# TSUNAMI

## Hyperspectral Imager for Ecological Analysis


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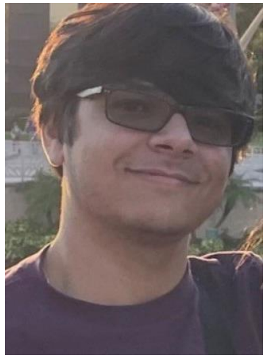
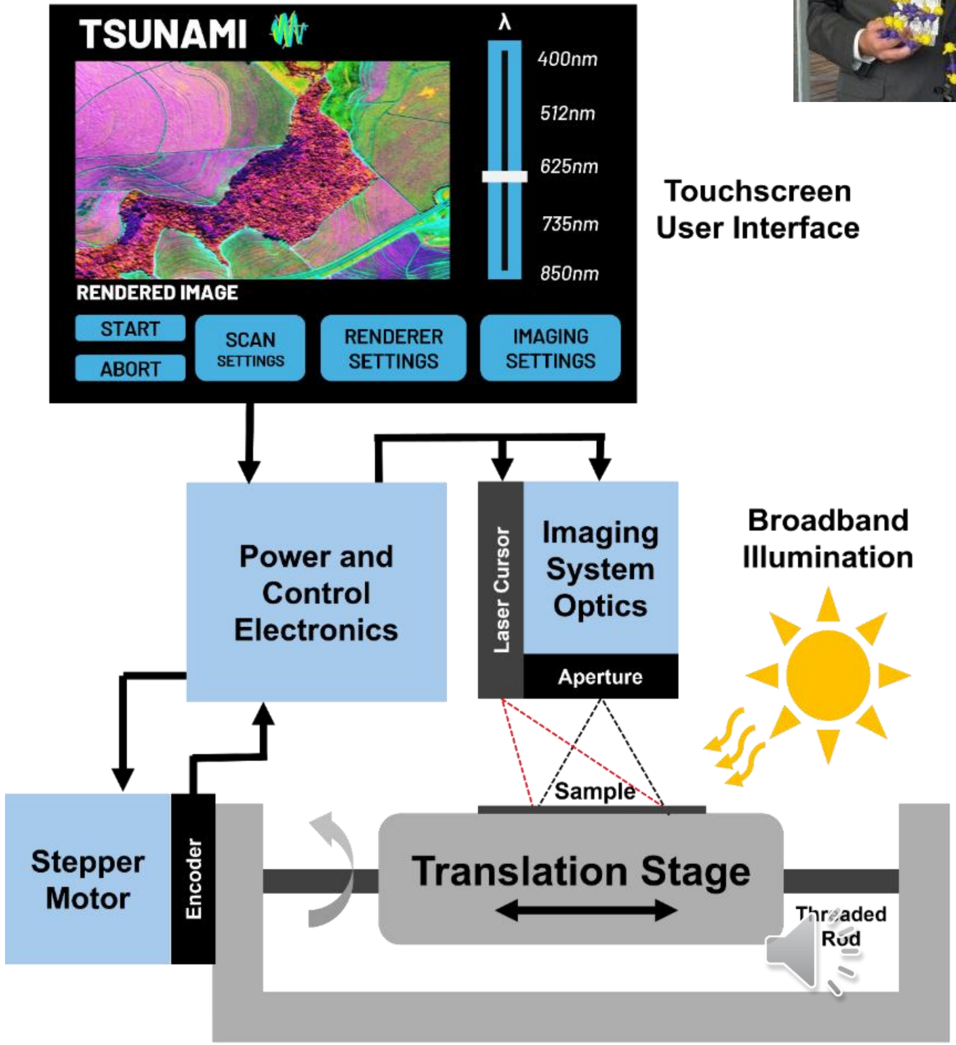


# Project Description

- TSUNAMI is a hyperspectral imager for environmental analysis. A three-dimensional (space x space x spectra) dataset is collected to analyze soil composition beyond a standard RGB camera. A motorized stage moves the sample and a laser cursor shows the user where the camera is looking.

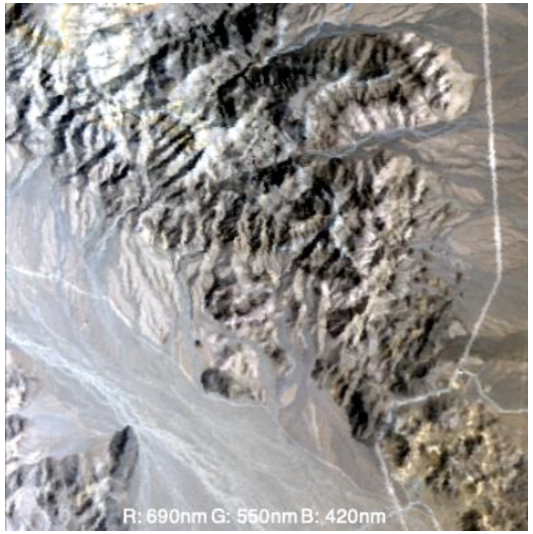


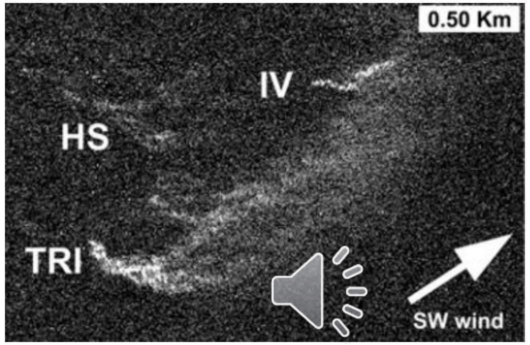
# Research and Background

- Spectral analysis is a common need. Commercial and scientific solutions have been made.

  - Top: Resonon Pika L-F 420-980 nm [1]

  - Bottom: Images from NASA “Classic” Airborne Visible Near Infrared Spectrometer (AVIRIS-C) [2, 3]

# Distribution of Work

| Electrical Engineering | Responsibilities |
|---|---|
| Emilio Armas | Project Lead |
| | MCU Integration and Implementation |
| | Motor Controller Power Supply Design |
| | Laser Diode Driver Circuit/Optoelectronics |
| | Power Bus and Power Entry Circuitry |
| | Final PCB design and assembly |
| Xander Kin | MCU 3.3V LDO Implementation |
| | Stepper Driver Implementation |
| | SBC Power Supply Design |
| | Subcircuit pre-validation PCB design |
| **Photonics Science and Engineering** | Responsibilities |
| Jacob Silver | SBC Image Processing Software |
| | Imaging System Optical Design |
| | Motor Mechanical Implementation |
| Emilio Armas | Laser Cursor Optical and Optoelectronic Design |

