AUTOMATED OPTICAL INSPECTION

GROUP 1

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SPONSORED BY

MEET THE TEAM

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INTRODUCTION – TECHNOLOGY SUMMARY

- Automated Optical Inspectors (AOIs) are a device that scans small parts on production lines to determine the quality of the product
- Use high resolution imaging systems
- Compiles said imagines and determines quality with machine learning and AI
- Higher end systems can use 3-D modeling for a more immersive analysis

MOTIVATION

- Designing an AOI that is cost efficient that will help the UCF Photonic MOFD Team with their manufacturing Quality Control (QC)
- The product that they are developing is a color changing fabric, with individual copper wires that heat thermochromic pigments
- Operating in the IR range in order to determine if the heat signature from the fabric matches noted patterns that resemble pass/fail patterns
- System will also have an attached laser counter in order to further help the MOFD keep track of the amount of material being used

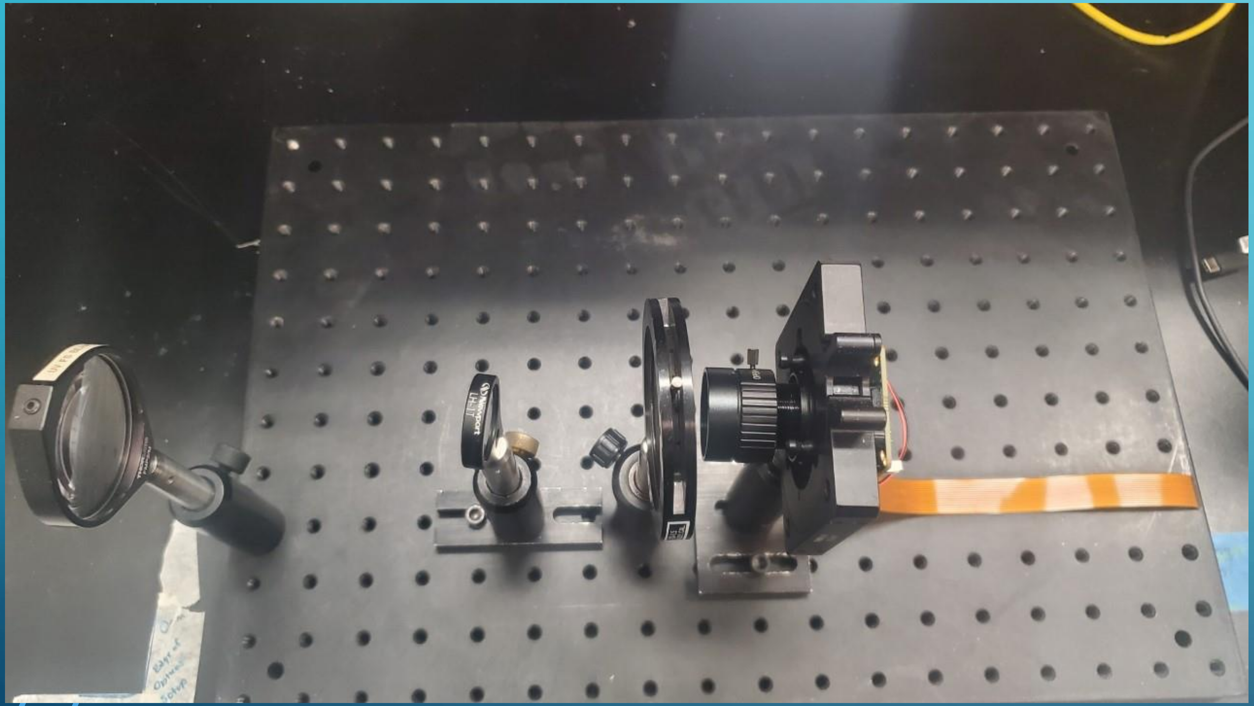
GOALS & OBJECTIVES

- Create a device that can take photos at a set rate
- System can process images at the same interval
- System can determine whether the image of the product passes or fails through machine learning
- Laser counter that can keep an accurate count of the fabric material

ENGINEERING SPECIFICATIONS

Description	**Project Minimum Targets**
A.I. Positive Detection rate	>70%
Error rate	<30%
Rate of reading and processing	>1 ft/s
Thermal inspection area	<100 um
Cost	<$2500
Photo Rate	>360 threads/sec

AOI SYSTEM DIAGRAM

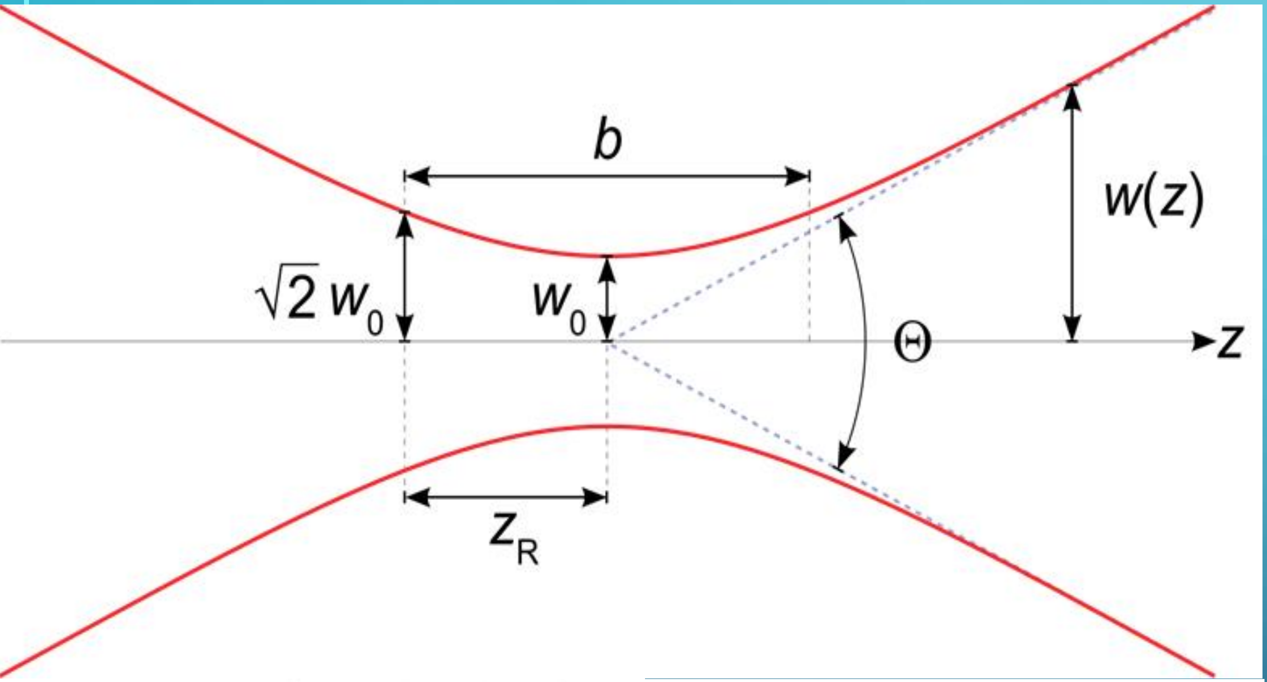


- Image of the fabric is captured on the production by our 150 mm front-end optic
- The image is further focused by a 75 mm lens
- The image is then focused and magnified by our camera system with an aperture to help correct most ambient light

LASER COUNTING SYSTEM

- Our laser is put through a Galilean Beam expander in order to expand the diameter by a rough factor of 3.
- The laser is then focused through a 150 mm Plano Convex lens in order to focus the beam so that it has an appropriate spot size of 50 microns

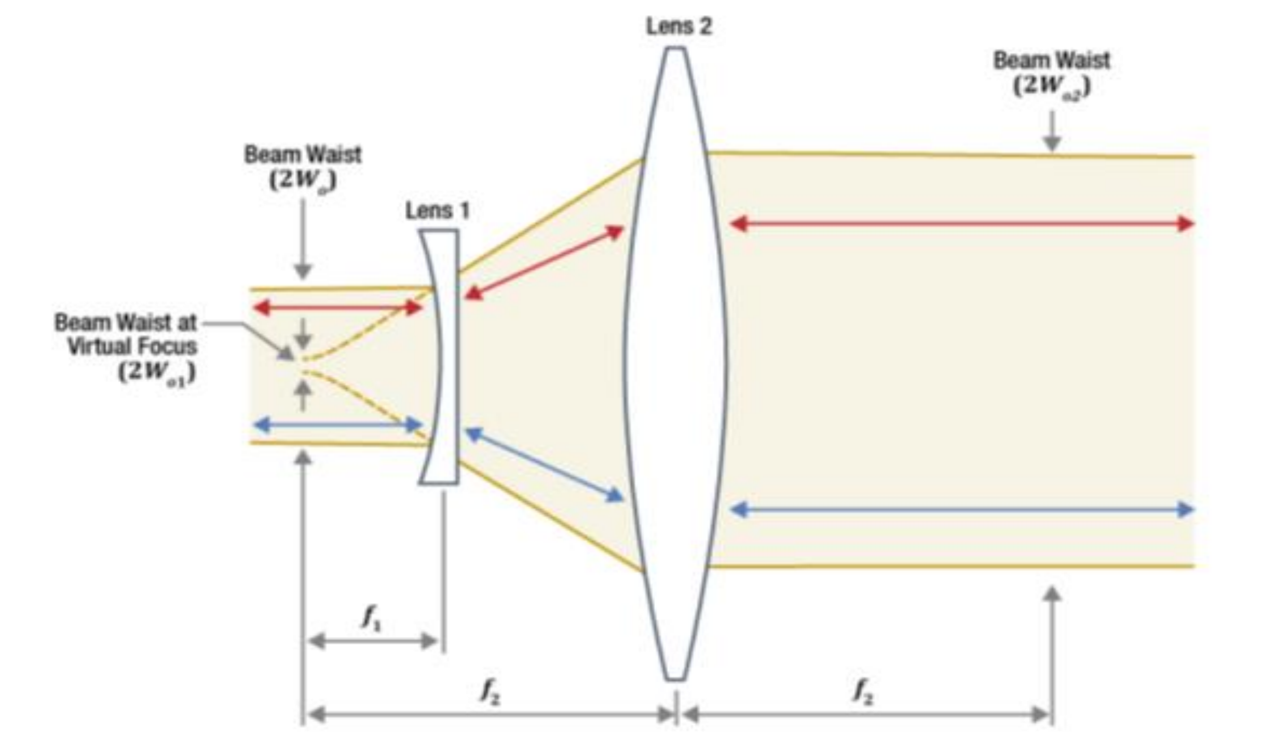
OPTICS THEORY – GAUSSIAN BEAM PROPAGATION



$$2w_0 = \left(\frac{4\lambda}{\pi}\right)\left(\frac{F}{D}\right) \qquad DOF = \left(\frac{8\lambda}{\pi}\right)\left(\frac{F}{D}\right)^2$$

- The beam waist and the Depth of Focus can be solved for with the following equations
- Finding the parameters in order to get an ideal value is also possible since the wavelength, diameter, and focal length can be constants

OPTICS THEORY – GALILEAN BEAM EXPANSION



$$2w_0 = \left(\frac{4\lambda}{\pi}\right)\left(\frac{F}{D}\right) \quad DOF = \left(\frac{8\lambda}{\pi}\right)\left(\frac{F}{D}\right)^2$$

- To achieve the proper beam diameter for target beam waist and depth of focus, a beam expander is used

- The Galilean Beam Expander is used with a convex and concave lens to increase the diameter by a factor of 3.

