SkinLumina: Inclusive Multispectral Skin Analysis Device

Senior Design Group 3 Summer 2025
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Meet the Team

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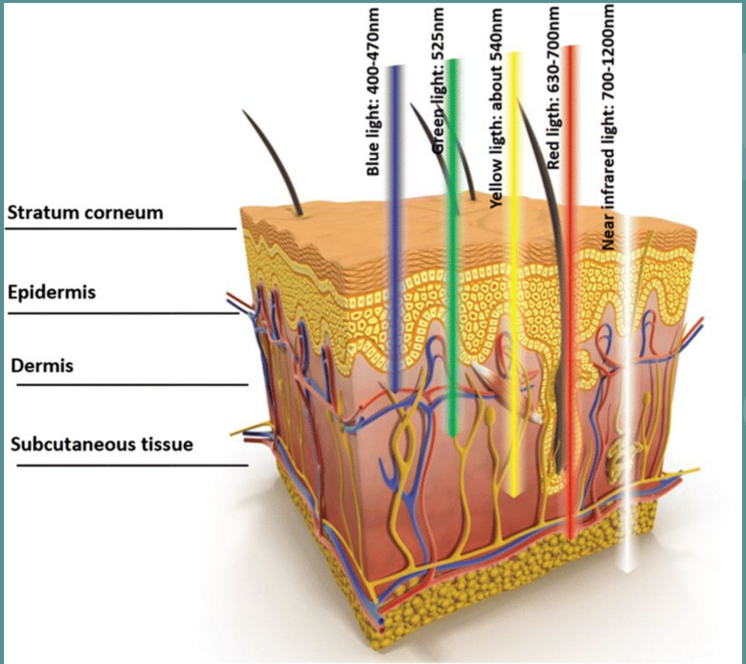
Motivation

Problem: Current dermatology imaging tools lack inclusivity and often misrepresent diverse skin tones by relying on a single reference model. Since different wavelengths of light interact uniquely with each patient's skin structure, this approach limits accuracy and reliability when identifying conditions across varied complexions.

Proposed Solution: SkinLumina is a portable multispectral imaging system that customizes the illumination and analysis for each patient's skin tone. By adapting visible and near infrared light for personalized scans, it improves diagnostic accuracy, inclusivity, and early detection of skin abnormalities.

Background

How we know a multispectral approach will work when imaging skin abnormalities.



SkinLumina uses spectral imaging and targets the 600–1300 nm “therapeutic window” to achieve deeper, noninvasive skin scanning. This approach accounts for variations in skin pigmentation and structure, allowing for more accurate detection of subsurface abnormalities.

Sorbellini, E., M. Rucco, and F. Rinaldi, Photodynamic and photobiological effects of light-emitting diode (LED) therapy in dermatological disease: an update. Lasers Med Sci, 2018. 33(7): p. 1431-1439.

Our Goals.

Basic Goals

- Build a multi-wavelength imaging system to detect skin abnormalities like bruising, scarring, discoloration, and melanoma.
- Create a 2-scan imaging process to provide an initial personalized baseline scan and a second scan to get more inclusive and accurate results across a wide-range of skin tones.

Advanced Goals

- Create a portable imaging system that can be used in real dermatologist settings to provide support in diagnosis and skin analysis.
- Integrate subsurface imaging techniques such as cross polarization to enhance contrast and visibility of subsurface structures.

Stretch Goals

- Design a modular optical system, allowing us to easily change lenses, apertures, filters, etc.

Skin Lumina

Our Objectives.

Basic Objectives

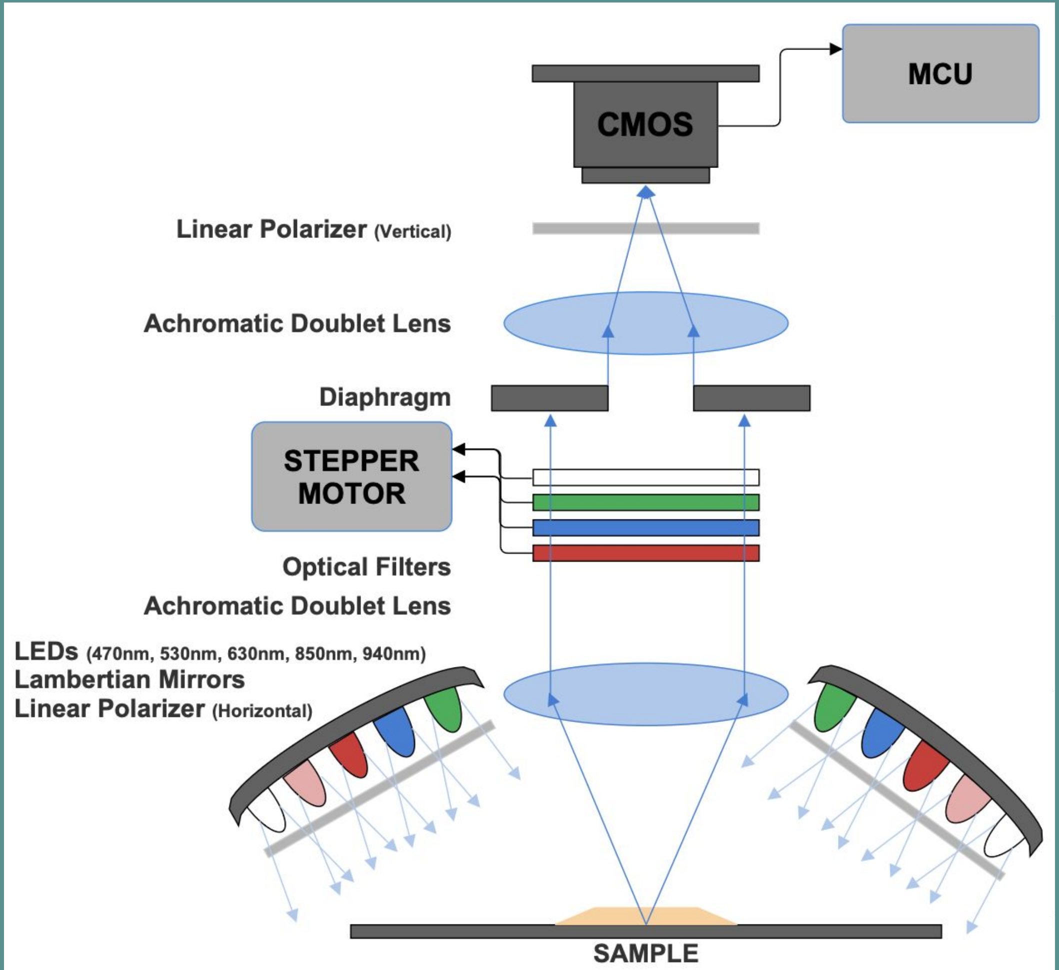
- Construct an optical system using lenses, LEDs, and filters, to minimize chromatic and spherical aberrations as well as increase image quality.
- Enable adaptive imaging with a two-scan approach for skin-tone inclusive results.
    1. Initial scan to create personalized imaging for each patient via brightness modulation
    2. Second multispectral set of scans to highlight skin features.