# Goals & Objectives

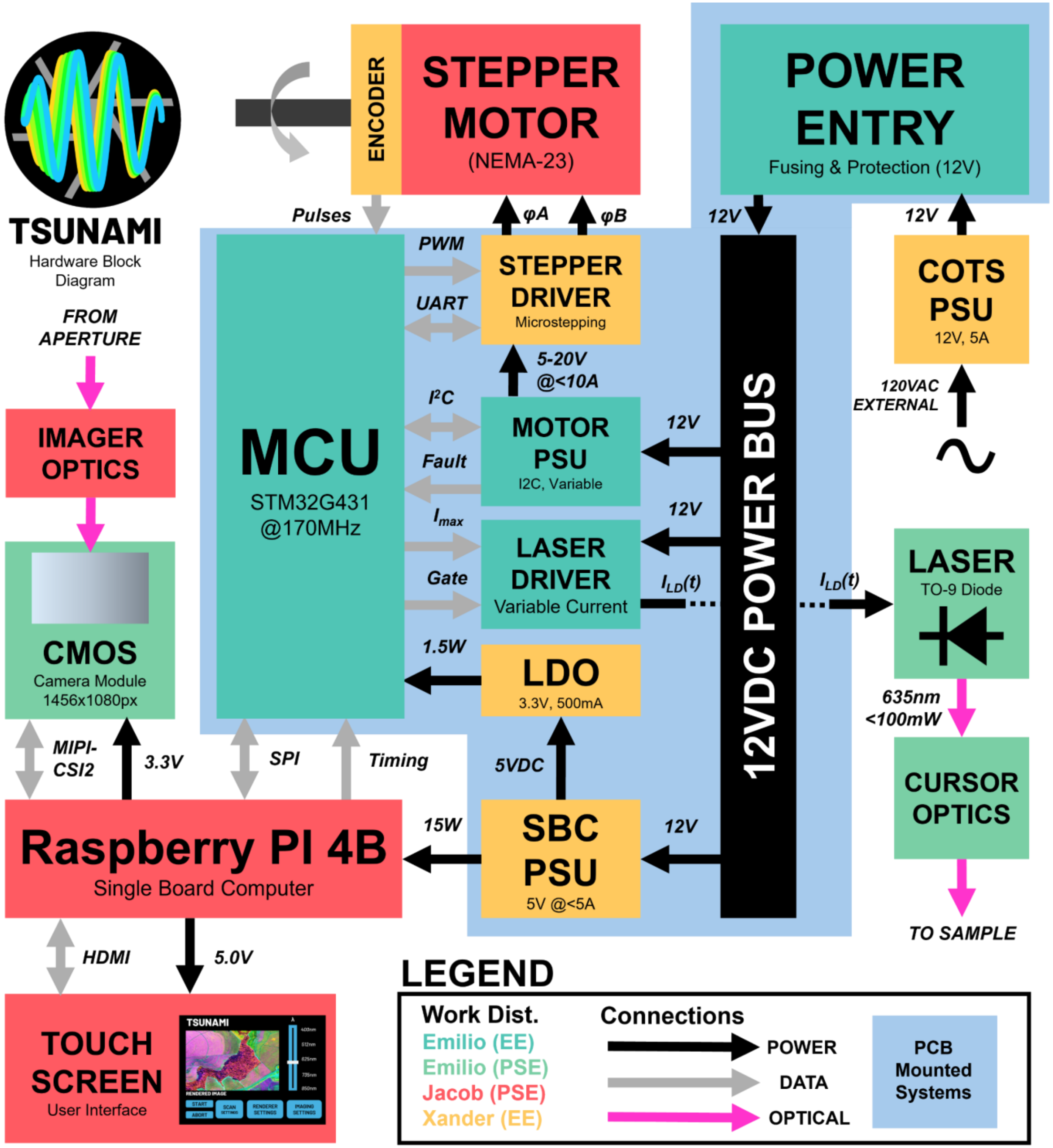
| Goals |
| --- |
| Capture spatial and VNIR spectral (400nm-850nm) data simultaneously |
| Capture and display data locally on an embedded computing platform, with a small touchscreen |
| Show false-color images as remapping of the RGB display channels |
| Implement a laterally moving translation stage to allow the instrument to scan a small ecological target, such as soil or plant matter |
| Create a line-shaped laser cursor to match the imager's linear target area, allowing for a user to see the scan location before capture |
| Design optics to allow for adjustment of target focal length to the sample |

| Objectives |
| --- |
| Implement embedded motor control of translation stage using a microcontroller's (MCU) timing and data-transfer peripherals |
| Utilize a graphics programming library on the embedded computer to design a custom, interactive touch user interface for rendering and control of the instrument |
| *Ensure the MCU handles all other tasks besides UI processing and CMOS sensor readout*, **being commanded by the UI software over serial interface** |
| Design the MCU firmware to support open-loop control of the motor's angular position, using micro-stepping techniques to move accurately. |
| Design power electronics to supply the computer, control, and MCU systems from a single external DC feed with their needed voltages and currents, reliably |

# Specifications

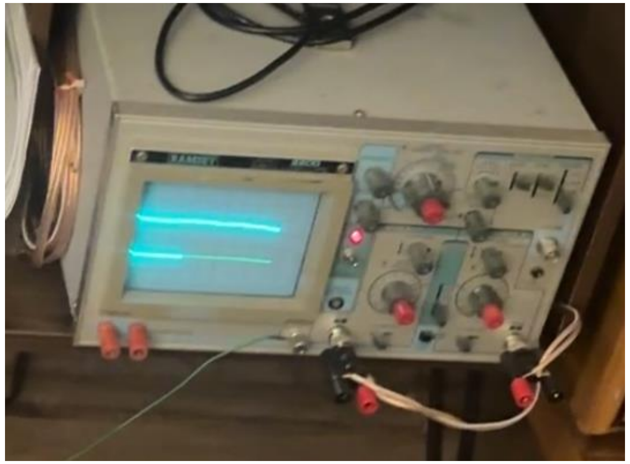
| Type | Specification | Value |
|---|---|---|
| Optical | Operational Wavelength Range | 400nm – 850nm |
| | Spectral Resolution (FWHM) | ≤ 10nm |
| | Entry Focal-Length Range | 20cm – ∞cm |
| | Laser Cursor Profile (FWHM asp. ratio) | ≥ 20:1 |
| | Laser Cursor Operational Output Power | 0mW – 20mW |
| | Laser Cursor Pulse Slew (10%-90%) | ≤ 10μs (rise/fall) |
| Electrical | Time Needed for Full Scan/Render | ≤ 10s |
| | System Power Consumption | ≤ 60W (peak) |
| | Imaging Sensor Type | CMOS |
| Mechanical | Instrument Weight (total) | ≤ 10kg |
| | Instrument Size (tentative, maximum) | ≤ 50x50x50cm |
| | Translation Stage Linear Resolution | ≤ 0.2mm |
| | Translation Stage Speed | ≥ 50mm/s |