- This telescopic methodology is the same process for our camera

OPTICS HARDWARE

Lenses : $280 from Thorlabs

Shape of Lens	Plano-Convex
Substrate	NBK-7
Wavelength Range	350 nm – 700 nm
Lens Diameter	1”

Shape of Lens	Plano-Convex
Substrate	NBK-7 Uncoated
Wavelength Range	350 nm – 2000 nm
Lens Diameter	1”

Laser: Procured from MOFD Team

Laser Type	Semiconductor
Wavelength	533 nm
Power Output	50mW +
Power Source	Two Double A Batteries
Beam Diameter	~ 1 mm
Beam Divergence	Unknown

OPTICS HARDWARE CONT.

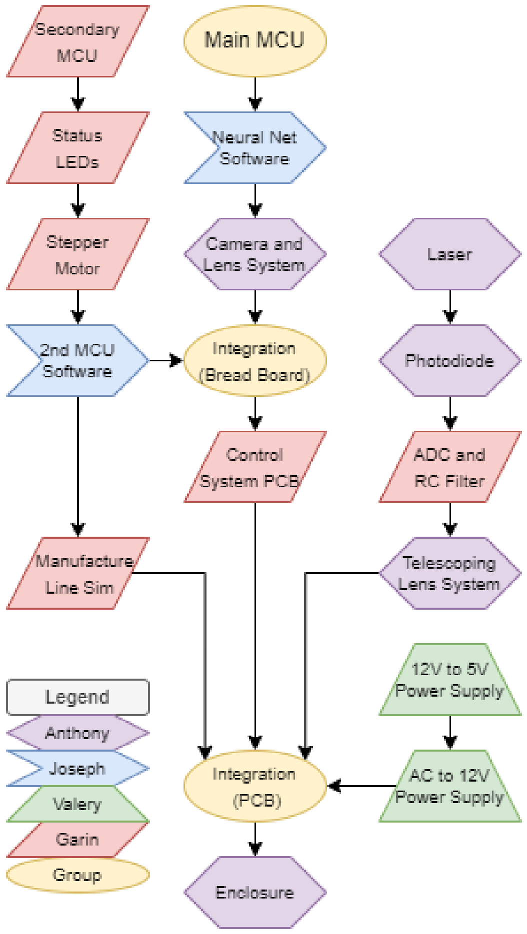
- Arducam HQ IR-CUT Camera 12.3MP 1/2.3-In IMX477 w/ 6mm CS Lens for Jetson Nano ($80)

- FD11A Si Photodiode (2 pack - $32)

WORK DISTRIBUTION

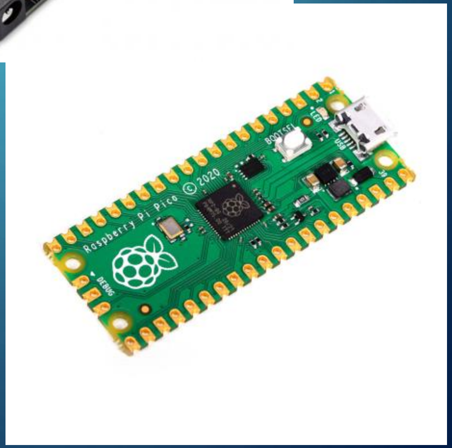
- Power Supply: Valery Jean
- AOI: Anthony Badillo
- Laser Counter: Anthony Badillo
- Stepper Motor: Garin Arabaci
- Control System PCB: Garin Arabaci
- Image Processing Software: Joseph Sauceda
- Secondary MCU Software: Joseph Sauceda
- Alert Interface (LEDs): Garin Arabaci
- Photodiode RC Filter: Garin Arabaci

DESIGN FLOW DIAGRAM



CONTROL SYSTEM

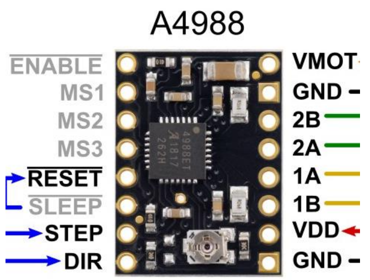
MICRO CONTROLLER UNIT SELECTION



	MSP430FR6989	ESP32	Raspberry Pi Pico (Secondary)	Raspberry Pi 4B	Jeston Nano (Main)
CPU Cores	1 core	1 or 2 core	2 cores	4 cores	4 cores
CPU Speed	16 MHz	240 MHz	133 MHz	1.5 GHz	1.43 GHz
Memory	2 KB	520 KB	264 KB	VideoCore VI 3D	128 core Maxwell
GPU	N/A	N/A	N/A	1,2, or 4 GB	2 or 4 GB
GPIOs	83 pins	36 pins	26 pins	28 pins	28 pins
Communication Protocols	UART, I2C, SPI	UART, I2C, I2S, SPI	UART, I2C, SPI	UART, I2C, SPI	UART, I2C, I2S, SPI
ADC	12-Bit	12-Bit	12-Bit	N/A	N/A
PWM	5 Channels	16 Channels	16 Channels	2 Channels	2 Channels
USB3.0	N/A	N/A	N/A	YES	YES
Ethernet	N/A	N/A	N/A	YES	YES
Storage	128 KB	16 KB	2 MB	microSD	microSD
Power Maximums	3.3V/1.6mA [0.005W]	3.3V/0.5A [1.65W]	5V/100mA [0.5W]	5V/3A [15W]	5V/5A [25W]
MISC	Low Power Modes	Bluetooth/Wi-Fi	Wi-Fi Variant	Bluetooth/Wi-Fi	Dedicated GPU, AI

STEPPER MOTOR FOR AUTO-FOCUSING

- The desired resolution of movement for the auto-focusing system was 0.1mm minimum.
- Using a belt driven system, with the following parameters we can achieve a resolution of 0.01mm.
  - NEMA17 motor with 200 steps per revolution (Srev)
  - A4988 at 1/16 steps (fm)
  - 2mm pitched belt (p)
  - 16 tooth pulley (Nt)



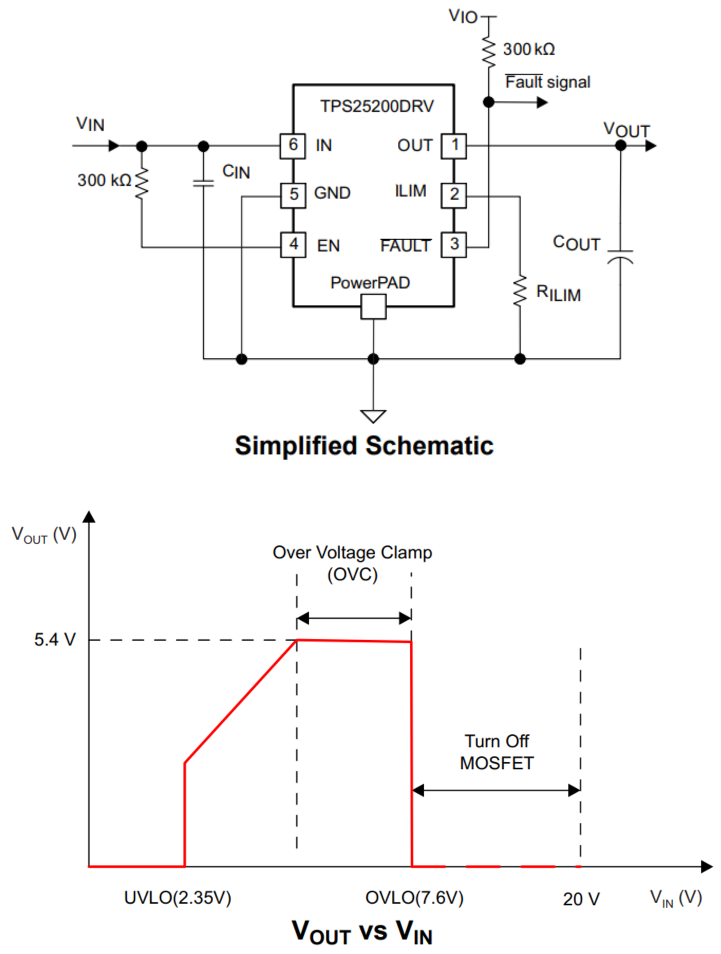
$$\frac{s_{rev} \cdot f_m}{p \cdot N_t}$$

	Allegro A4988 (Selected)	TI DRV8825	TB6560AHQ
Min Motor Voltage	8V	8.2V	4.5V
Max Motor Voltage	35V	45V	34V
Continuous Current	1.2A per phase	2.2A	3A per phase
Max Current	2A per phase	2.2A	3A per phase
Min Logic Voltage	3V	1V	4.5V
Max Logic Voltage	5.5V	3.5V	5.5V
Microsteps	Full, 1/2, 1/4, 1/8, 1/16	Full, 1/2, 1/4, 1/8, 1/16, 1/32	Full, 1/2, 1/4, 1/8, 1/16

POWER REQUIREMENTS AND PROTECTIONS

Device	Estimated	MAXIMUM
Jetson GPU	5V/2A (10W)	5V/5A [2.5A per pin] (25W)
Jeston USB (IR CAM)	5V/0.77A (3.85W)	From GPU power
PICO	5V/?A	5V/100mA (0.5W)
PICO ADC	3.3V/?A	Only for Reference
A4988 Logic	3 to 5.5V/?A	3.3V/8mA (0.03W)
A4988 Motor	12V/1A (12W)	12V/2A (24W)
Totals	26W	50W

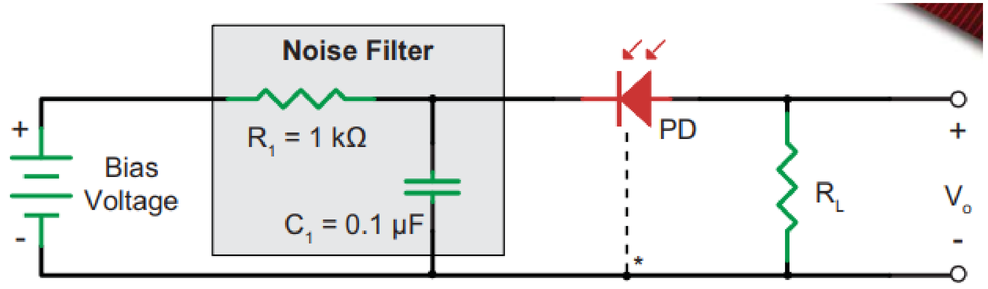
- The Jeston will be powered via 3 pins found in its 40-pin jumper. Pins 2 and 4 both accept 5V, but each have a maximum of 2.5A. Pin 6 will be GND.
- In order to protect the Jetson, 2 eFuses will be implemented to restrict the current and voltage that can be delivered to these pins.
- The PICO will be powered via the VSYS pin at 5V.
- As detailed by the PICO's datasheet a Schottky diode is recommended.
    - The same Schottky diode used internally to protect the VBUS pin will be used in this case. Which is a 20V 1A Schottky.



