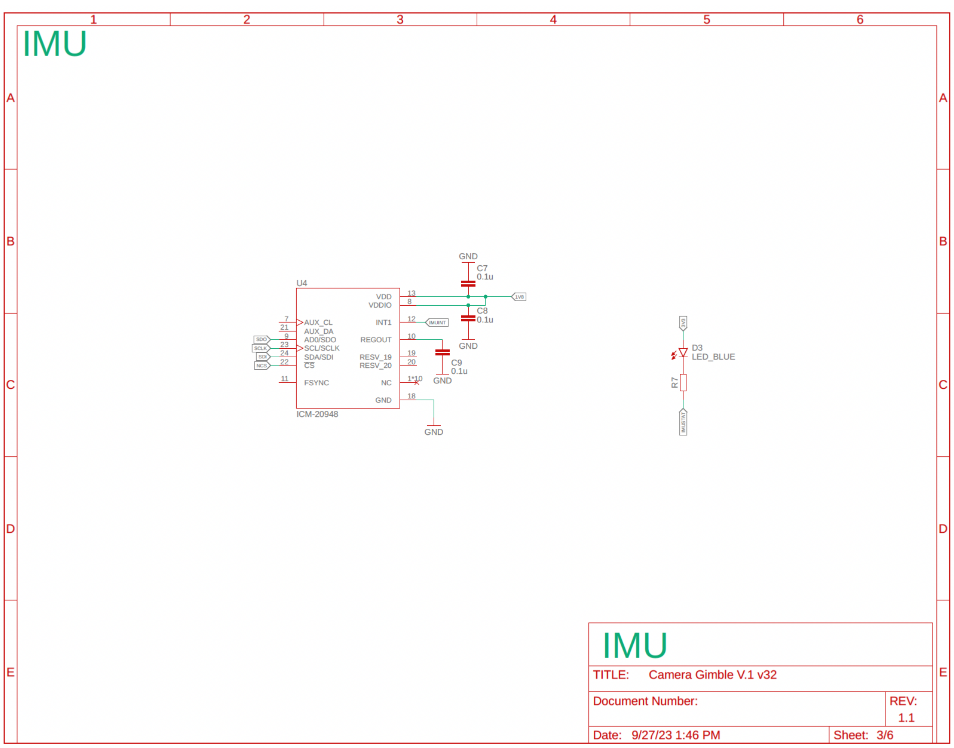

Fig. 9. Version 1.1 IMU Schematic

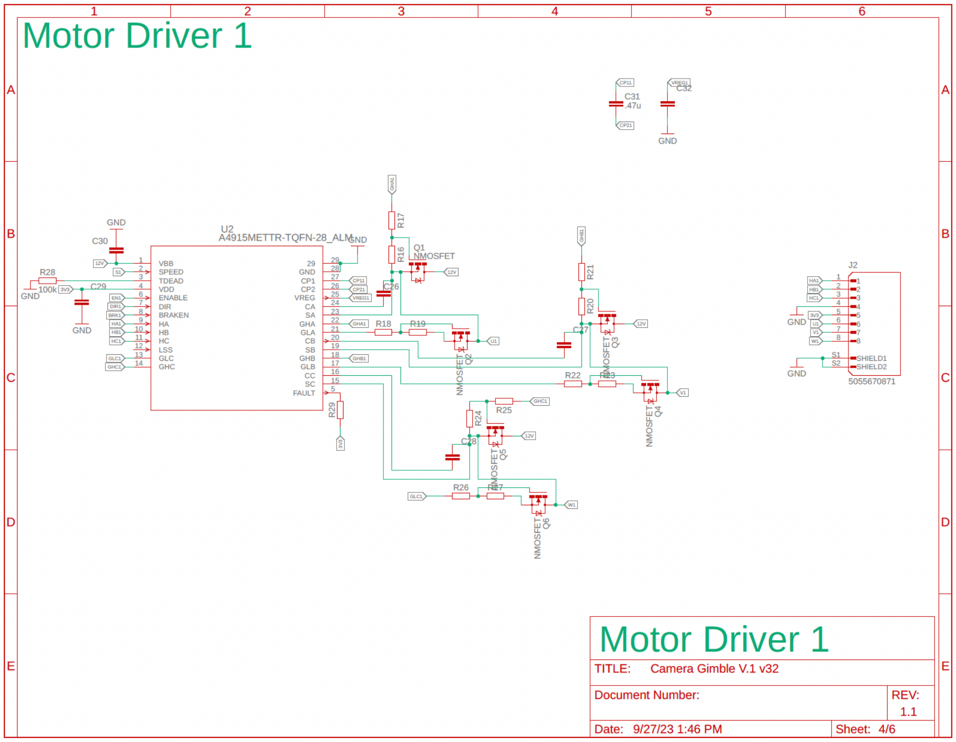

Fig. 10. Version 1.1 Motor Driver 1 Schematic

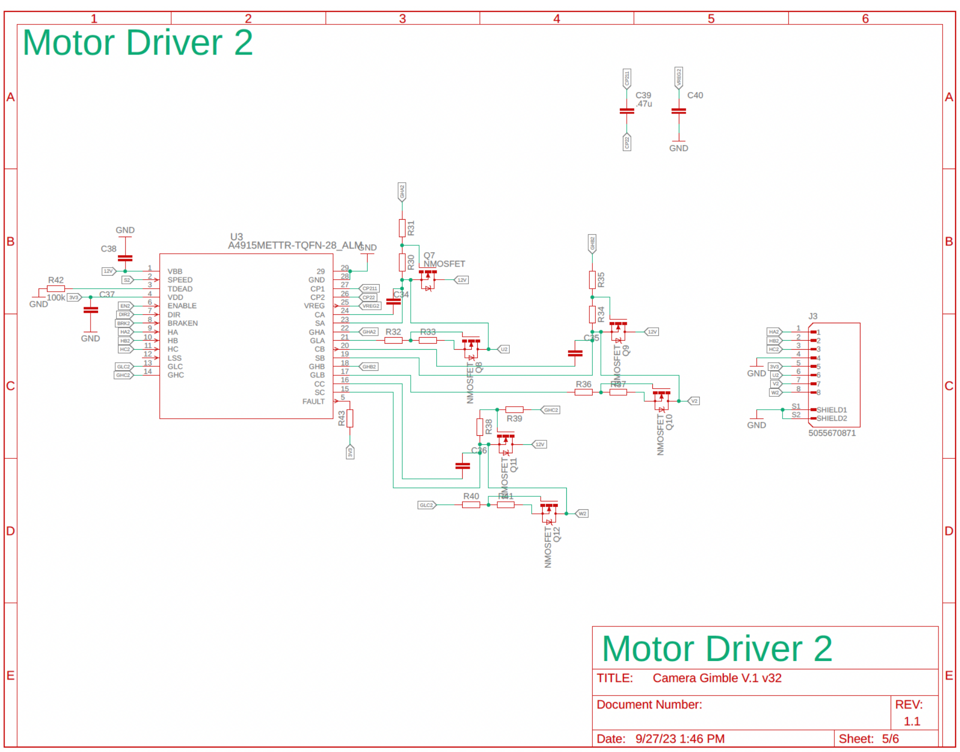

Fig. 11. Version 1.1 Motor Driver 2 Schematic

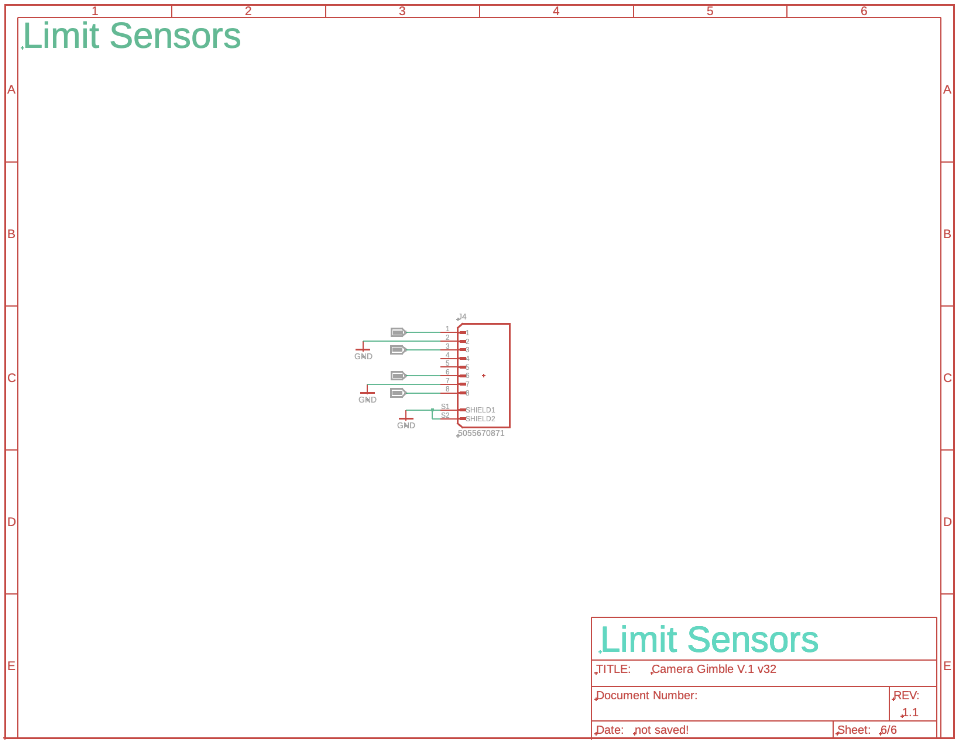

Fig. 12. Version 1.1 Limit Sensors Schematic

Appendix II
3D Rendering

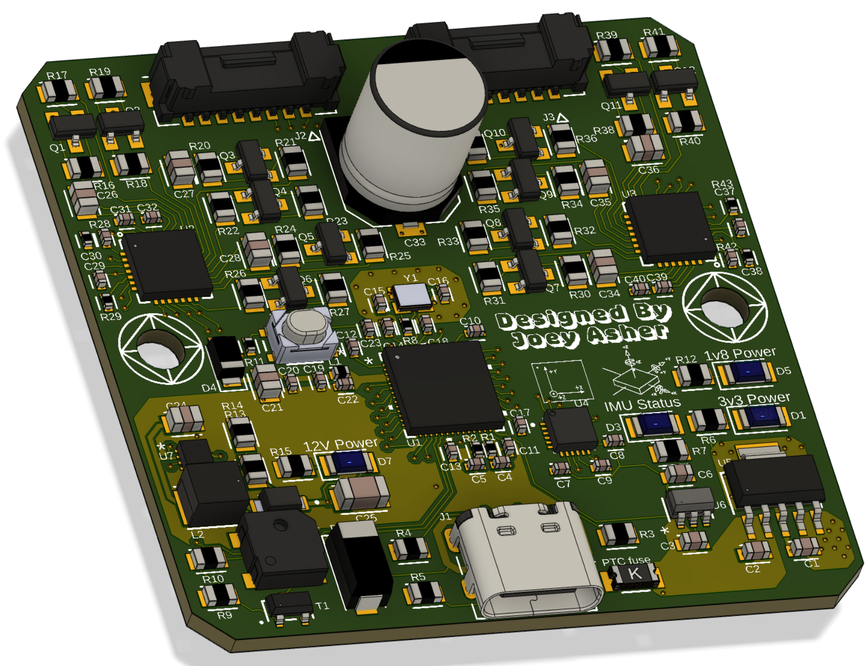

Fig. 13. 3D Rendering

APPENDIX III
BILL OF MATERIALS

TABLE II
SAMPLE TABLE FROM CSV

Part	Value	Device	Package
C1	10u	C˙CHIP-0603(1608-METRIC)	CAPC1608X85
C2	10u	C˙CHIP-0603(1608-METRIC)	CAPC1608X85
C3	1u	C˙CHIP-0603(1608-METRIC)	CAPC1608X85
C4	47p	C˙CHIP-0402(1005-METRIC)	CAPC1005X60
C5	47p	C˙CHIP-0402(1005-METRIC)	CAPC1005X60
C6	1u	C˙CHIP-0603(1608-METRIC)	CAPC1608X85
C7	0.1u	C˙CHIP-0402(1005-METRIC)	CAPC1005X60
C8	0.1u	C˙CHIP-0402(1005-METRIC)	CAPC1005X60
C9	0.1u	C˙CHIP-0402(1005-METRIC)	CAPC1005X60