Advanced Objectives

- Develop a scalable and portable structure for real-world usability.
- Use polarization and optical enhancements for at least 1024x1024 pixel images.

Stretch Objectives

- Explore system modularity, enabling customizations such as interchangeable lenses, filters, and optical elements for different clinical need settings.
- Mobile platform support and AI integration.



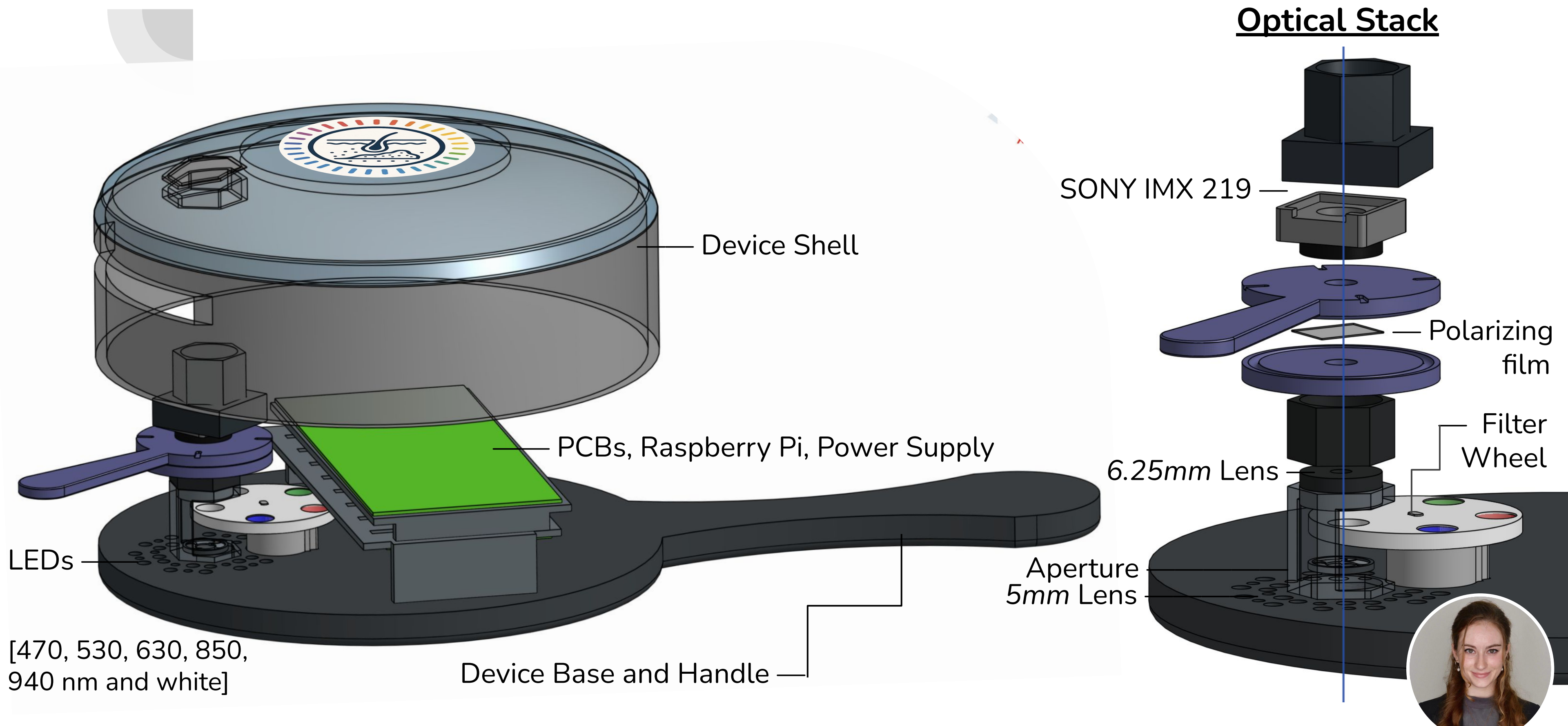
Optical Design

- *Multiple LED clusters*, both white, visible, and NIR allow varying depth imaging and shadow enhanced images.
- *Reflective material* surrounding the LEDs in the system to increase lambertian intensity.
- *Linear polarizer* in front of the camera to create to reduces surface reflections from oily or wet skin.
- *Aperture* in imaging plane to allow variability of depth of field.
- *Achromatic doublet objective and imaging lenses* to minimize spherical and chromatic aberrations.

System Specifications

Engineering Requirement	Requirement Specification	Unit
Image Processing Time	< 5 ± 0.5	seconds
Spatial/Image Resolution	~10-20	um/pixel
Magnification	0.1-0.5	Unitless
FOV (Field of View)	10 × 10	mm
NIR Penetration Depth	> 4 ± 0.5	mm
Visible Penetration Depth	0.2–0.8	mm
System Power	5–12	Watts
System Current Draw	1–2	Amps
Portability	Yes (handheld)	—
Weight	< 3	lbs
Exposure Time	10–50	ms
Wavelength Bands	5 discrete (VIS + NIR)	—
Filter Switching Time	< 1	second
LED Control Latency	< 100	ms
Safety Irradiance Limit	< 10	mW/cm^2 per LED