EFUSES

- The eFuse allows for precision current limiting and overvoltage clamping
- In this case, I made use of the TPS25200 from TI which I configured for exactly 2455.12mA max current limiting. This was accomplished with the following value
  - Rlim = 42.2K Ohm 1%
  - Cin = 0.1uF ceramic bypass
  - Cout = 20uF (using 2 10uF in parallel) low ESR ceramic
- 4 Operational Modes
  - Undervoltage Lockout (UVLO)
  - Overcurrent Protection (OCP)
  - Overvoltage Clamp (OVC)
  - Overvoltage Lockout (OVLO)
- Feature's fault signaling which will be routed to the PICO and is Active-Low. This will trigger for Overcurrent or Overvoltage, or Overtemperature situations.

PHOTODIODE

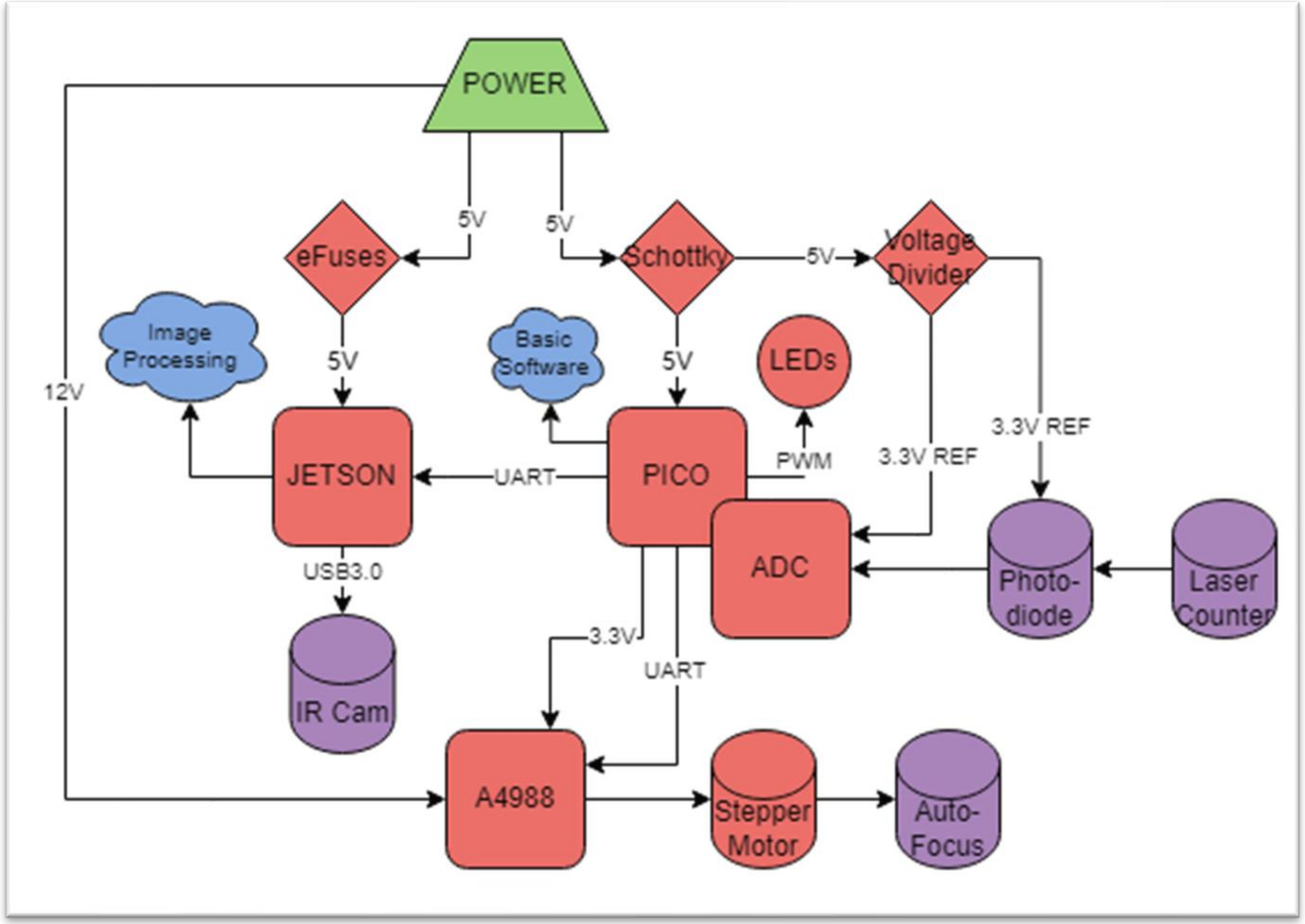


Specifications

Specifications[a]		
Wavelength Range	λ	320 - 1100 nm
Peak Wavelength	λ_P	960 nm
Responsivity (960 nm)	$\Re(\lambda)$	0.60 A/W
Active Area		1.21 mm^2
Rise Time (650 nm, R_L=1 kΩ, 0 V)	t_r	400 ns (Typ.)
NEP (960 nm, 0 V)	$W/\sqrt{Hz}$	6.8×10^{-16}
Dark Current (10 mV)	I_d	2 pA (Max)
Capacitance (0 V)	C_j	140 pF (Typ.)
Package		TO-18
Sensor Material		Si

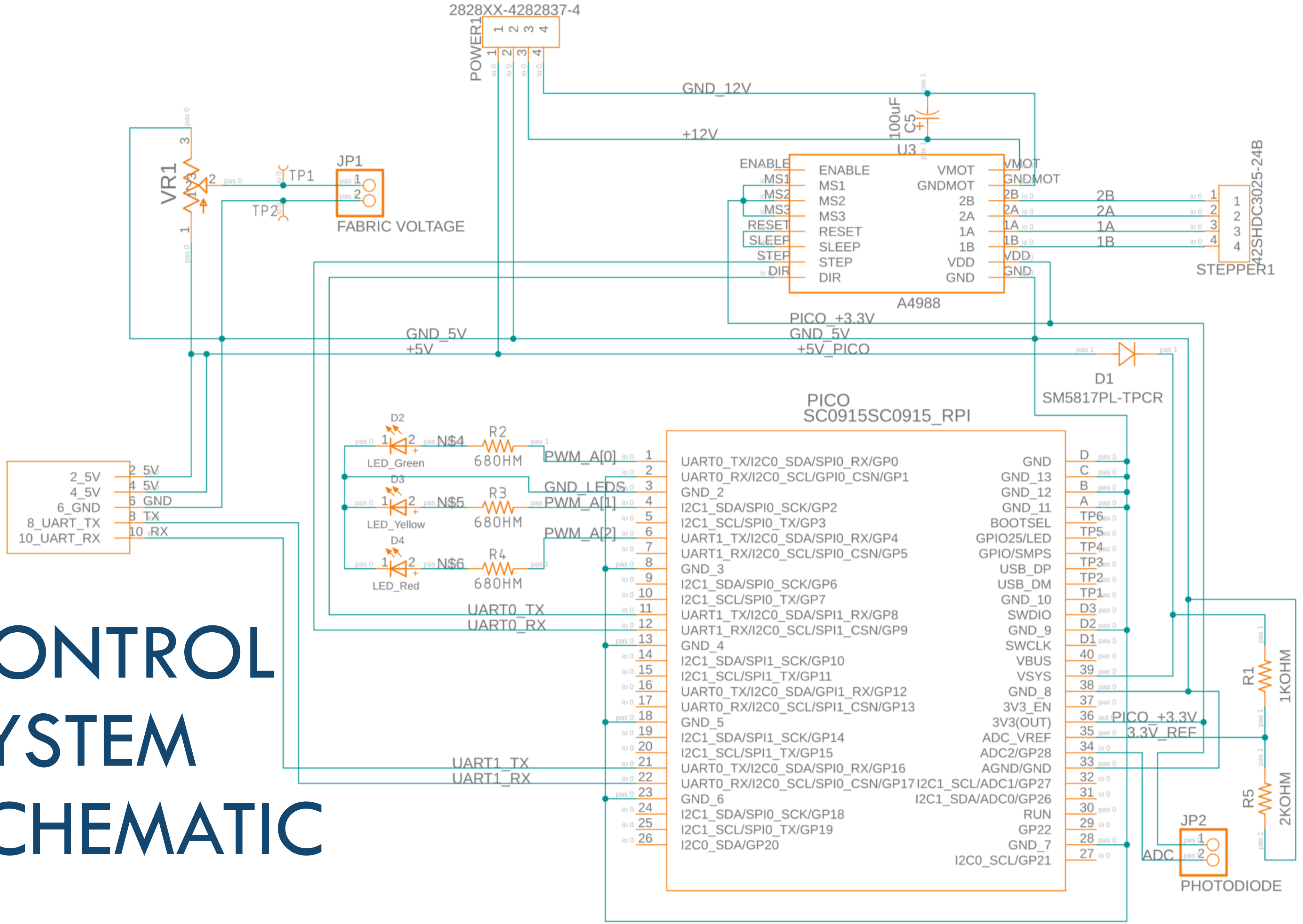
Maximum Rating	
Bias Voltage (Reverse)	30 V
Reverse Current	-
Operating Temperature	-40 to 100 °C
Storage Temperature	-55 to 125 °C

- THORLABS FD11A
- Reverse biased the diode with 3.3V from the Pico
- RC Low Pass Noise Filter
  - Cutoff Frequency of 1500Hz
- Connects to pin ADC2 of the Pico