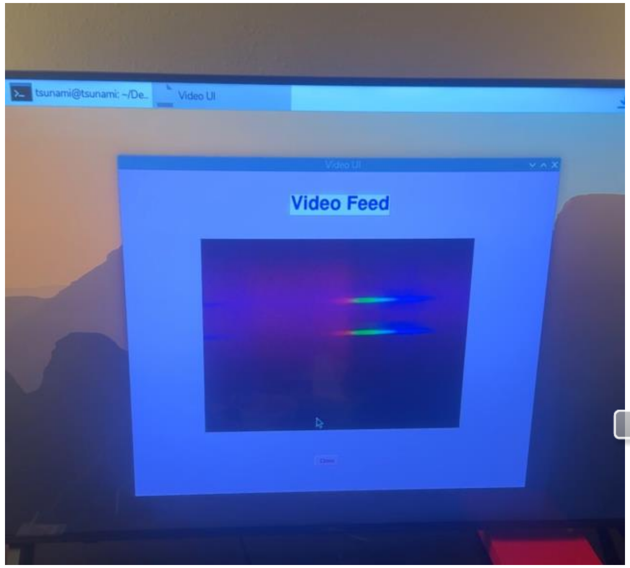
# Hardware Block Diagram



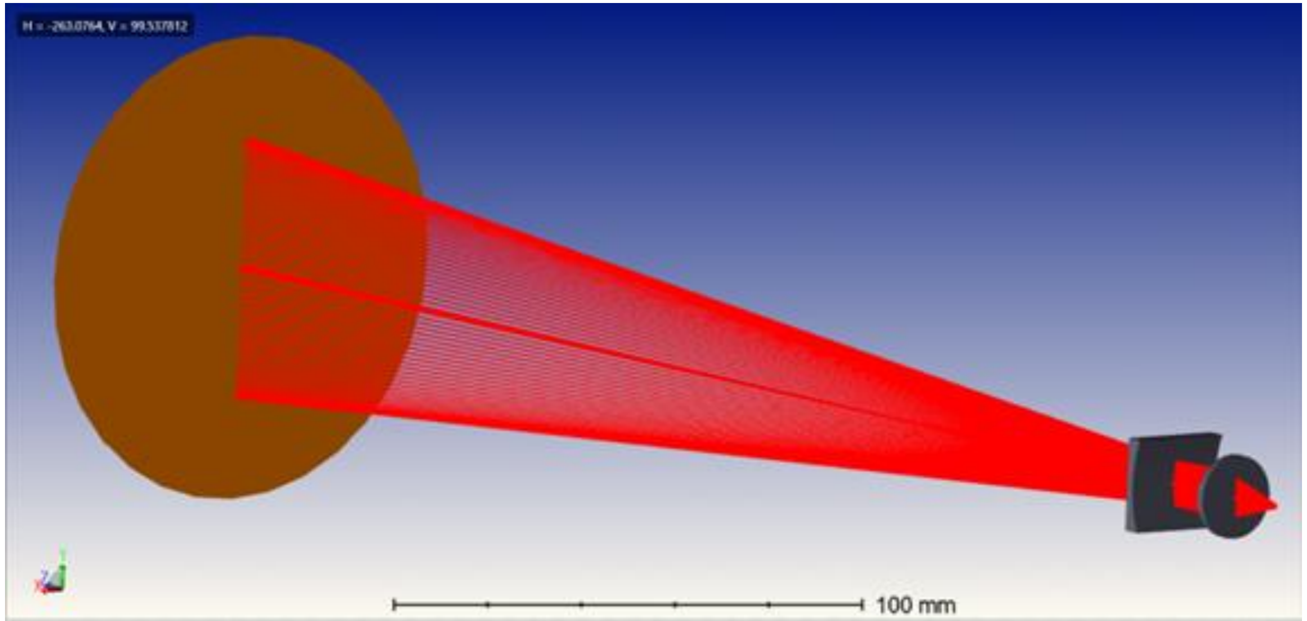

# Imager Design

- Top Left: First prototype in flexible TPU (for tolerances)
- Bottom Left: Most recent (2/11) housing design with earlier iteration behind
- Top Right: Test object
- Bottom Right: Image of object w/ spatial axis vertical & spectral axis horizontal




# Laser Cursor Optical Design



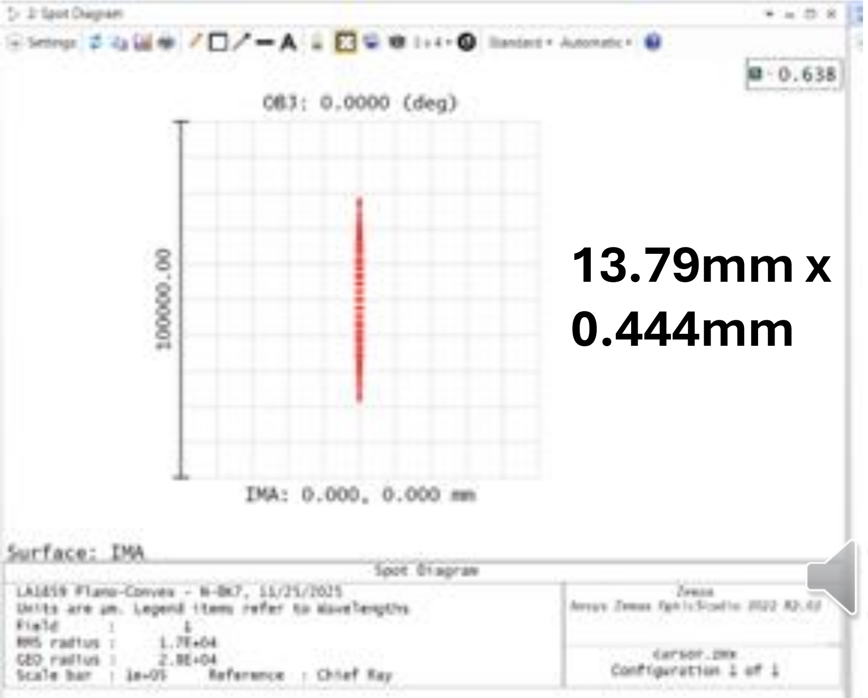


Update: All Windows

Surface 7 Properties | Configuration 1/1

| | Surface Type | | Comment | Radius | Thickness | | Material | Coating | Clear Semi-Dia | | Chip Zone | Mech Semi-Dia | | Conic | TCE x 1E-6 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | OBJECT (ap | Standard | | Infinity | 0.000 | | | | 0.000 | | - | - | | 0.0... | 0.000 |
| 1 | | Standard | | Infinity | 1.000 | | | | 0.000 | | 0.000 | 0.000 | | 0.0... | 0.000 |
| 2 | (aper) | Standard | | Infinity | 14.500 | V | | | 5.000 | U | - | - | | 0.0... | 0.000 |
| 3 | STOP (aper) | Standard | LA1859 | Infinity | 7.080 | | N-BK7 | | 9.000 | U | 0.000 | 9.000 | | 0.0... | - |
| 4 | (aper) | Standard | | -10.300 | 15.000 | | | | 9.000 | U | 0.000 | 9.000 | | 0.0... | 0.000 |
| 5 | (aper) | Toroidal | LK1662L1 | -25.840 | 2.000 | | N-BK7 | | 10.000 | U | - | - | | 0.0... | - |
| 6 | (aper) | Toroidal | | Infinity | 330.000 | | | | 10.000 | U | - | - | | 0.0... | 0.000 |
| 7 | IMAGE | Standard | | Infinity | - | | | | 50.000 | U | 0.000 | 50.000 | U | 0.0... | 0.000 |

- Needs at least 20:1 shaped spot at target distance
- Must operate at 635nm
- Must compensate for elliptical laser diode beam