SkinLumina Device: Full CAD Assembly Overview



Calculating Lens System Parameters

We want an Imaging FOV of 10mm x 10mm

$$Magnification\ (M) = \frac{Sensor\ Diagonal}{Object\ Diagonal} = \frac{f_{tube}}{f_{obj}}$$

$$Sensor\ Diagonal = \sqrt{(3.68mm)^2 + (2.76mm)^2} = 4.6mm$$

$$Object\ Diagonal = \sqrt{(10mm)^2 + (10mm)^2} = 14.14mm$$

$$M = \frac{4.6mm}{14.14mm} = 0.325 \cong 0.333$$

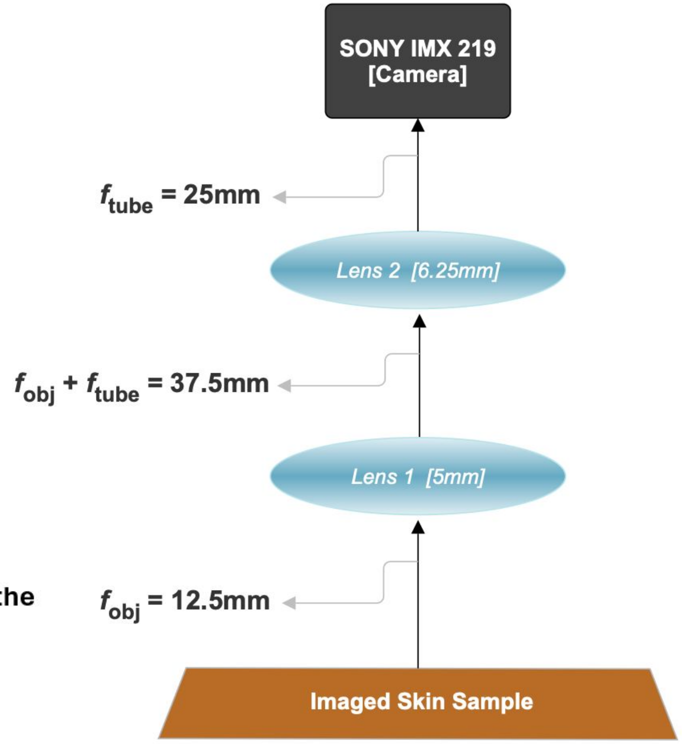
This is the lowest magnification we can have to be able to image in our FOV the features of the skin we are targeting.

Now to calculate focal lengths:

First, we chose an appropriate objective lens focal length that is reasonable for the goals of our system; $f_{obj} = 12.5mm$

$$f_{tube} = M * 12.5mm = 0.333 * 12.5mm \cong 4.2mm$$

Since commercial lenses at our minimum calculated focal length are very expensive and hard to find off the shelf, we decided to target a 2x magnification for our system giving us a focal length for the tube lens at 25mm.



Irradiance and Spot Diameter

$D = distance\ from\ LED\ to\ skin{:}\ goal\ is\ 5cm$

$\theta = full\ beam\ angle{:}\ an\ assumption\ based\ on\ our\ LED\ allignment\ plan\ is\ 30°$

$$Spot\ Diameter{:}\ d = 2 * D * tan\left(\frac{\theta}{2}\right) = 2 * (5cm) * tan\left(\frac{30°}{2}\right) = 2.68cm$$

$$A = area\ of\ illumination\ on\ skin{:}\ \pi * \left(\frac{d}{2}\right)^2 = \pi * \left(\frac{2.68cm}{2}\right)^2 = 5.64cm^2$$

$$\text{Irradiance: } E = \frac{P_{out} * \cos(\theta)}{A}$$

$$E_{470nm} = \frac{24mW}{5.64cm^2} = 4.25mW/cm^2$$

$$E_{525nm} = \frac{4mW}{5.64cm^2} = 0.25mW/cm^2$$

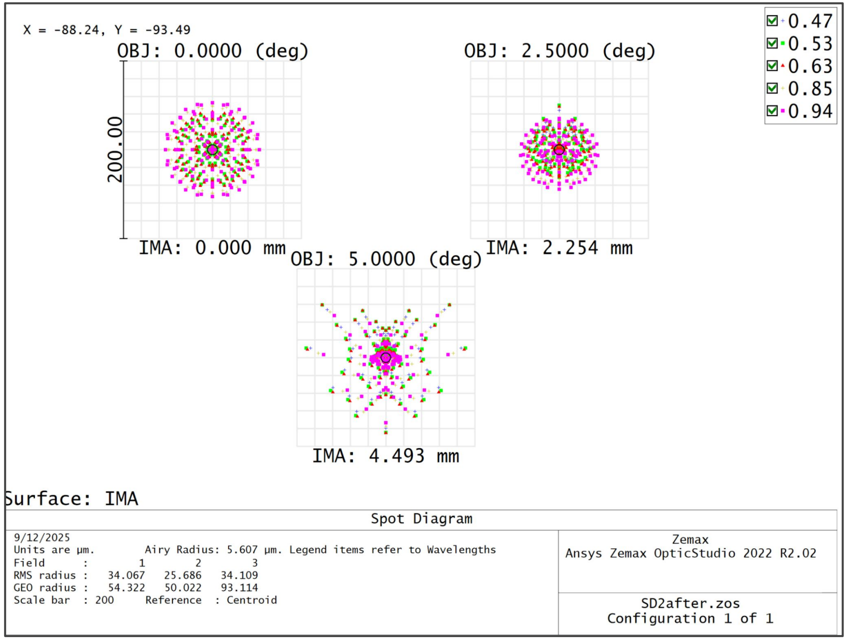
$$E_{630nm} = \frac{16mW}{5.64cm^2} = 2.84mW/cm^2$$

$$E_{850nm} = \frac{10mW}{5.64cm^2} = 1.77mW/cm^2$$

$$E_{940nm} = \frac{18mW}{5.64cm^2} = 3.19mW/cm^2$$

$$E_{white} = \frac{15mW}{5.64cm^2} = 2.66mW/cm^2$$

https://www.thorlabs.com/newgrouppage9.cfm?objectgroup_id=2814



Simulated spot sizes in Zemax for each LED wavelength on the camera sensor.

Imaging Spatial Resolution

$$Pixel\ Resolution = \frac{FOV\ Dimension}{\#\ of\ Pixels}$$

Horizontal

$$Resolution = \frac{10mm}{3280\ Pixels} = 3.05\mu m/Pixel$$

Vertical

$$Resolution = \frac{10mm}{2464\ Pixels} = 4.06\mu m/Pixel$$

Spatial Resolution is the ability of our system to be able to record fine details and features.