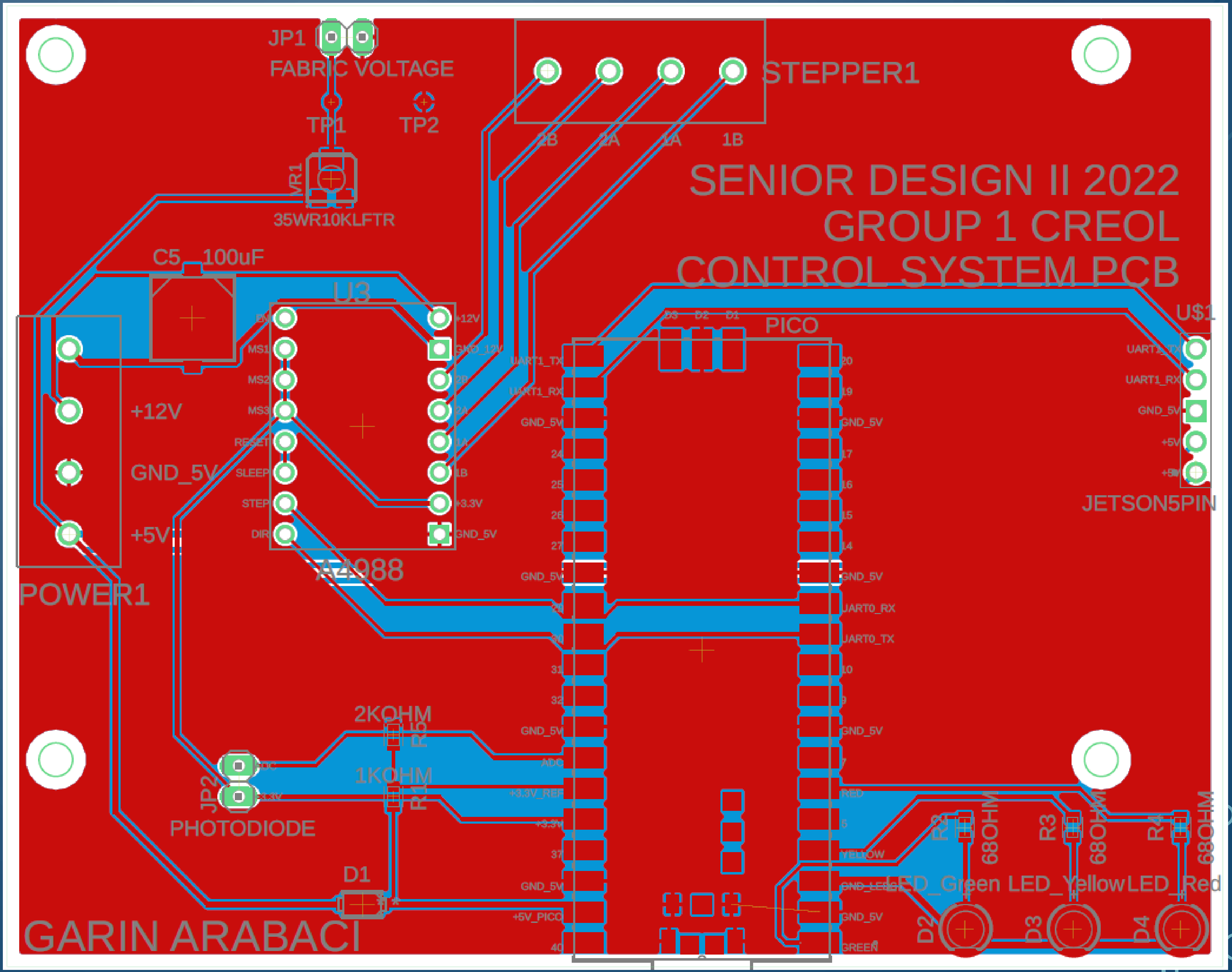
CONTROL SYSTEM BLOCK DIAGRAM

CONTROL SYSTEM SCHEMATIC

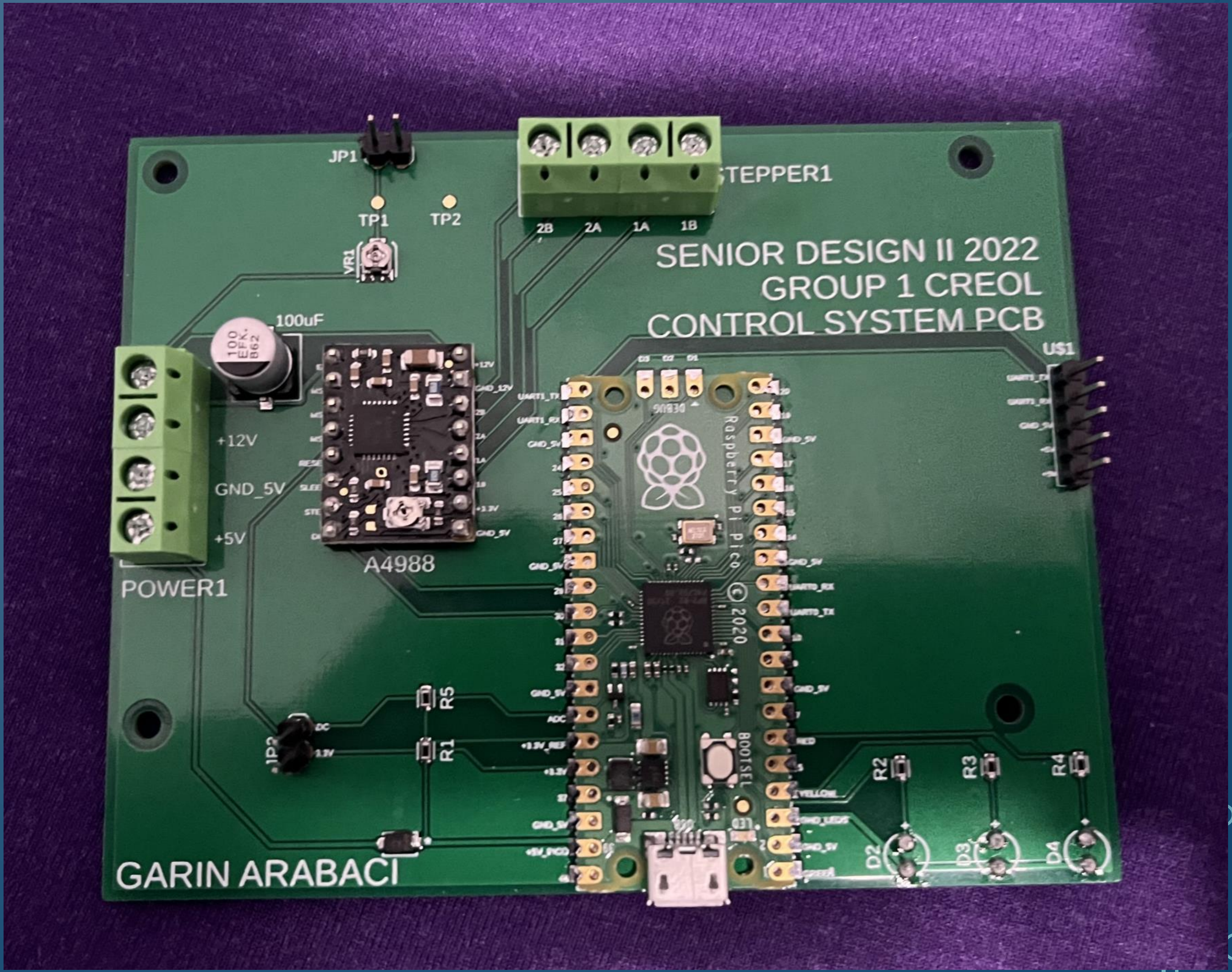


11/28/2022 10:24 AM f=2.65 C:\Users\garin\AppData\Local\Temp\Neutron\ElectronFileOutput\15984\sch-0088fc12-6763-4a35-bc82-4f00b483bcd4\Control System Schematic v2.sch (Sheet: 1/1)