C10	0.1u	C˙CHIP-0402(1005-METRIC)	CAPC1005X60
C11	0.1u	C˙CHIP-0402(1005-METRIC)	CAPC1005X60
C12	0.1u	C˙CHIP-0402(1005-METRIC)	CAPC1005X60
C13	0.1u	C˙CHIP-0402(1005-METRIC)	CAPC1005X60
C14	.1u	C˙CHIP-0402(1005-METRIC)	CAPC1005X60
C15	TBD	C˙CHIP-0402(1005-METRIC)	CAPC1005X60
C16	TBD	C˙CHIP-0402(1005-METRIC)	CAPC1005X60
C17	1u	C˙CHIP-0402(1005-METRIC)	CAPC1005X60
C18	0.1u	C˙CHIP-0402(1005-METRIC)	CAPC1005X60
C19	.1u	C˙CHIP-0402(1005-METRIC)	CAPC1005X60
C20	1u	C˙CHIP-0402(1005-METRIC)	CAPC1005X60
C21	10u	C˙CHIP-0805(2012-METRIC)	CAPC2012X110
C22	TBD	C˙CHIP-0402(1005-METRIC)	CAPC1005X60
C23	1u	C˙CHIP-0402(1005-METRIC)	CAPC1005X60
C24	2.2u	C˙CHIP-0805(2012-METRIC)	CAPC2012X110
C25	10u	C˙CHIP-1206(3216-METRIC)	CAPC3216X135
C26		C˙CHIP-0805(2012-METRIC)	CAPC2012X110
C27		C˙CHIP-0805(2012-METRIC)	CAPC2012X110
C28		C˙CHIP-0805(2012-METRIC)	CAPC2012X110
C29		C˙CHIP-0402(1005-METRIC)	CAPC1005X60
C30		C˙CHIP-0402(1005-METRIC)	CAPC1005X60