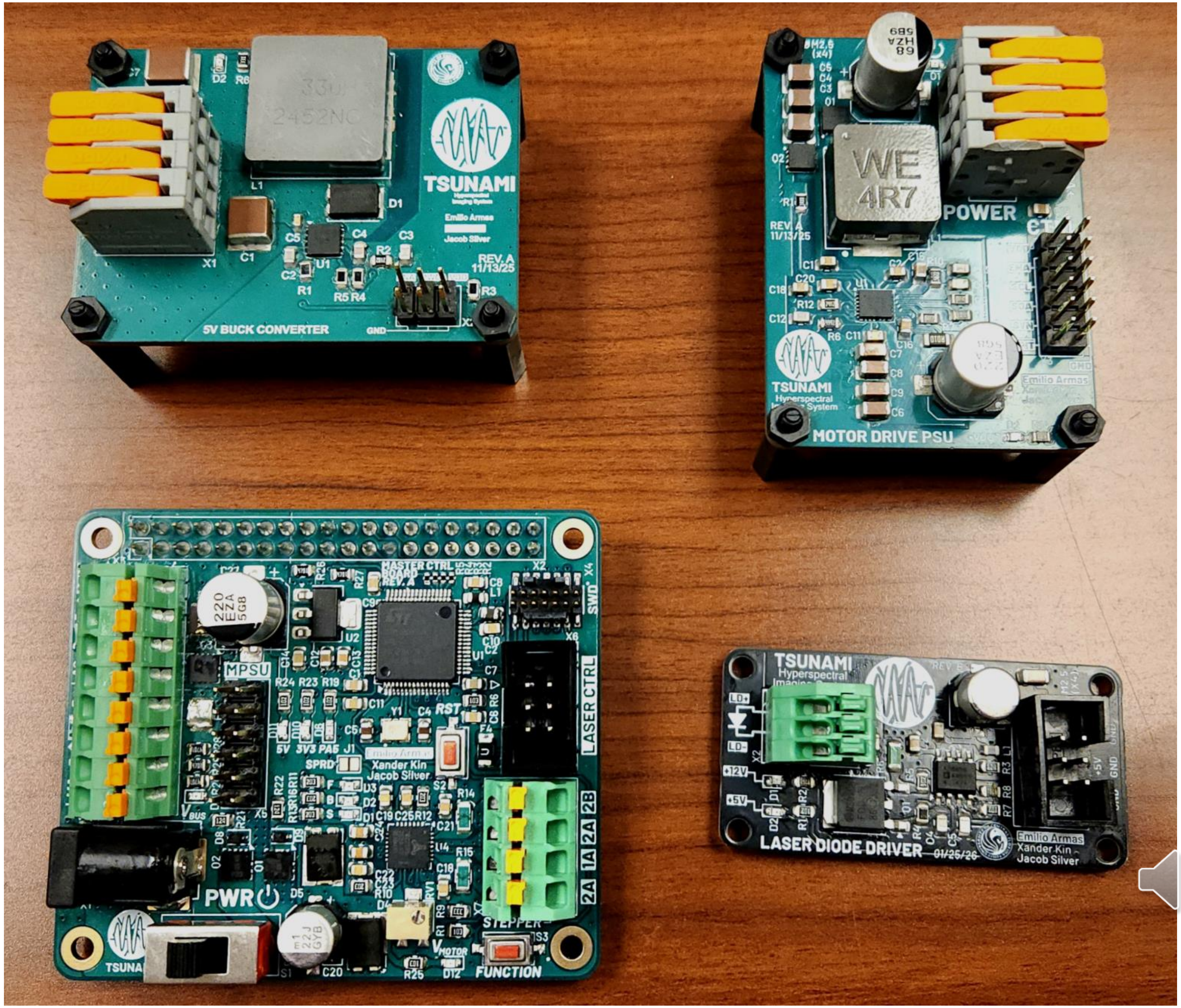




13.79mm x 0.444mm

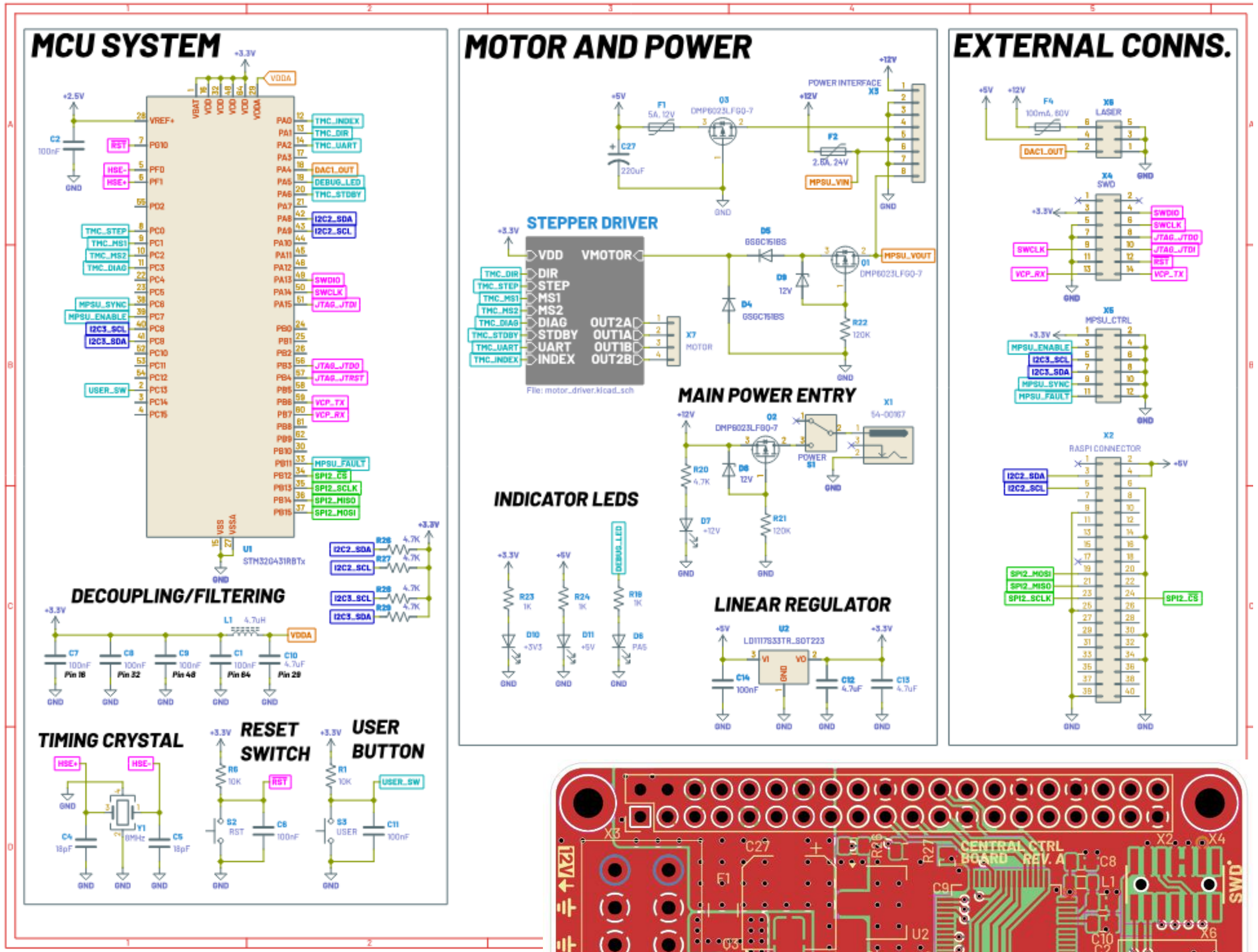
# PCB Design

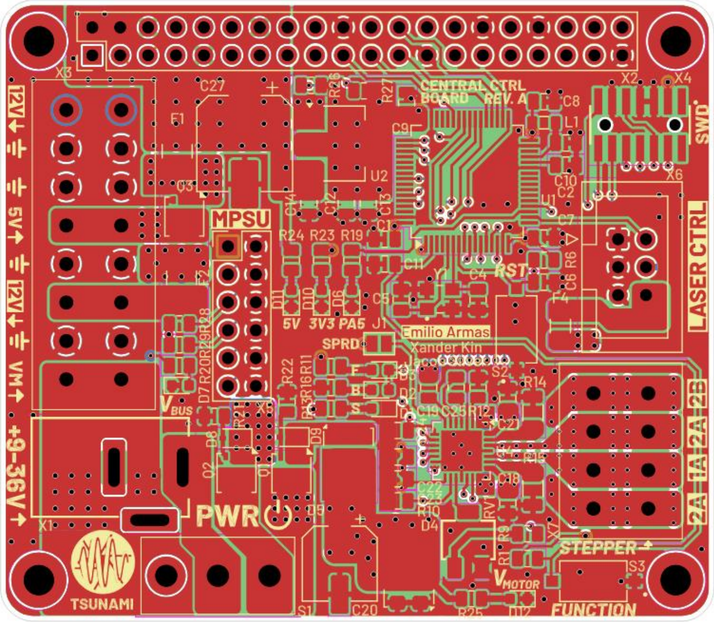
- Top Left:
  5.1V 5A DC/DC converter (powers Raspberry Pi 4B)
- Bottom Left:
  Master control board, hosts stepper driver, MCU, and power distribution for system. Raspberry Pi “hat” form factor
- Top Right:
  Stepper motor driver PSU. Digitally programmable voltage/current buck-boost converter.
- Bottom Right:
  High-speed laser diode driver