CONTROL SYSTEM PCB



CONTROL SYSTEM PCB



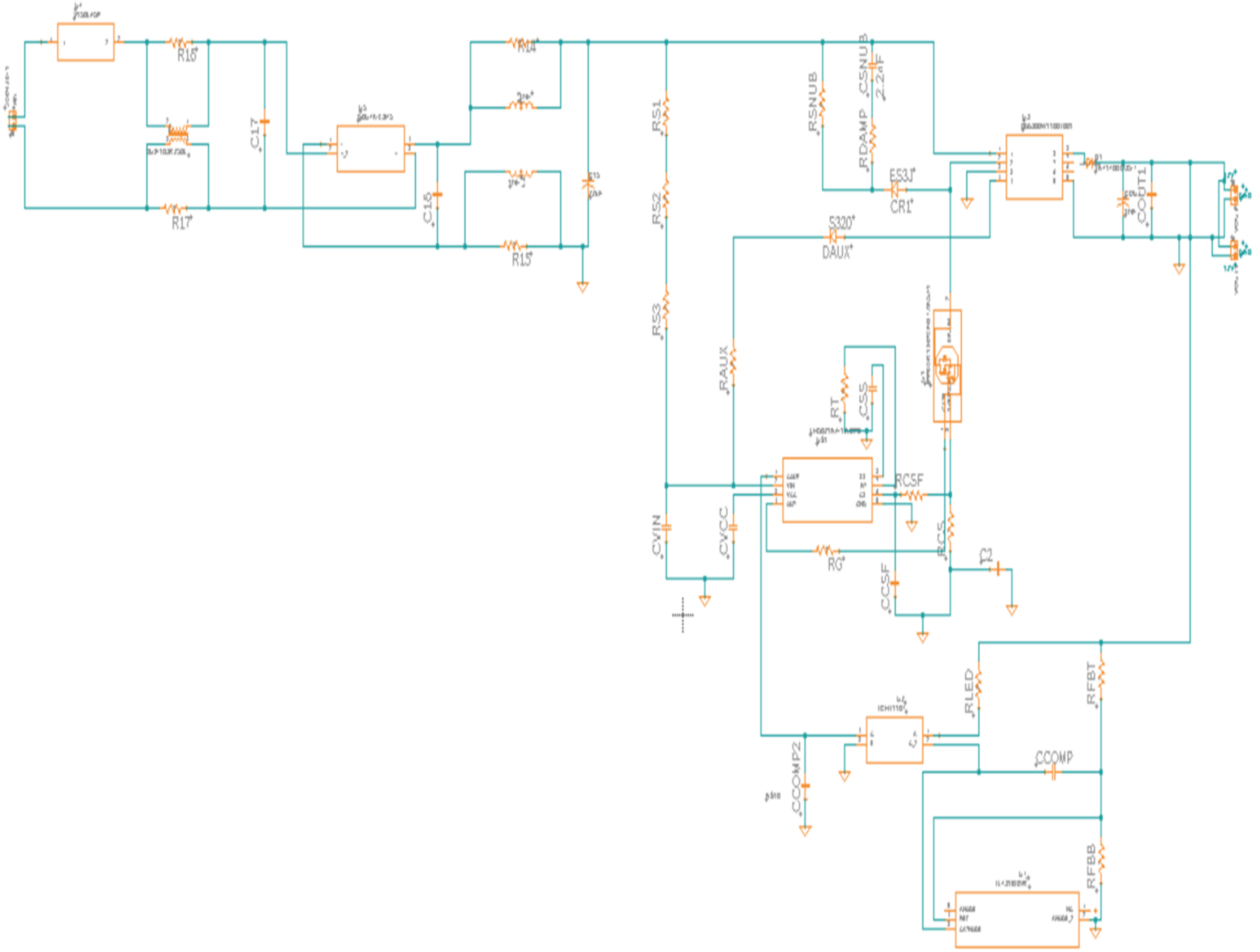
POWER CONTROL

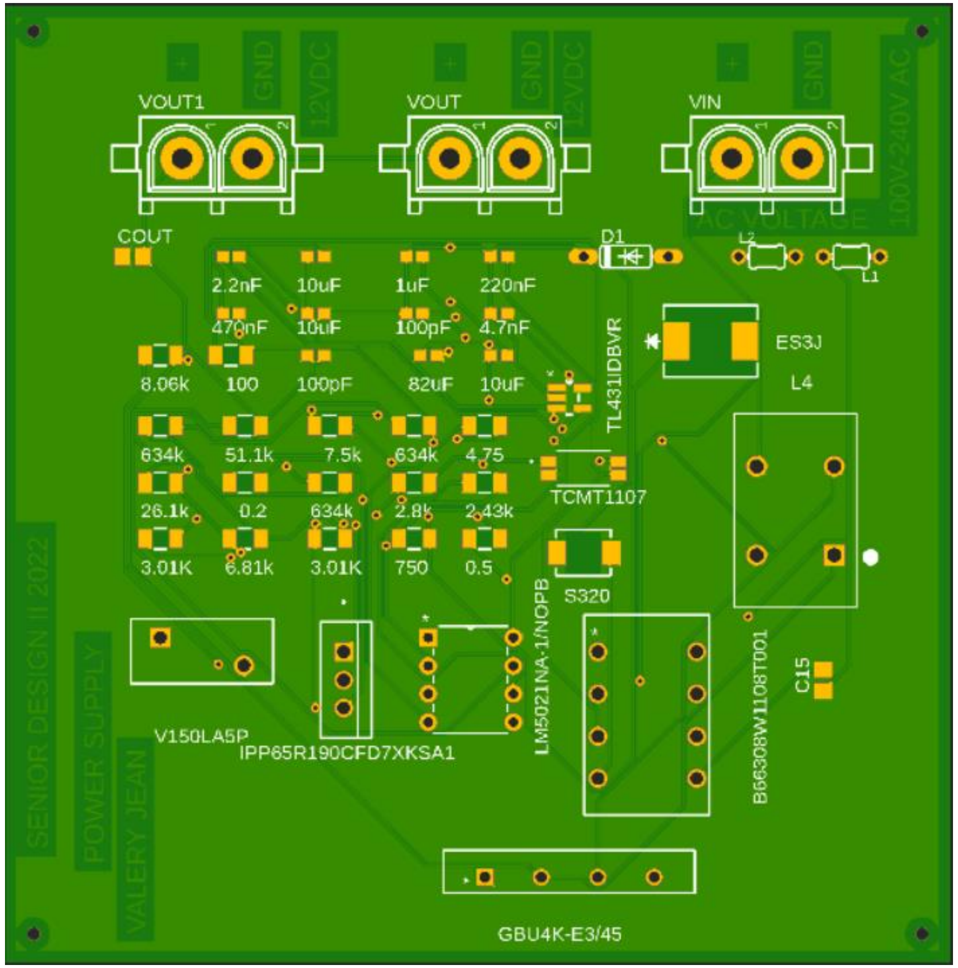
Two Types of Power Supply

- AC/DC Converter
- DC/DC Converter

AC/DC CONVERTER

- LM5021 From TI
- AC input range 100VAC to 240 VAC
- DC output of 12V, 4A

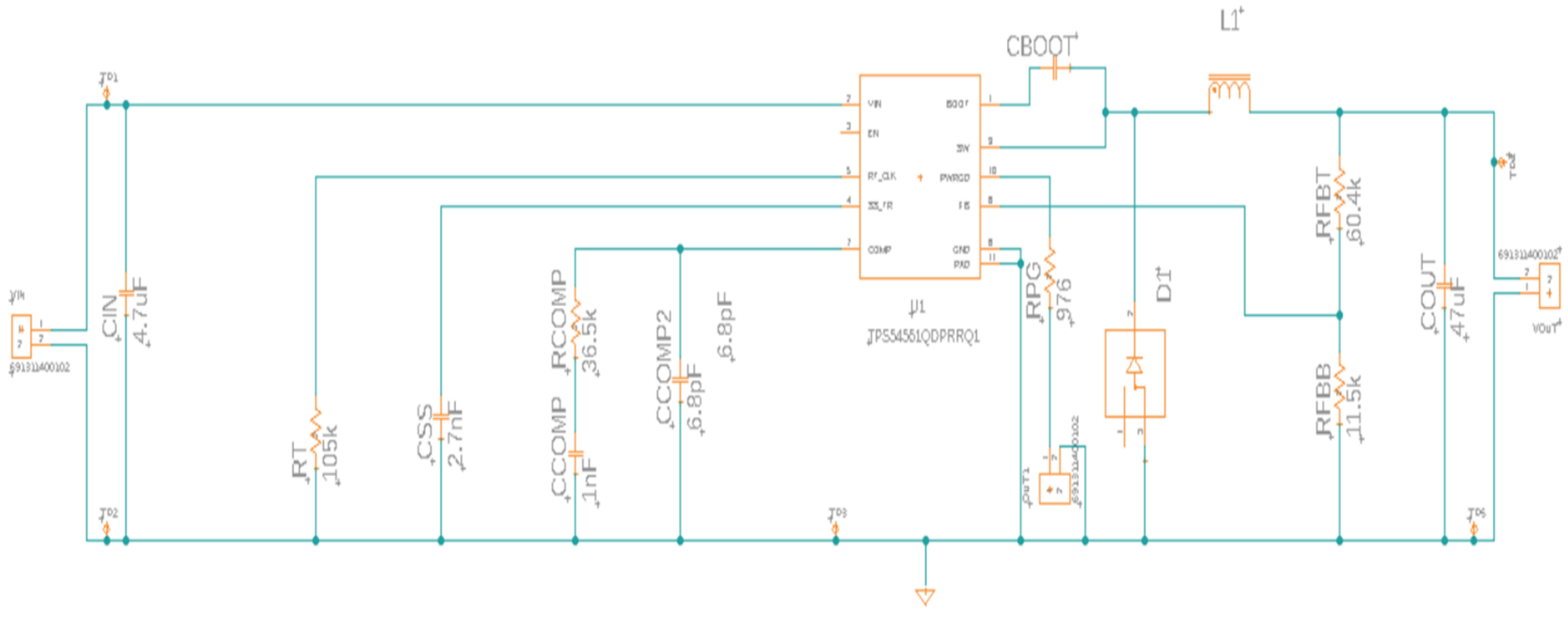




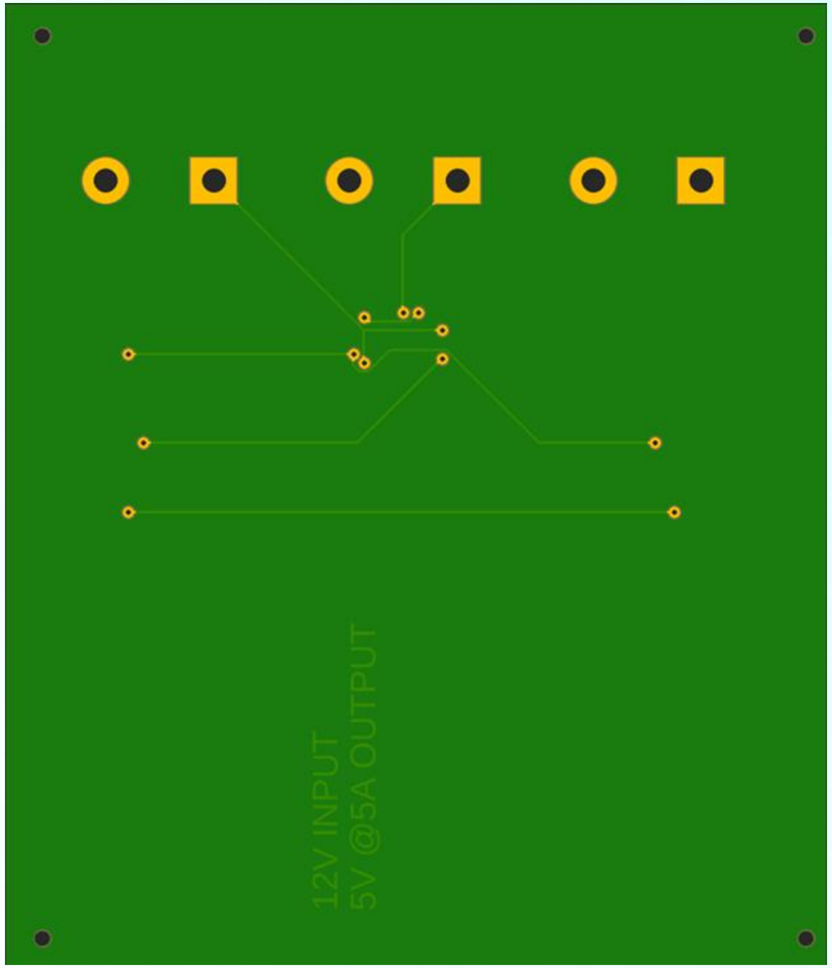
- AC-DC POWER SUPPLY PCB

BUCK DC/DC CONVERTER

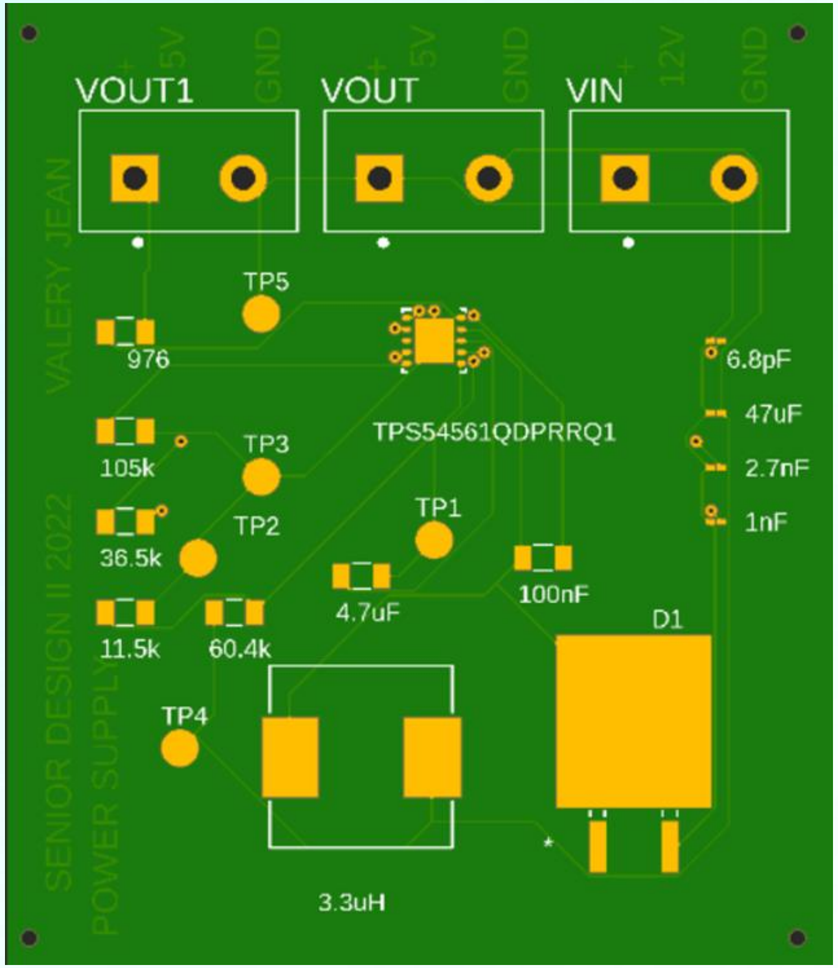
- TPS54561-Q1 from TI
- Input Voltage range : 7V to 60V
- Output Voltage 5V at 5A