C31	.47u	C˙CHIP-0402(1005-METRIC)	CAPC1005X60
C32		C˙CHIP-0402(1005-METRIC)	CAPC1005X60
C33		C-POL˙ECAP-8.5MM	CAPAE830X1050N
C34		C˙CHIP-0805(2012-METRIC)	CAPC2012X110
C35		C˙CHIP-0805(2012-METRIC)	CAPC2012X110
C36		C˙CHIP-0805(2012-METRIC)	CAPC2012X110
C37		C˙CHIP-0402(1005-METRIC)	CAPC1005X60
C38		C˙CHIP-0402(1005-METRIC)	CAPC1005X60
C39	.47u	C˙CHIP-0402(1005-METRIC)	CAPC1005X60
C40		C˙CHIP-0402(1005-METRIC)	CAPC1005X60
C41	0.1u	C˙CHIP-0402(1005-METRIC)	CAPC1005X60
C42	0.1u	C˙CHIP-0402(1005-METRIC)	CAPC1005X60
D1	LED˙BLUE	CHIP-FLAT-B˙1206	LEDC3216X75N˙FLAT-B
D2	ZENER	ZENERDO-214AC(SMA)	DIOM5226X290N
D3	LED˙BLUE	CHIP-FLAT-B˙1206	LEDC3216X75N˙FLAT-B
D4	ZENER	ZENER˙DO-219-AB(SOD123F)	SODFL3718X115
D5	LED˙BLUE	CHIP-FLAT-B˙1206	LEDC3216X75N˙FLAT-B
D6	DSS14UTR	DSS14UTR	SODFL3618X110N
D7	LED˙BLUE	CHIP-FLAT-B˙1206	LEDC3216X75N˙FLAT-B
J1	CQ-USB-C16PSMT01	CQ-USB-C16PSMT01	SHENZHEN-CHUANGQIN-TECHNO
L1	2nH	L˙CHIP-0402(1006-METRIC)	INDC1006X60N