# Master Control PCB

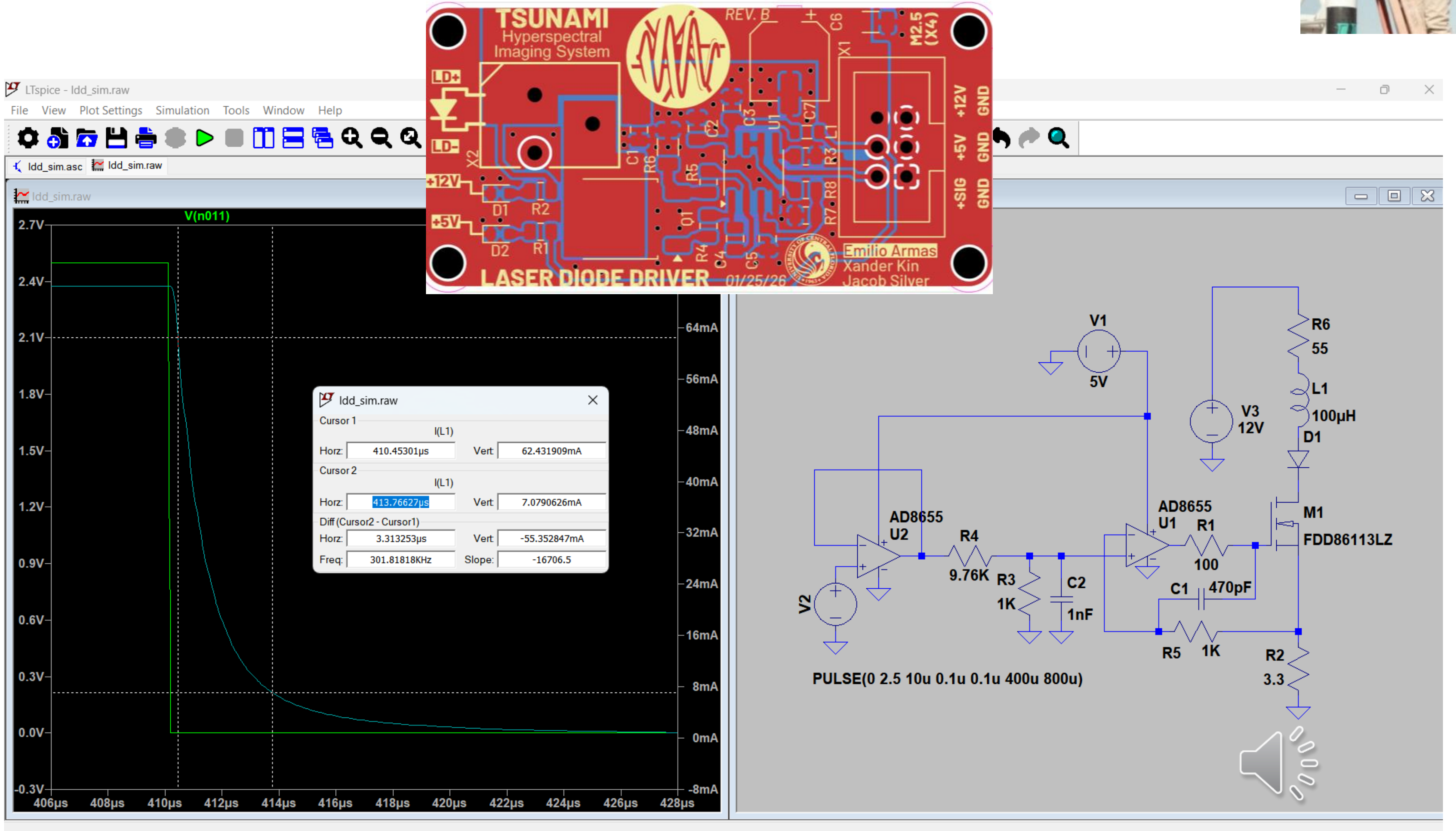
- Hosts system microcontroller (STM32G431)
- MCU has integrated DAC to digitally synthesize laser cursor control signal
- 9-36V input power bus (12V nominal)
- Extensive protection circuitry
- Power distribution
- TMC2209 Stepper Driver