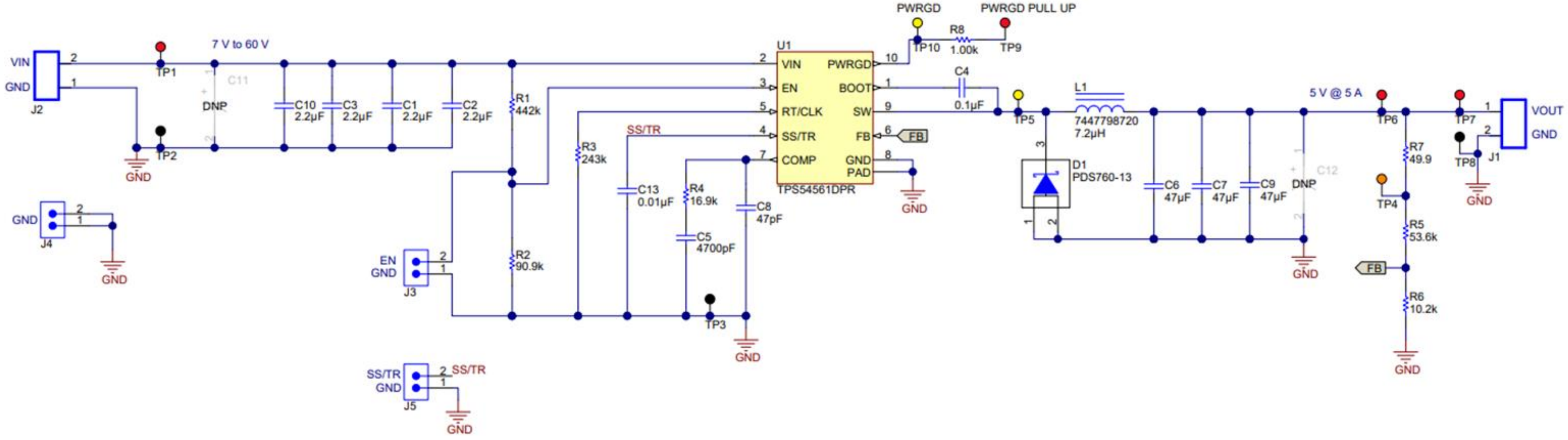


BOTTOM SIDE

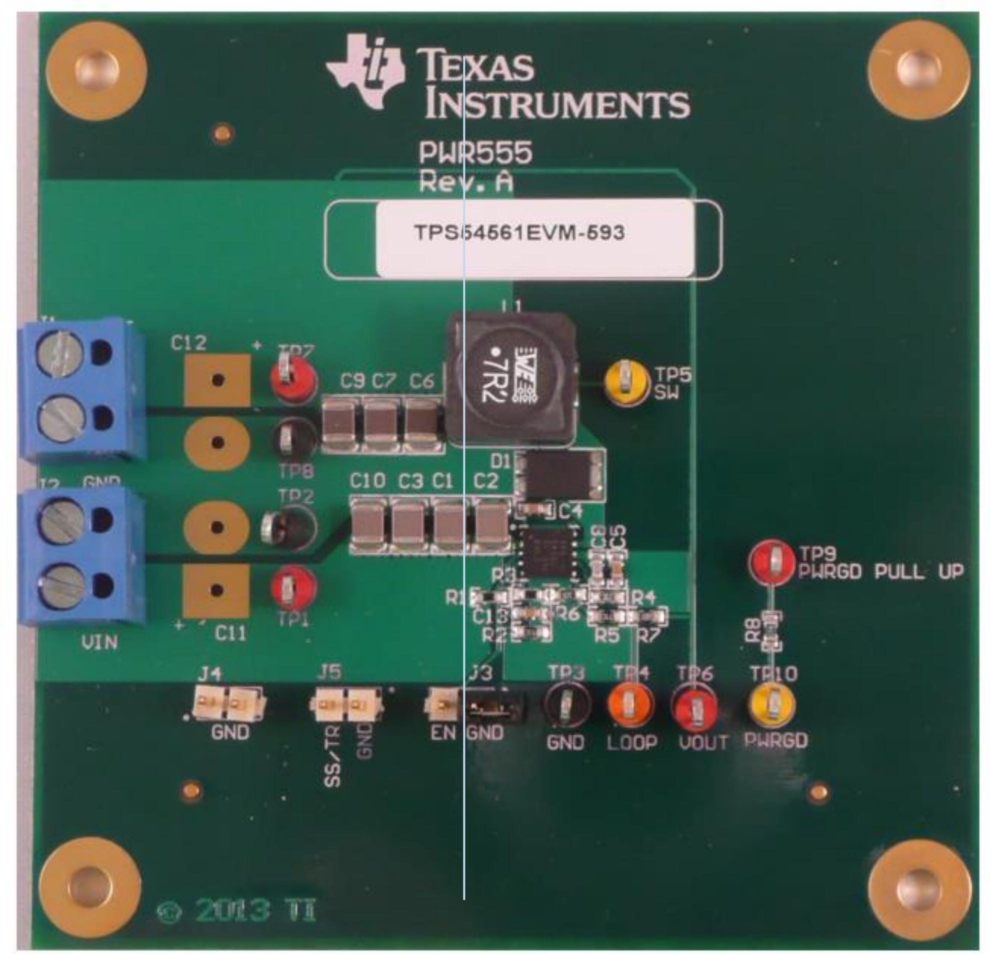


TOP SIDE

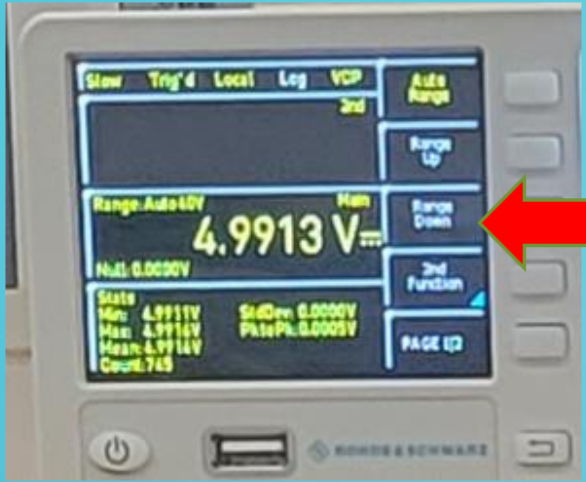




VIN
GND
J2
7 V to 60 V
TP1
TP2
C11
DNP
C10 2.2µF
C3 2.2µF
C1 2.2µF
C2 2.2µF
R1 442k
R2 90.9k
R3 243k
SS/TR
C13 0.01µF
R4 16.9k
C5 4700pF
C8 47pF
TP3
GND
J4
EN
GND
J3
SS/TR
GND
J5
U1
VIN
EN
RT/CLK
SS/TR
COMP
PWRGD
BOOT
SW
FB
GND
PAD
TPS54561DPR
PWRGD
PWRGD PULL UP
TP10
R8 1.00k
TP9
C4 0.1µF
FB
TP5
L1
7447798720
7.2µH
D1
PDS760-13
C6 47µF
C7 47µF
C9 47µF
DNP
C12
5 V @ 5 A
TP6
TP7
TP8
TP4
R7 49.9
R5 53.6k
R6 10.2k
FB
J1
VOUT
GND

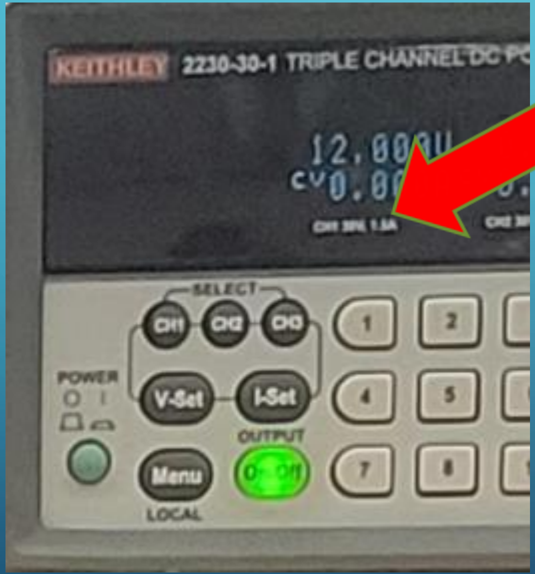

TEXAS INSTRUMENTS
PWR555
Rev. A
TPS54561EVM-593
C12
C9 C7 C6
TP5
SW
TP8
C10 C3 C1 C2
D1
C4
TP2
TP9
PWRGD PULL UP
TP1
C11
VIN
GND
J4
J5
J3
TP3
TP4
TP6
TP10
GND
SS/TR
EN
LOOP
VOUT
PWRGD
© 2013 TI