Wavelength Penetration Depth

$\lambda(nm)$	$\mu_{a(mm)}$	$\mu_{s(mm)}$
525	1.2	17.0
850	0.15	8.5
940	0.2	7.8

$$\delta = \frac{1}{\sqrt{3 * \mu_a * (\mu_a + \mu_s)}}$$

525nm

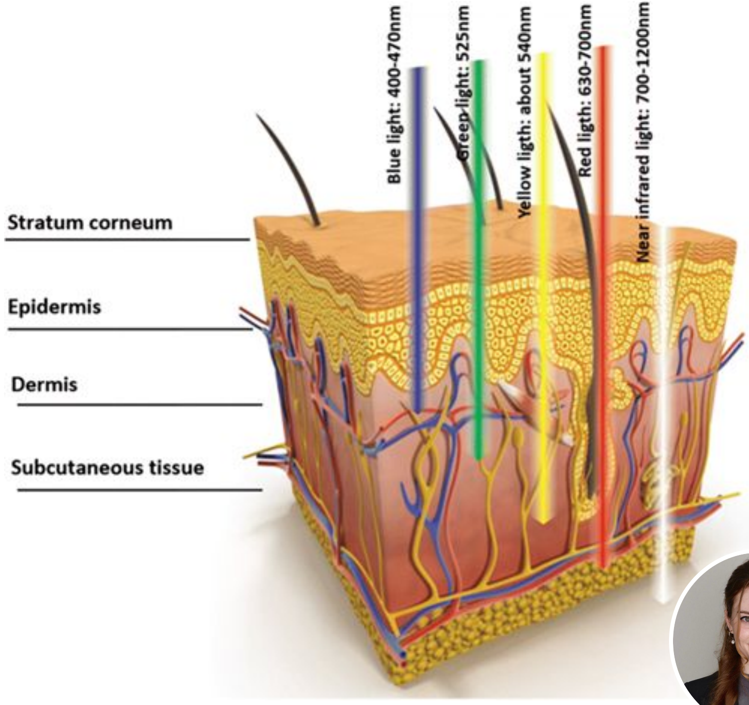
$$\delta = \frac{1}{\sqrt{3 * 1.2 * (1.2 + 17)}} = 0.124mm$$

850nm

$$\delta = \frac{1}{\sqrt{3 * .15 * (.15 + 8.5)}} = 0.507mm$$

940nm

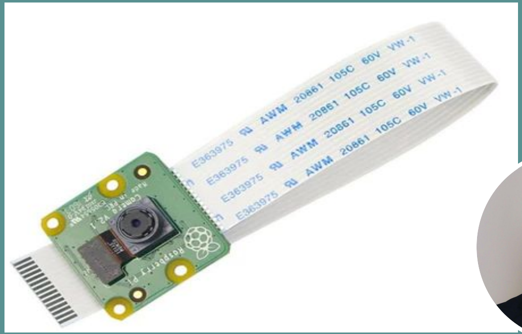
$$\delta = \frac{1}{\sqrt{3 * 0.2 * (0.2 + 7.8)}} = 0.457mm$$



Imaging Technology + Camera Selection

Technology	Pros	Cons
CMOS Imaging	- Lower Power - Compact - Cost Effective	- Lower low light Sensitivity - Lower Resolution
CCD Imaging	- Better low light performance - Better Image Resolution	- Power Hungry - Bulky - Expensive
Smartphone Imaging	- Portable - User Friendly - Great Image Processing	- Limited control over optics - Hardware harder to integrate

- Ultimately chose CMOS for its cost-effectiveness and lower power requirements.
- In terms of specific camera; we chose the Sony IMX219 sensor module.
- We chose this module as it allows us to meet our 2MP resolution target, is IR sensitive, as well as, being a cost-effective part

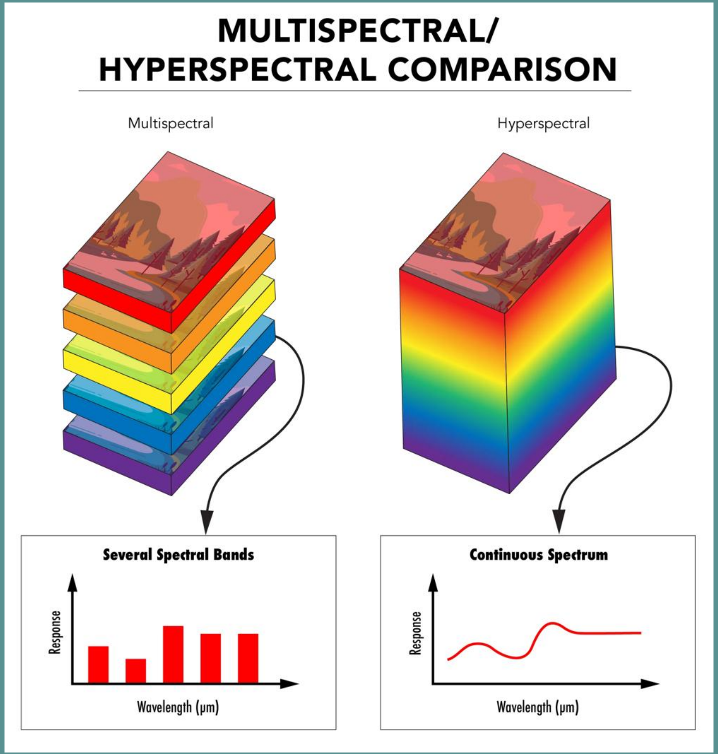


Illumination Source

- Selected LEDs as the illumination source for their safety, compact size, low cost, and wide availability.

- Implemented as a multispectral LED array to target specific skin features by using wavelengths that interact differently with tissue. A multispectral design also provides high spectral control, portability, and programmability.

- Chosen wavelengths (470, 530, 640, 850, 940 nm) span from visible to NIR, enabling both surface detail and deeper structural imaging.