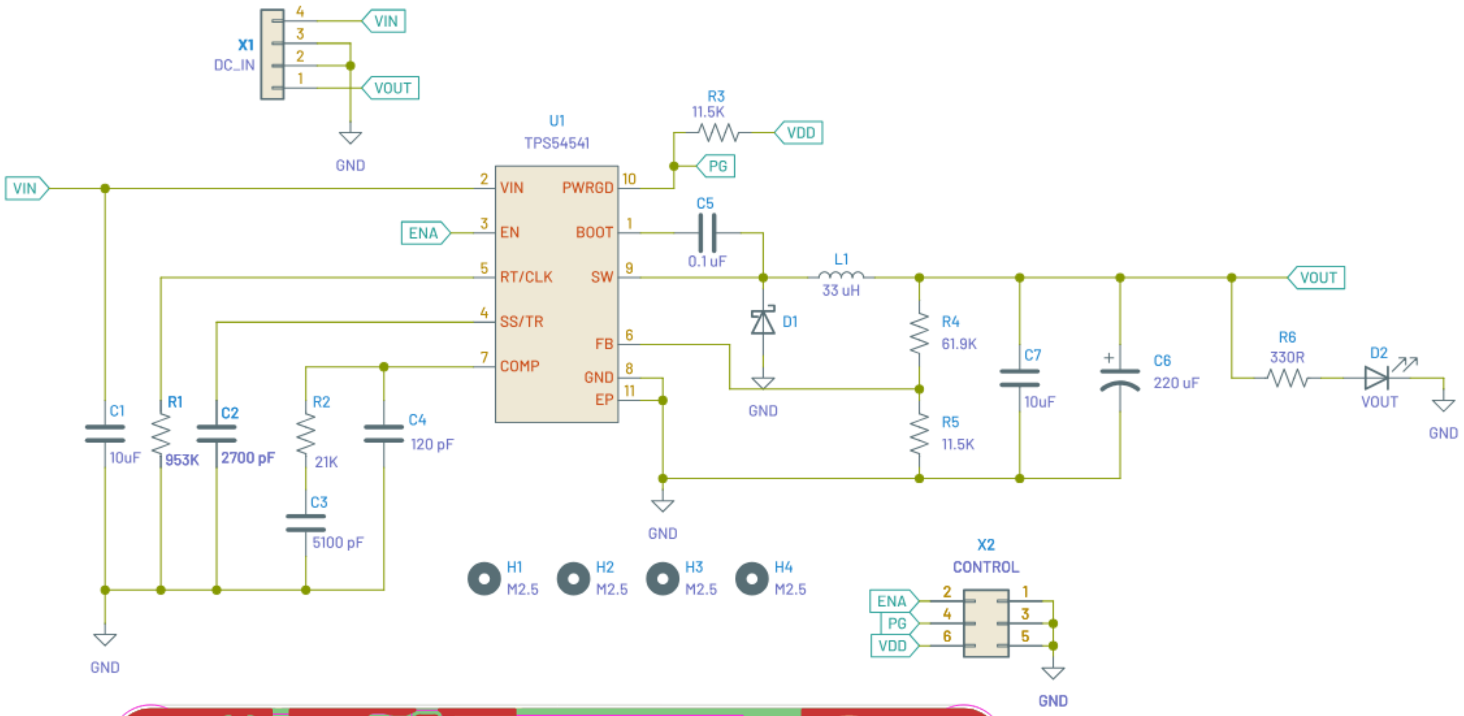

# High-Speed Laser Diode Driver

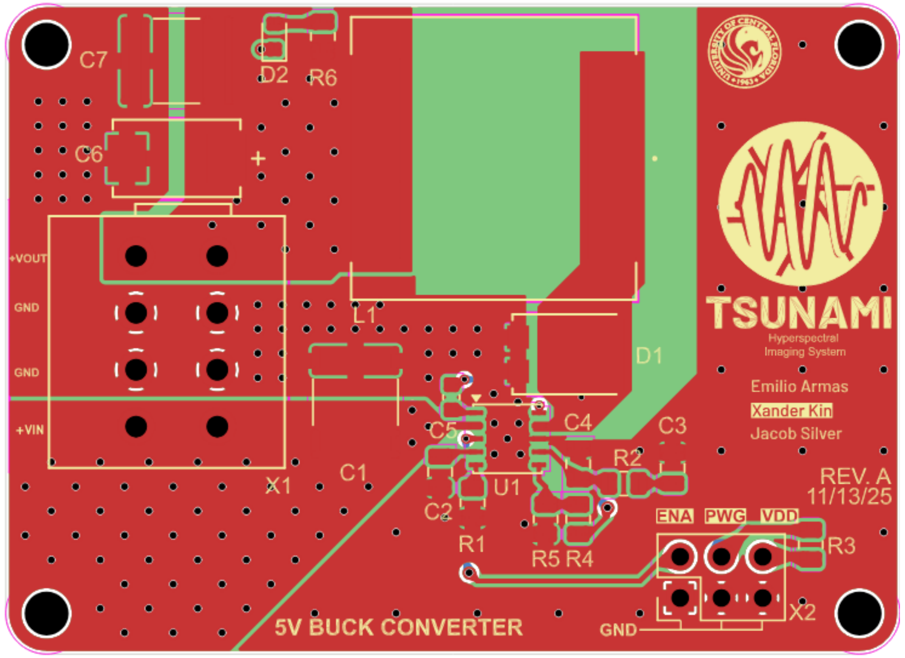
- Converts 0-2.5V DAC control voltage to 0-70mA laser diode current
- 10µs rise/fall time requirement
- 9-36V laser diode supply voltage
- Low-side linear FET for current control
- Designed to be stable even with extreme lead inductance



# Raspberry Pi PSU

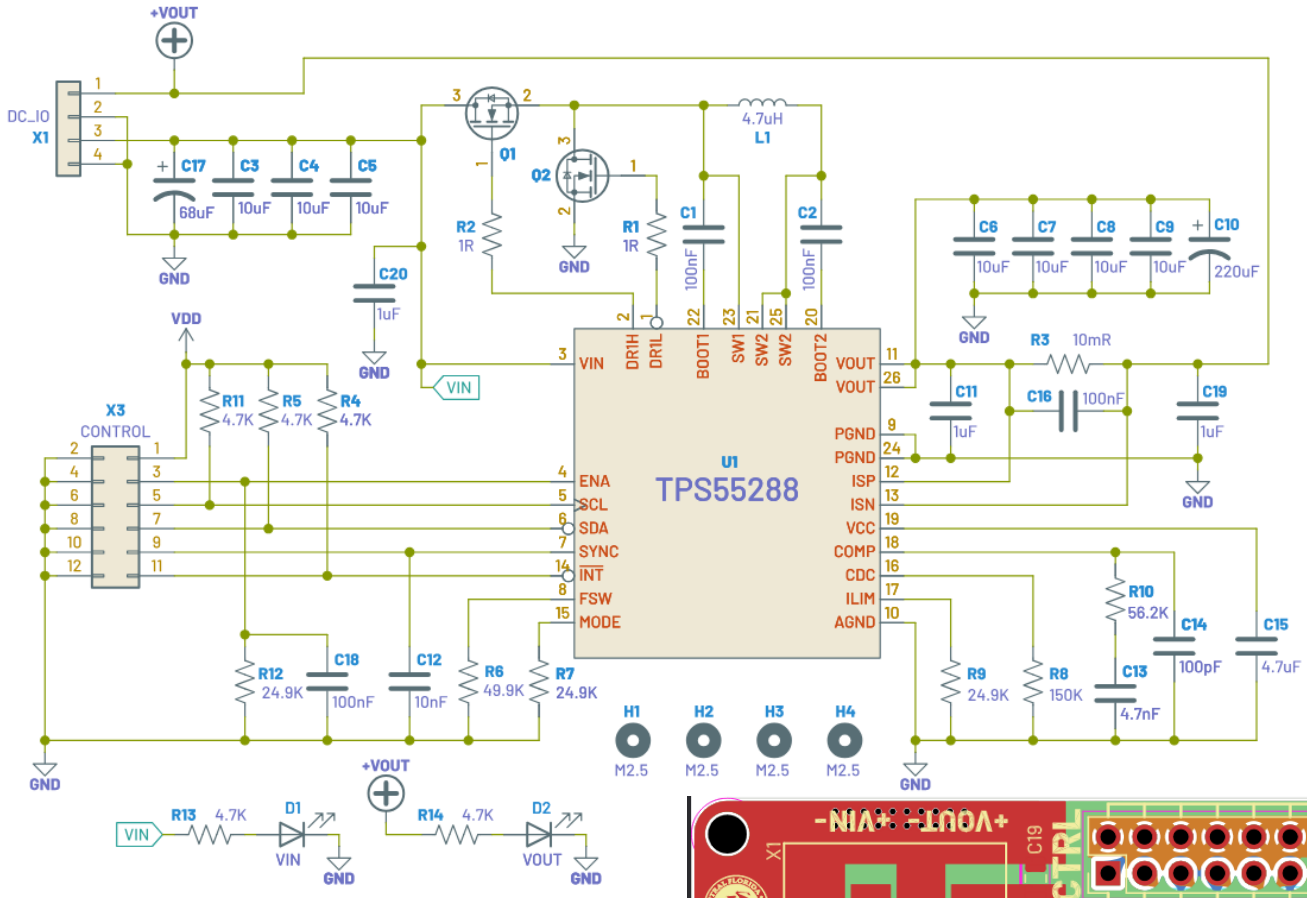
- Accepts 9-36V bus input
- Regulates up to 5A at 5.1V output continuously
- 5.1V to account for cable/connector loss
- Designed to supply a Raspberry Pi model 4B with continuous draw of roughly 3A
- TPS54541 based