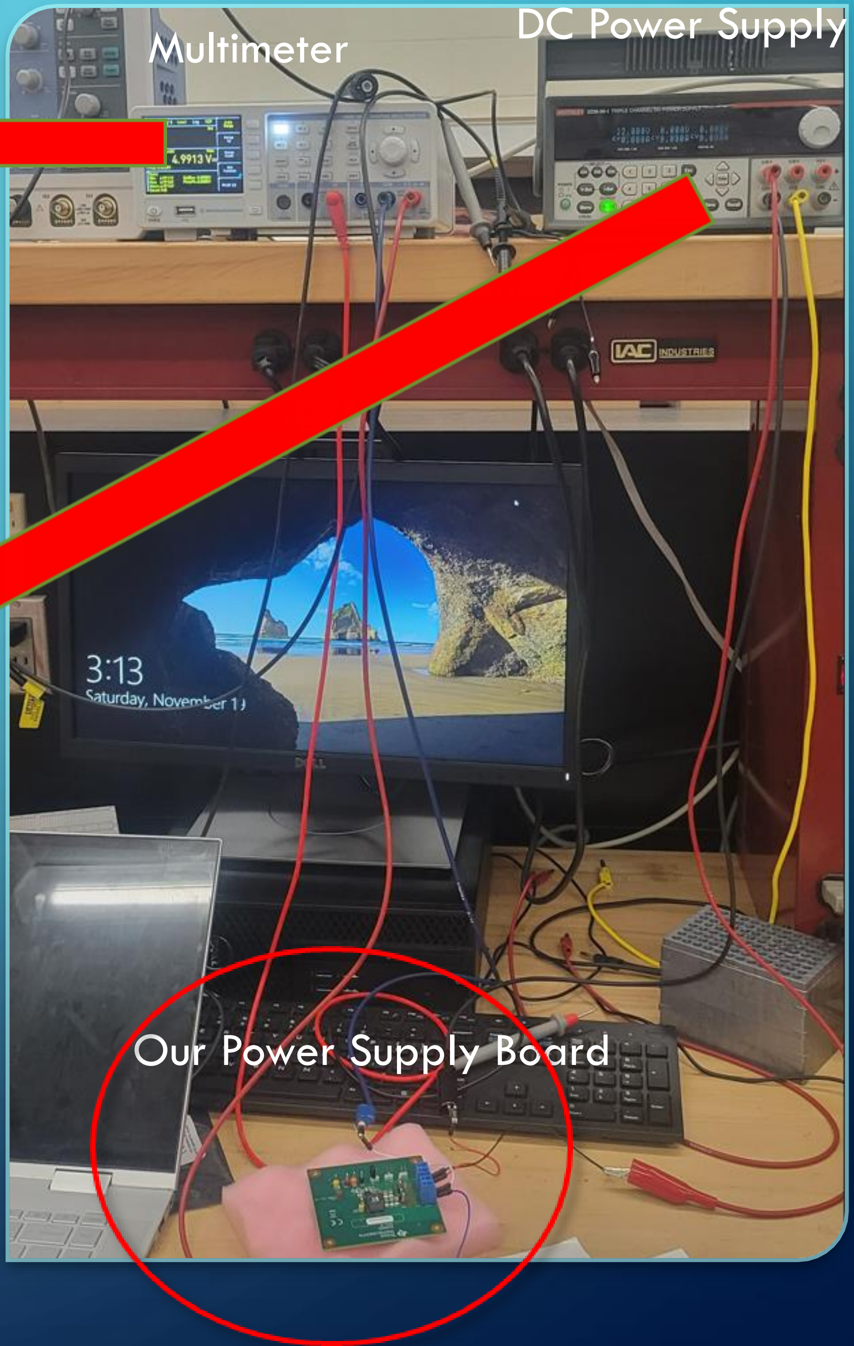
OUTPUT
VOLTAGE



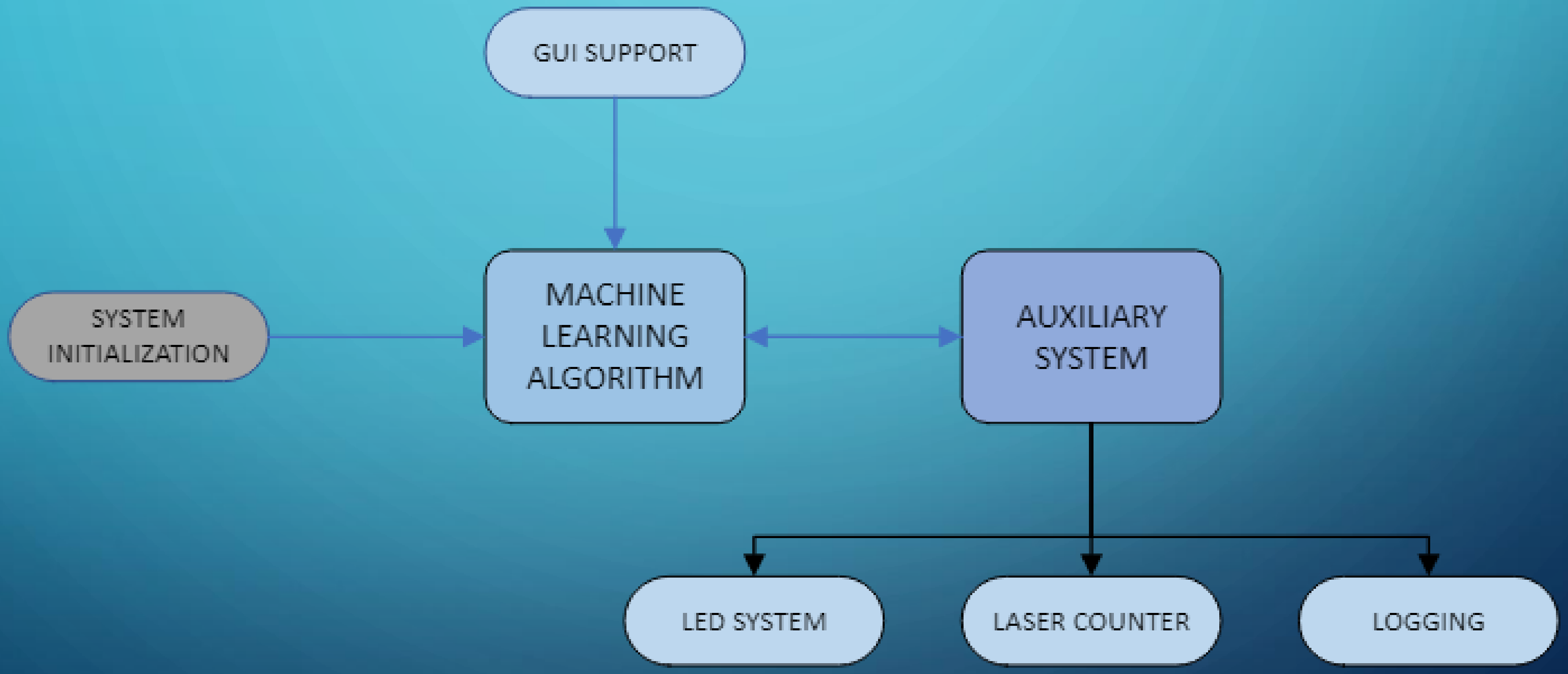
- POWER SUPPLY TESTING

INPUT
VOLTAGE





SOFTWARE DESIGN OVERVIEW



SOFTWARE TOOLS

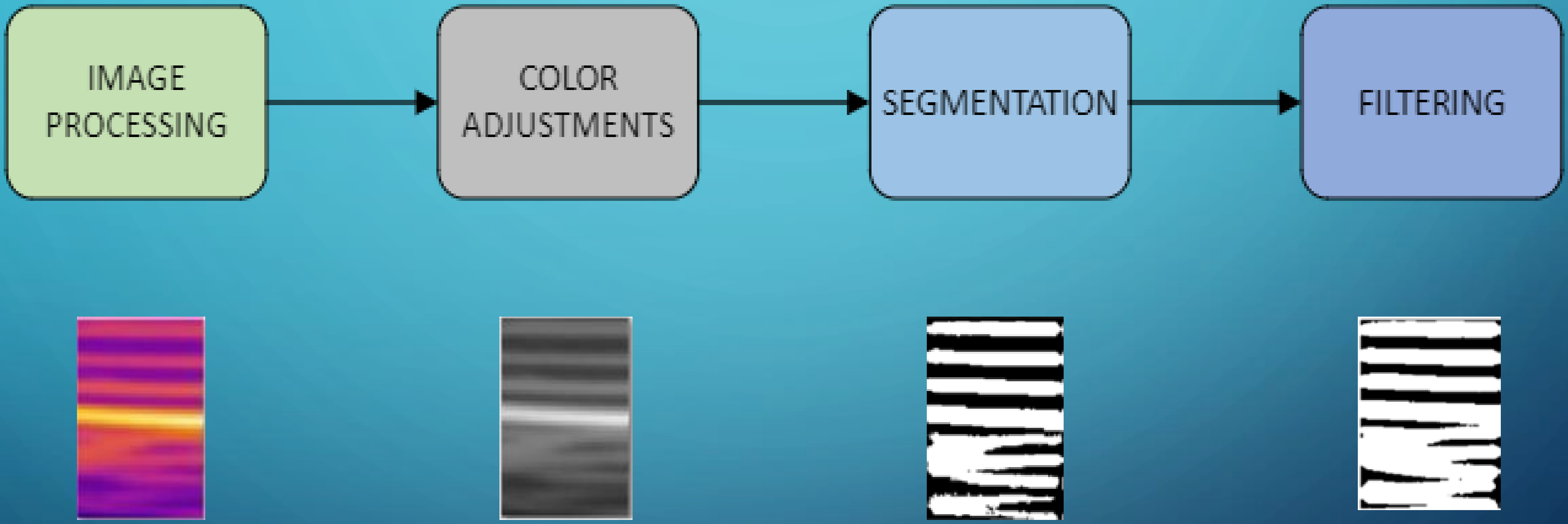
- PYTHON
- VISUAL STUDIO CODE
- GITHUB

IMAGE CAPTURING USING OPENCV

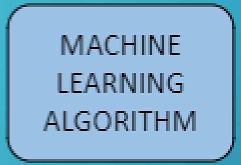
- OPENCV
  - Extensive Libraries
  - Optimized for Real-time Applications
- Python Support
- Initial Image Preprocessing

IMAGE PRE-PROCESSING (DSP)