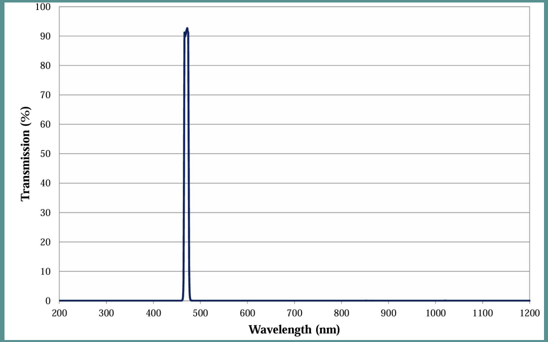


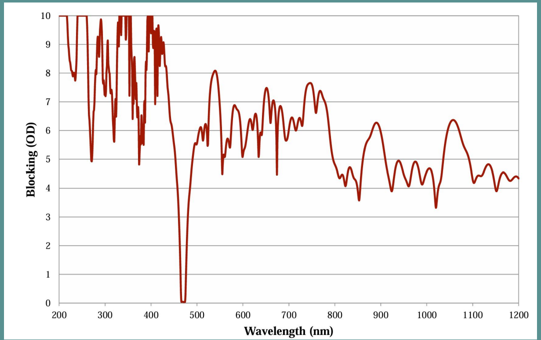
Multispectral: selected wavelengths
Hyperspectral: many bands

Optical Filter Selection

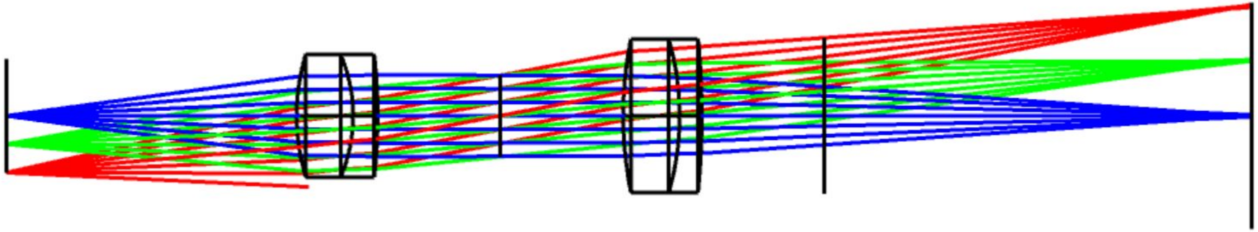
3D printed optical filter wheel with chosen filters.

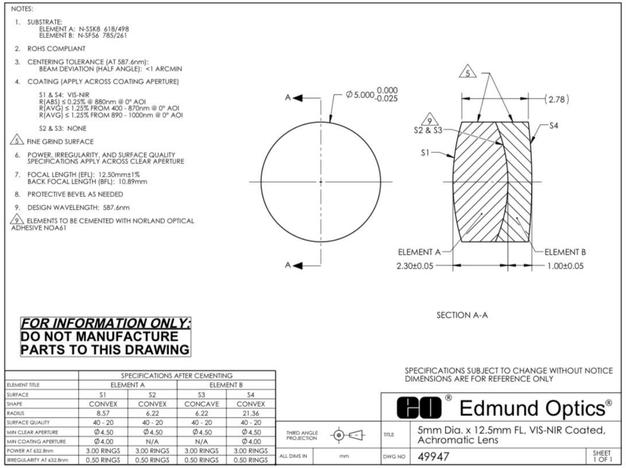
- Visible narrowband filters (±10 nm) chosen to isolate individual LED wavelengths.
- OD 4 filters (Edmund Optics) provide strong blocking of outside light down to 0.0001 transmission.
- 12.5 mm diameter filters selected to match the portable system design.
- Filters integrated into a 3D printed custom filter wheel for rapid wavelength switching and selective imaging.

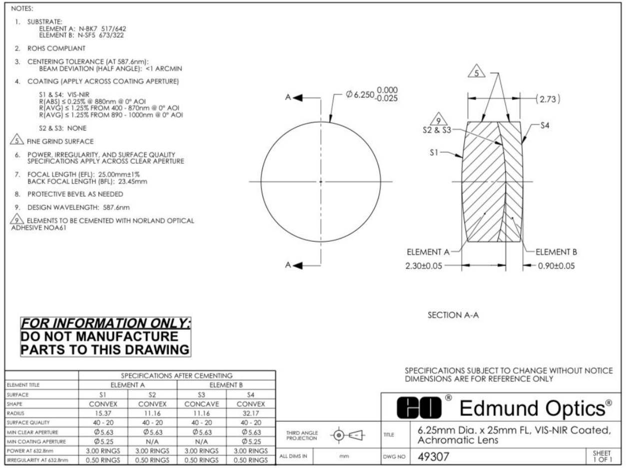




Lens Selection







Achromatic doublets chosen for both objective and tube lens to minimize chromatic aberrations across visible and NIR LED bands.

Objective lens designed for short working distance and high clarity to ensure accurate skin surface and subsurface imaging.

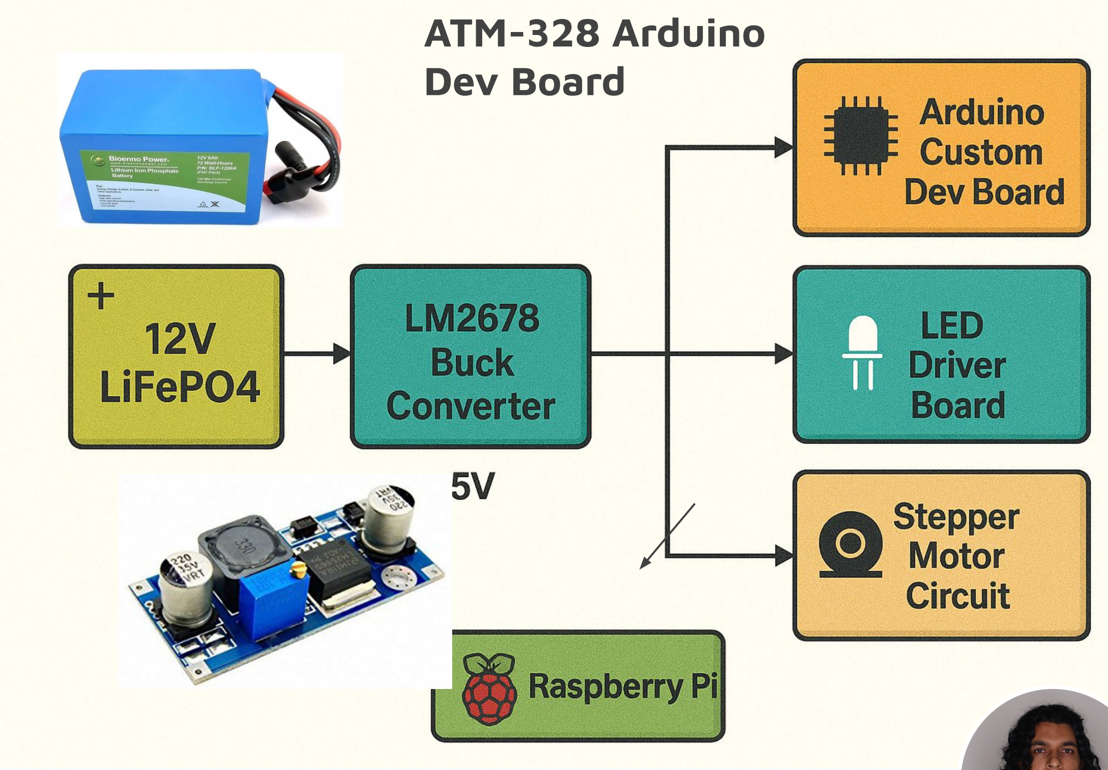
Tube lens provides proper magnification and coupling with CMOS sensor for full field capture.