L2	LQH43CN100K03LIND˙LQH43˙MUR	LQH43CN100K03LIND˙LQH43˙MUR	IND˙LQH43˙MUR
PTCFUSE	PTCFUSE	1206L012WR1206LSERIES˙LTF-M	1206LSERIES˙LTF-M
Q1	NMOSFET	NMOSFET˙SOT23-GSD	SOT23
Q2	NMOSFET	NMOSFET˙SOT23-GSD	SOT23
Q3	NMOSFET	NMOSFETSOT23-GSD	SOT23
Q4	NMOSFET	NMOSFET˙SOT23-GSD	SOT23
Q5	NMOSFET	NMOSFET˙SOT23-GSD	SOT23
Q6	NMOSFET	NMOSFET˙SOT23-GSD	SOT23
Q7	NMOSFET	NMOSFET˙SOT23-GSD	SOT23
Q8	NMOSFET	NMOSFET˙SOT23-GSD	SOT23
Q9	NMOSFET	NMOSFETSOT23-GSD	SOT23
Q10	NMOSFET	NMOSFET˙SOT23-GSD	SOT23
Q11	NMOSFET	NMOSFET˙SOT23-GSD	SOT23
Q12	NMOSFET	NMOSFET˙SOT23-GSD	SOT23
R1	39	R˙CHIP-0402(1005-METRIC)	RESC1005X40
R2	39	R˙CHIP-0402(1005-METRIC)	RESC1005X40
R3	5.1k	R˙CHIP-0805(2012-METRIC)	RESC2012X65
R4	5.1k	R˙CHIP-0805(2012-METRIC)	RESC2012X65
R5	1M	R˙CHIP-0805(2012-METRIC)	RESC2012X65
R6		R˙CHIP-0805(2012-METRIC)	RESC2012X65
R7		R˙CHIP-0805(2012-METRIC)	RESC2012X65
R8	0	R˙CHIP-0402(1005-METRIC)	RESC1005X40
R9		R˙CHIP-0805(2012-METRIC)	RESC2012X65