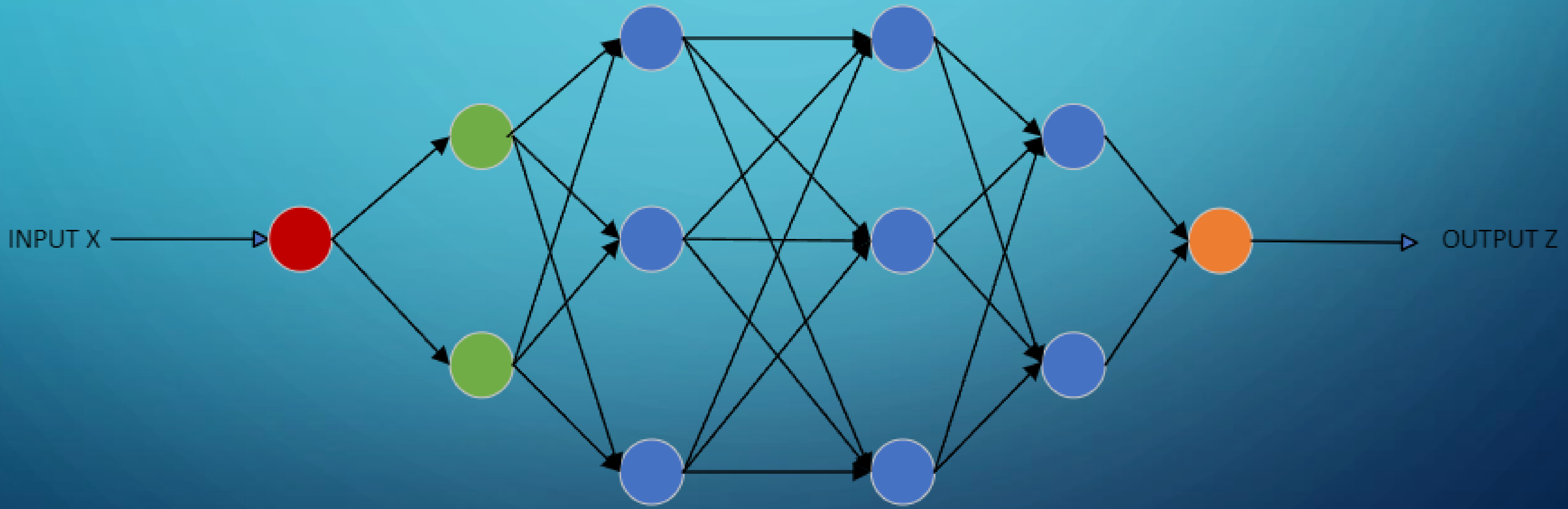
DSP



MACHINE LEARNING BINARY CLASSIFICATION



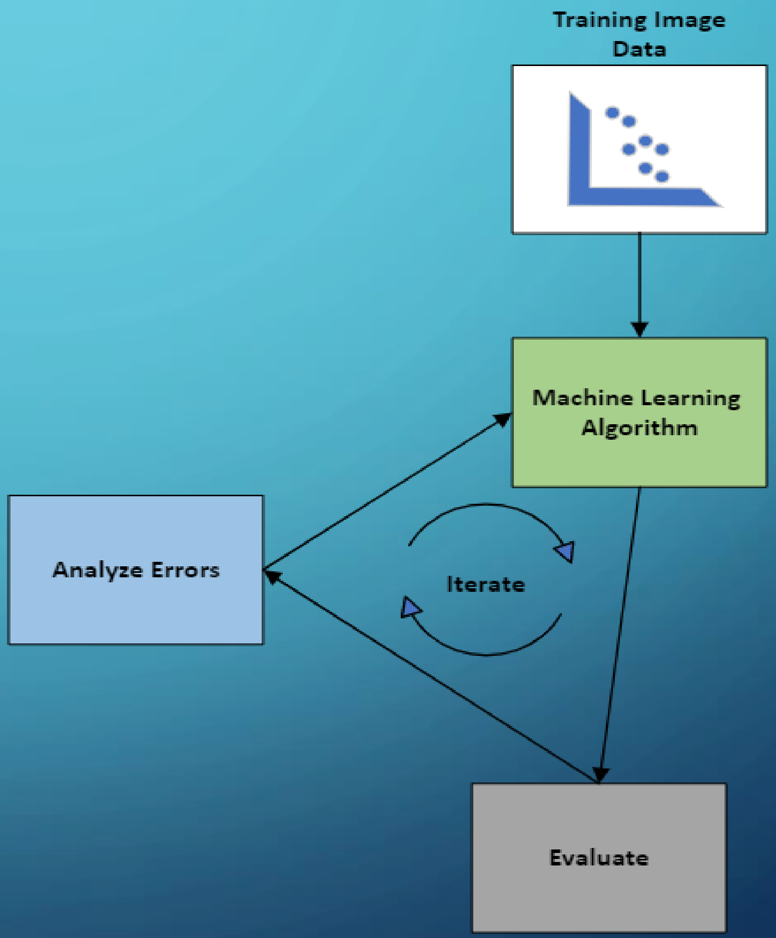
- Deep Neural Network



MACHINE LEARNING MODEL TRAINING

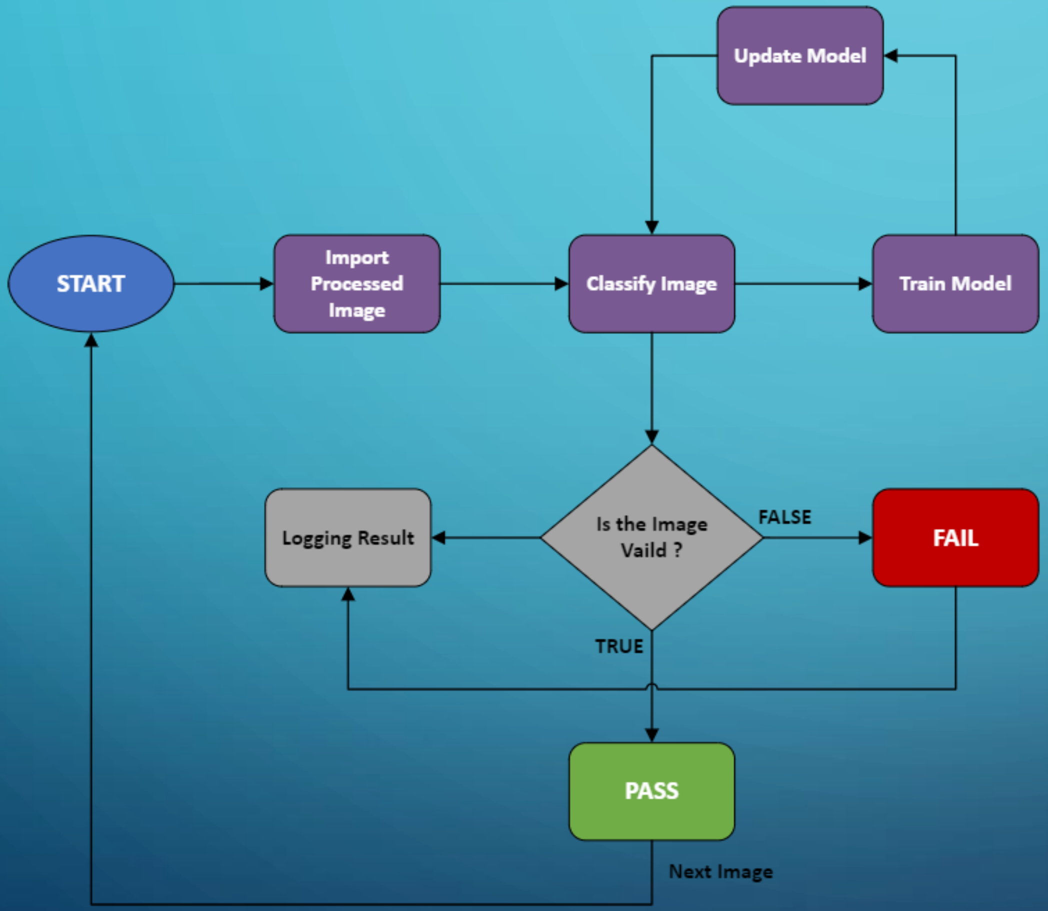
MACHINE LEARNING ALGORITHM

- Train
- Test
- Evaluate
- Optimize



ML CLASSIFICATION PROCESS

MACHINE LEARNING ALGORITHM



- Import Image
- Classify Result
- Improve Model
- Log Outcomes

AUXILIARY SYSTEM

LOGGING, ALERTS AND LASER COUNTER

- Logging Service
  - Historical Data Store
- Alerts
  - LED System
  - GUI Interface

BUDGET

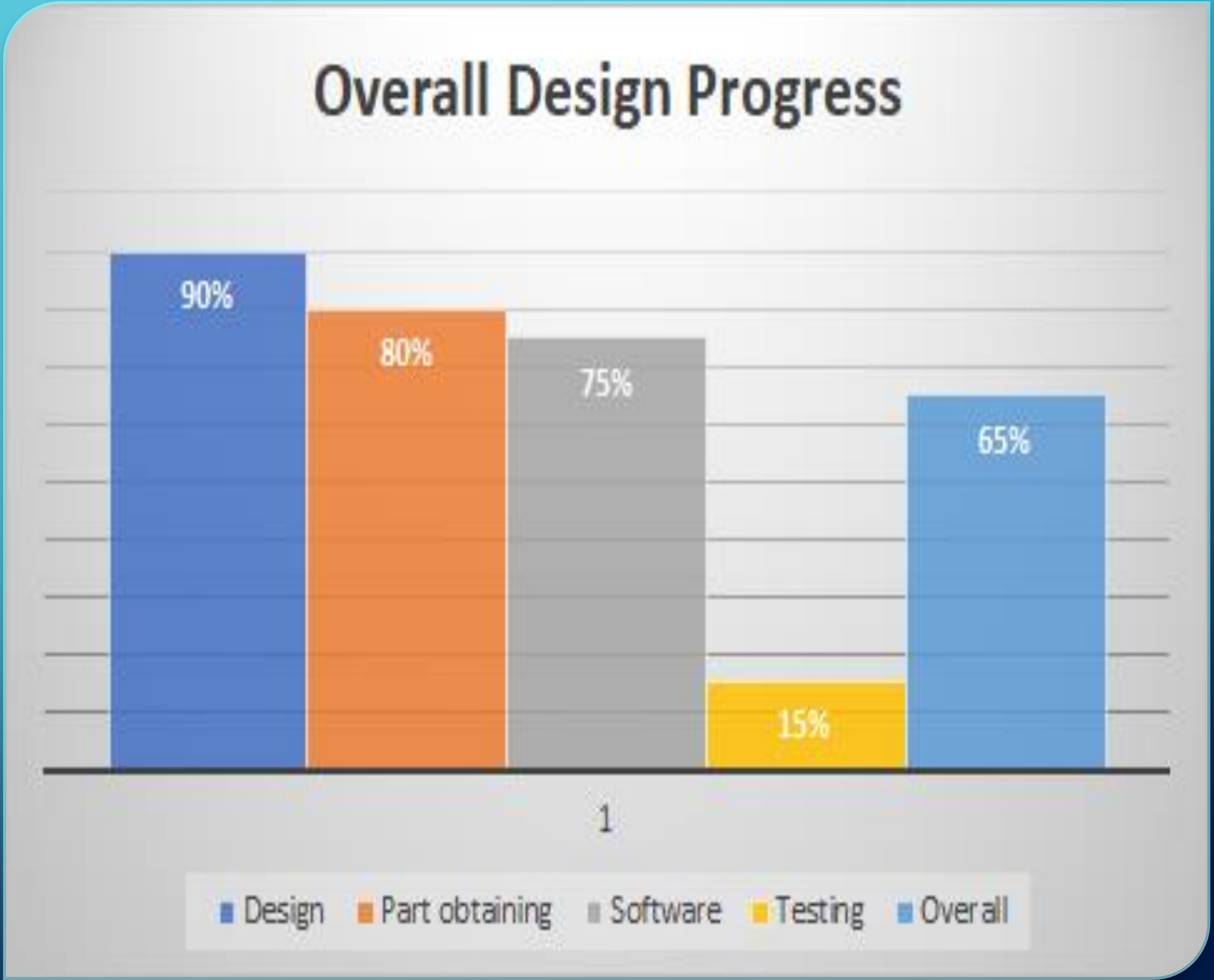
Electronics and Power Budget Spending

Item	Current Spending
Custom Power Supply	$100
Custom PCB	$3.70
Custom Enclosure (3D print)	$20
Microcontroller	$455
Stepper Motor Driver	$11.45
Circuit Components	$20
Total	$610.15

Optics Budget Estimation

Item	Cost Estimated
Camera System	$120
Lenses	$280
Laser	$0
Total	$4000

PROGRESS



Overall Design Progress
90%
80%
75%
15%
65%
1
Design
Part obtaining
Software
Testing
Overall

ISSUES

- Learning curve to applying each Python Library
  - OpenCV
  - Micropython
  - PyTorch
- Training is time intensive
- Hardware delays
- Camera issues
  - Resolution
  - Framerate

QUESTIONS?