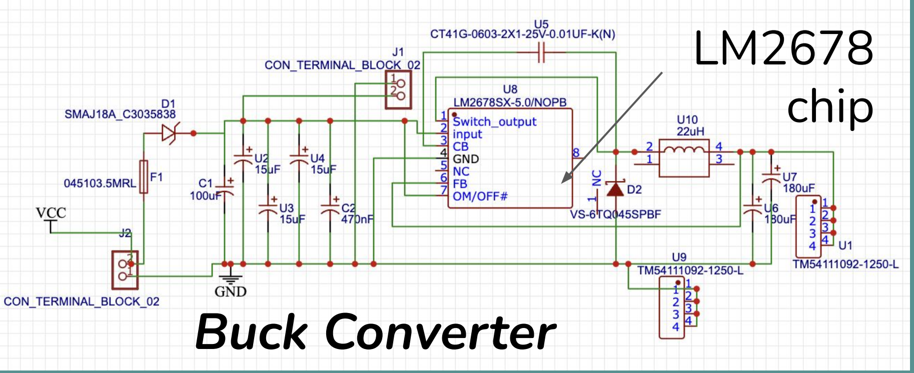
Optical coatings optimized for 400–1000 nm to reduce reflection losses and enhance illumination efficiency.

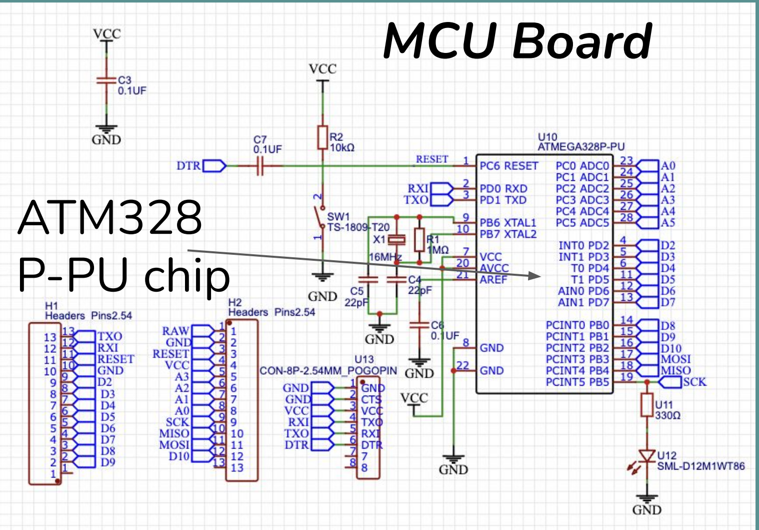
Hardware Design

- A 12-volt lithium iron phosphate drives power into a buck converter. This buck board converts power from 12 to 5V at an output voltage of 5A.

- The 5V power is then driven to the project peripherals, the Raspberry Pi, the custom Arduino dev board, the LED driver board and the filter wheel stepper motor.







LM2678 Buck Converter

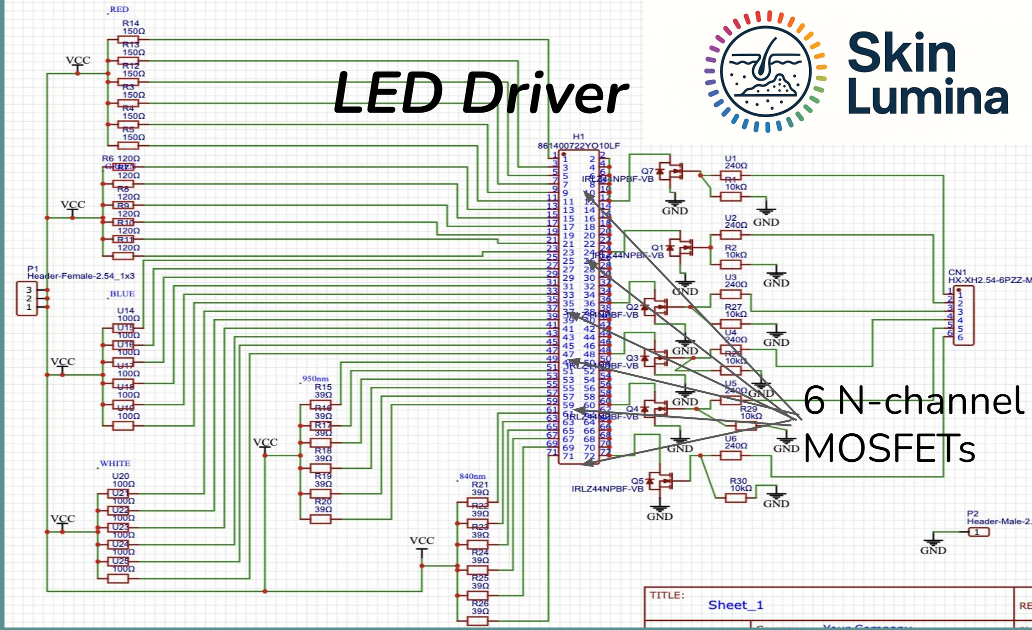
- The LM2678 was chosen for its high efficiency and ability to supply a clean 5V at up to 5A, outperforming many lower-current buck converters. Its low ripple and strong thermal performance make it more suitable for sensitive imaging electronics than cheaper alternatives.