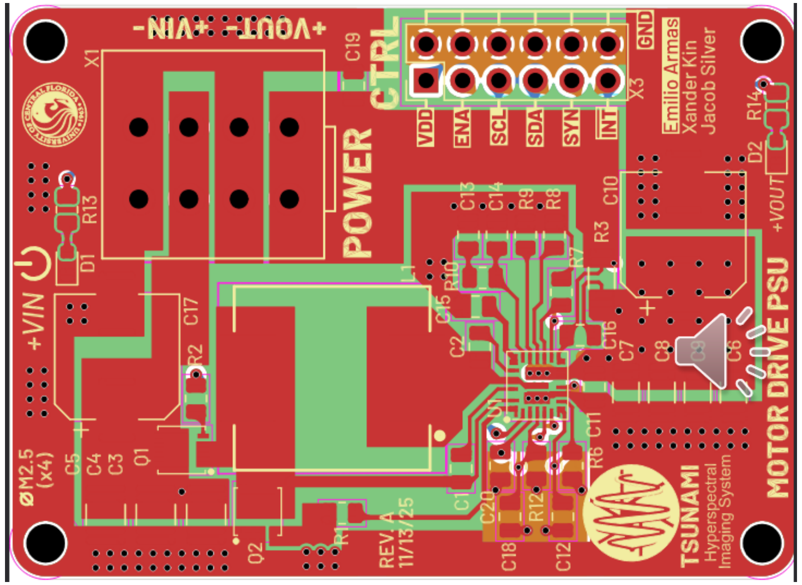



# Stepper Motor Driver PSU

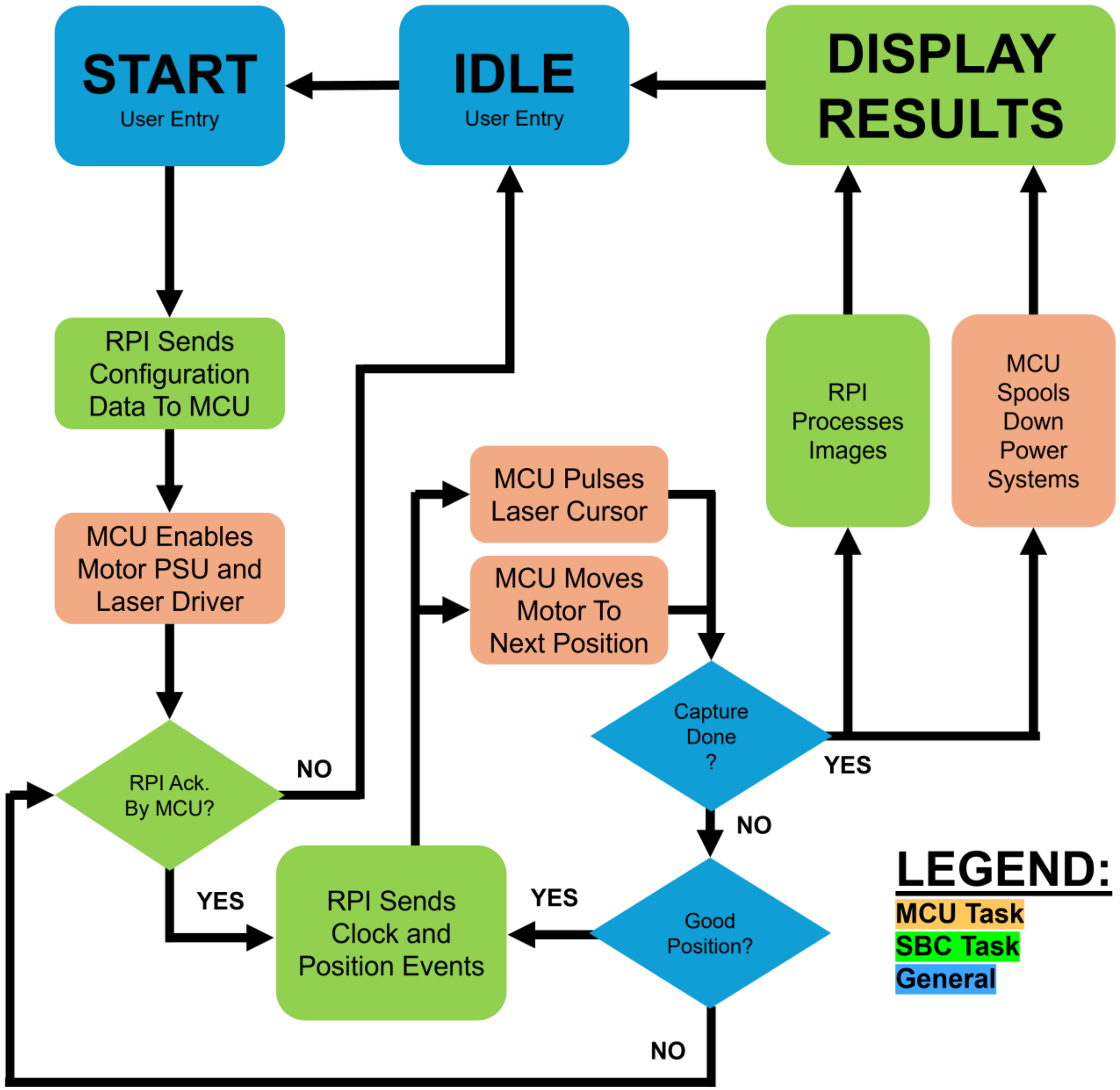
- Accepts 9-36V bus input
- Regulates from 5-20V up to 3A
- Buck/boost topology
- Output voltage/current and system status digitally controllable via I2C interconnect to MCU
- Variable voltage to control motor step energy/speed
- TPS55288 based