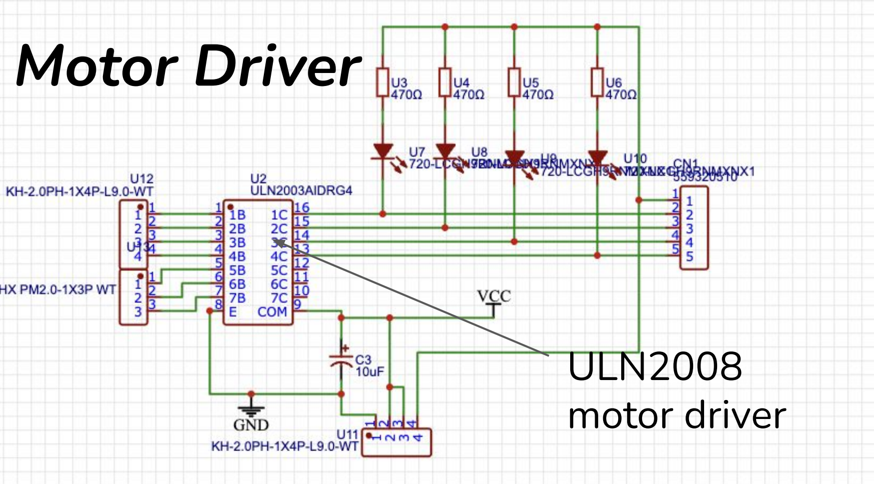
ATmega328

- The ATmega328 was chosen due to its reliability, low noise, and proven stability compared to more complex microcontrollers. Its widespread support and predictable behavior make it better for timing-critical biomedical tasks than higher-overhead processors.

N-Channel MOSFETs

- N-channel MOSFETs were selected because they provide lower on-resistance and higher switching efficiency than equivalent P-channel devices. Their reduced heat generation and faster response make them better for precise, stable LED driving.

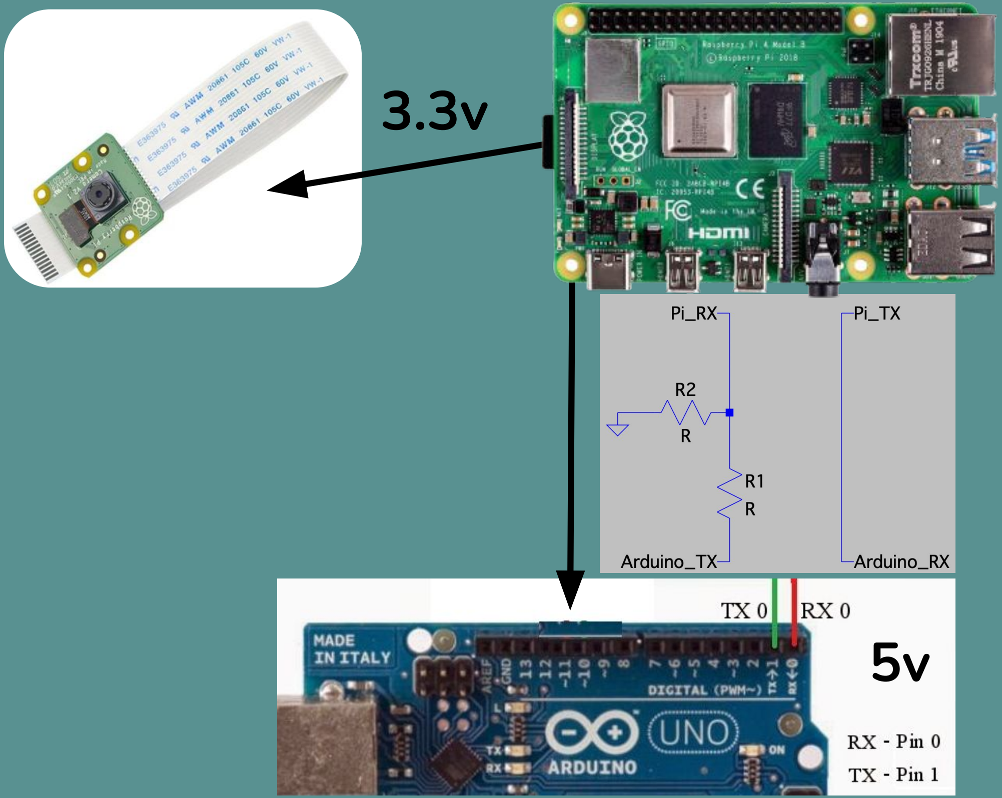




ULN2003 Motor Drive

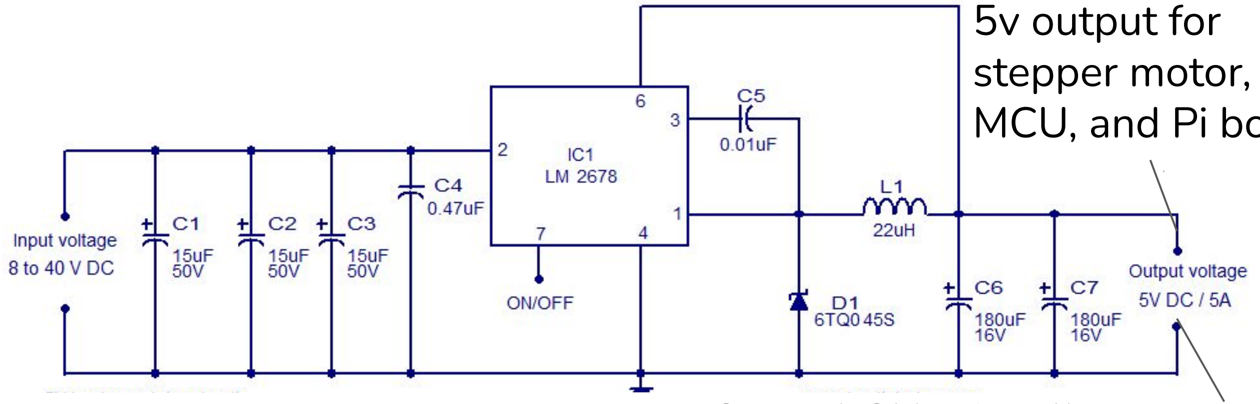
- The ULN2003 was selected for its ability to drive stepper motors safely with integrated flyback protection, outperforming simpler transistor arrays. Its robustness and current-handling capability make it more suitable than many compact driver alternatives for mechanical filter positioning.