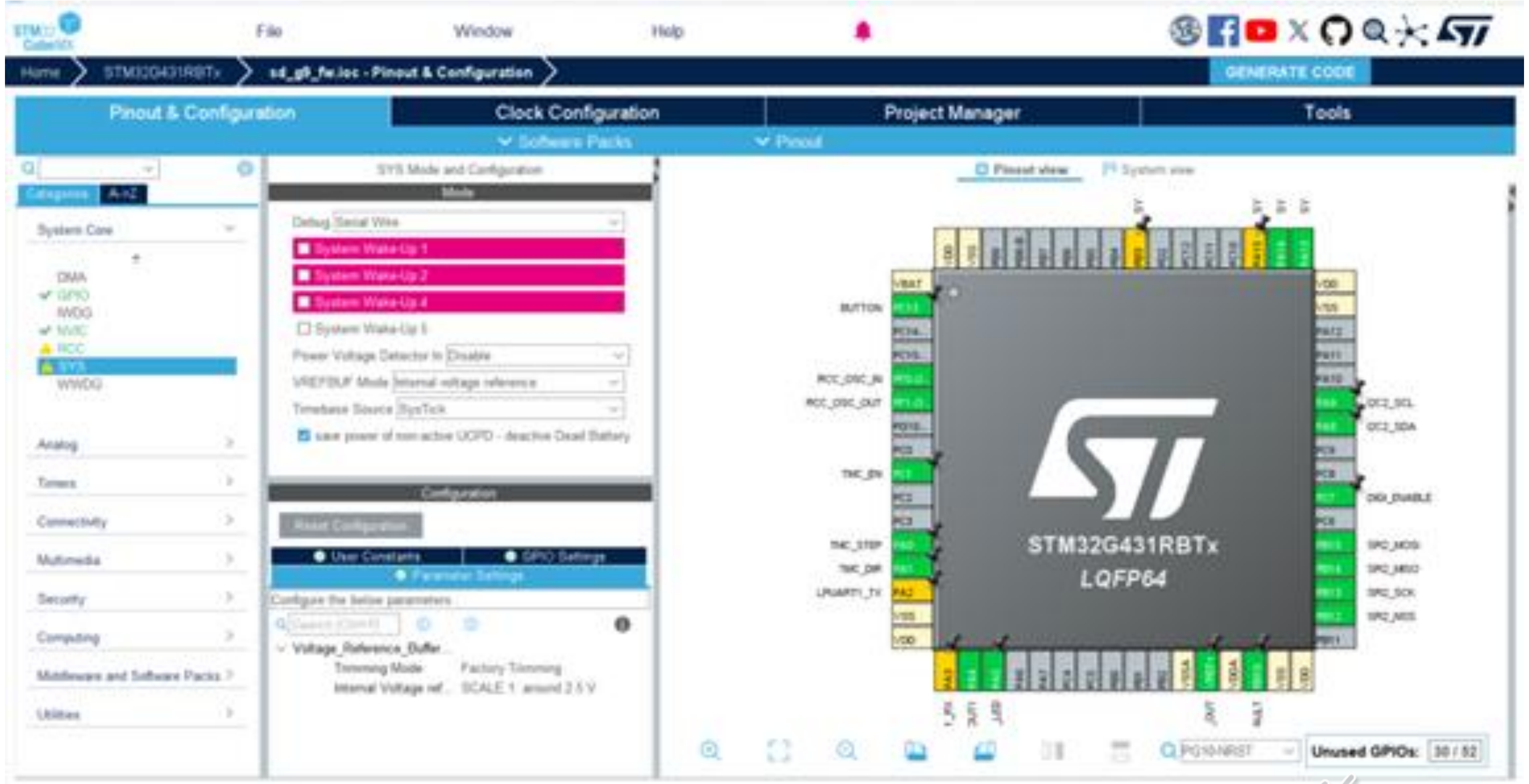

# Inter-Controller Software Design

- Camera image processing, frame capture, and GUI hosting best done on SBC
- MCU to work to fill all other roles, specifically close-to-hardware tasks
- MCU to interface with Raspberry Pi via digital serial communication and direct GPIO for timing signals
- WiringPi library used to control kernel drivers of GPIO and I2C on the SBC




# Inter-Controller Software Design (Cont'd)

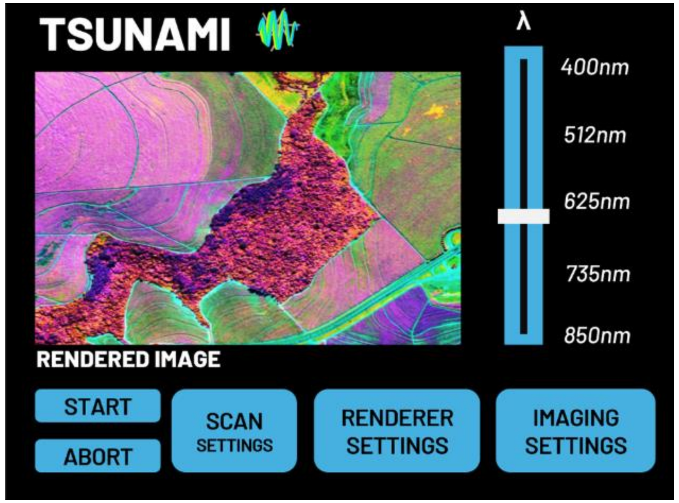
- MCU firmware written for an STM32G431, hosting a 32-bit ARM Cortex-M4
- MCU peripheral instantiation, pin-planning, and operational drivers handled by STMicro's Hardware Abstraction Layer (HAL) libraries.
- Significant ease of development with GUI editors for timing, system configuration, and interactive debugger

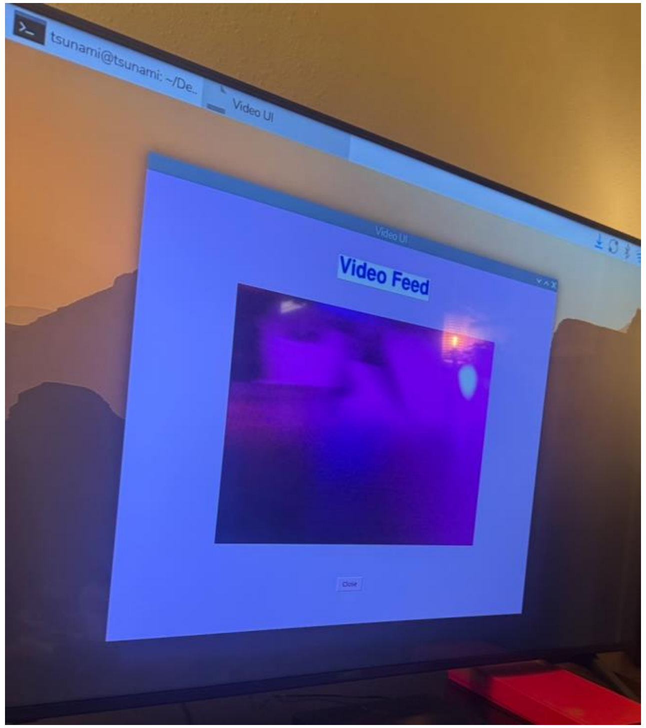



**STM32 *CubeMX GUI***

# Imaging Software Design

- UI will display false color images at user selected wavelengths. Testing UI is elementary (show current frame) as final UI is integrated with motors.
  - Top: Target UI Design
  - Bottom: Most recent UI (2/11).
    Camera has grating taken out to test focal distance. Purple shows the prevalence of near-IR light.




# Budget

| Component | Subsystem | Quantity | Unit Cost | Total |
|---|---|---|---|---|
| PLA Filament, 1kg | Mechincal Structures | 3 | $22.76 | $68.28 |
| Stepper Motor | Mechanical Structures | 1 | $14.00 | $14.00 |
| Transmissive Grating | Hyperspectral Camera | 1 | $17.76 | $17.76 |
| Achromatic Lens Doublet | Hyperspectral Camera | 2 | $135.09 | $270.18 |
| Positive/Negative Focal Le | Hyperspectral Camera | 2 | $120.00 | $240.00 |
| 650 nm 7mW Laser Diode | Cursor | 1 | $20.17 | $20.17 |
| MCU | Electronics | 1 | $4.87 | $4.87 |
| CMOS Camera | Hyperspectral Camera | 1 | $25.00 | $25.00 |
| Miscellaneous | All | 1 | $100.00 | $100.00 |
| | | | **Total** | $760.26 |

# Conclusion

**Thank you for listening! :) :) :)**

**We’re excited to hear your questions and comments on Friday.**

# Bibliography


- [1] “Pika L-F (420-980nm).” *Resonon Pika L-F Hyperspectral Imaging Camera*, Resonon Inc., 2025, resonon.com/Pika-L-F.
- [2] Thompson, D. R., J. W. Boardman, M. L. Eastwood, R. O. Green (2017), A large airborne survey of Earth’s visible-infrared spectral dimensionality. Optics Express 25, 9186-9195 (2017).
- [3] Thorpe, A.K., Roberts, D.A., Bradley, E.S., Funk, C.C., Dennison, P.E., Leifer I. (2013). High resolution mapping of methane emissions from marine and terrestrial sources using a Cluster-Tuned Matched Filter technique and imaging spectrometry. Remote Sensing of Environment, 134, 305-318.