Hardware Communication



- The Raspberry Pi is configured as the master controller, managing both the MCU and the CMOS camera.
- Powered by 5 V input, the Pi internally regulates to 3.3 V operation.
- Communication between the Pi and MCU occurs via RX and TX pins, interfaced through a logic level shifter.
- The shifter ensures proper voltage matching between the boards' different operating levels.

System Power Analysis



5v output for stepper motor, LED, MCU, and Pi board

Central GND for all components

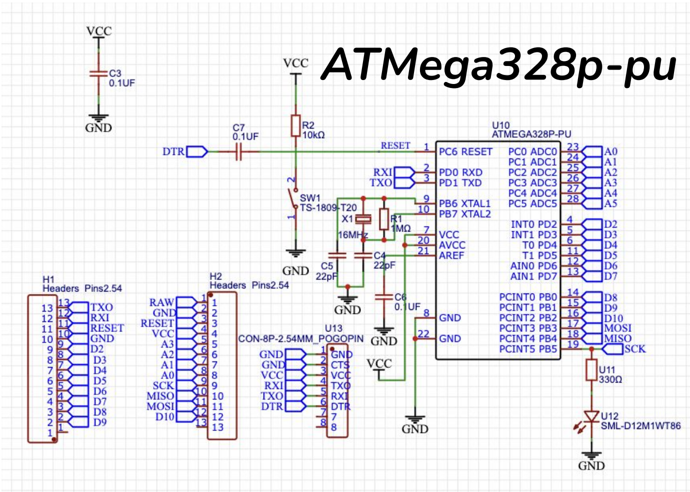
The buck converter supplies 5V to all components. All components share a common ground at the buck converter.

The LM2678 chip is an optimal choice because it's a monolithic 5A switching regulator, simplifying circuit design while meeting high current demands. Its high efficiency (~85-90%) drastically reduces heat loss compared to inefficient linear regulators, allowing for a reliable, cool-running power source. While sacrificing the scalability of a discrete design, the single monolithic chip minimizes component count, complexity, and board space, which is critical for a custom development board.

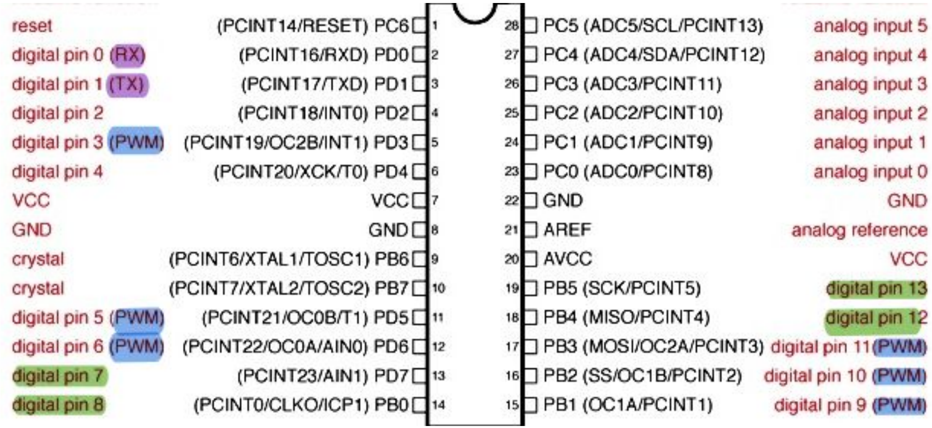
MCU Board

Skin Lumina

ATMega328p-pu Chip



- **Blue pins**: Pulse Width Modulation (PWM) pins used for precise LED control, beyond the capability of standard digital pins.
- **Green pins**: Digital Input/Output pins that provide simple high/low logic, sufficient for operating the stepper motor.
- **Purple pins**: Communication pins (RX and TX) enabling data exchange between the MCU and the Raspberry Pi.

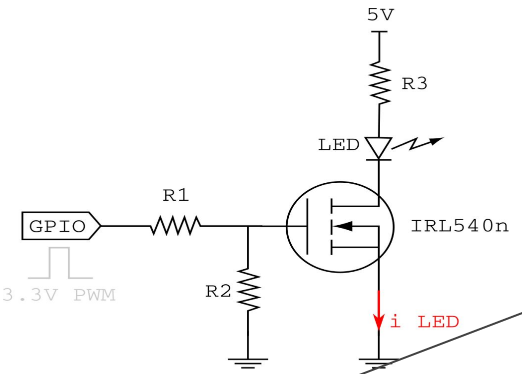


The ATmega board was chosen for its simplicity and reliable real-time control. Its built-in PWM timers provide precise, flicker-free LED dimming and accurate motor control, without the timing issues of more complex boards. Its 5V operation also makes it easy to connect with standard drivers and simplifies software setup.

Control Circuit

LED Type	Resistor (Ω)	Current (mA)	Power (W)
Red	150	~20	0.06
Blue	110	~20	0.04
Green	91	~20	0.04
White	91	~20	0.04
850 nm IR	36	~97–106	0.35
940 nm IR	36–39	~94–101	0.36

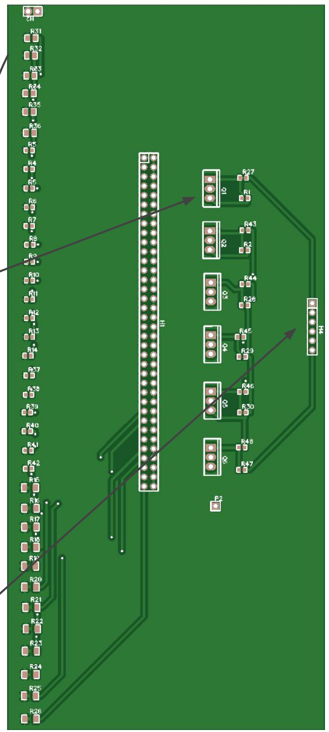
MOSFET LED Driver



MOSFETs

Resistors—meant for each LED based of forward voltage and current draw

Arduino PWM connection pins

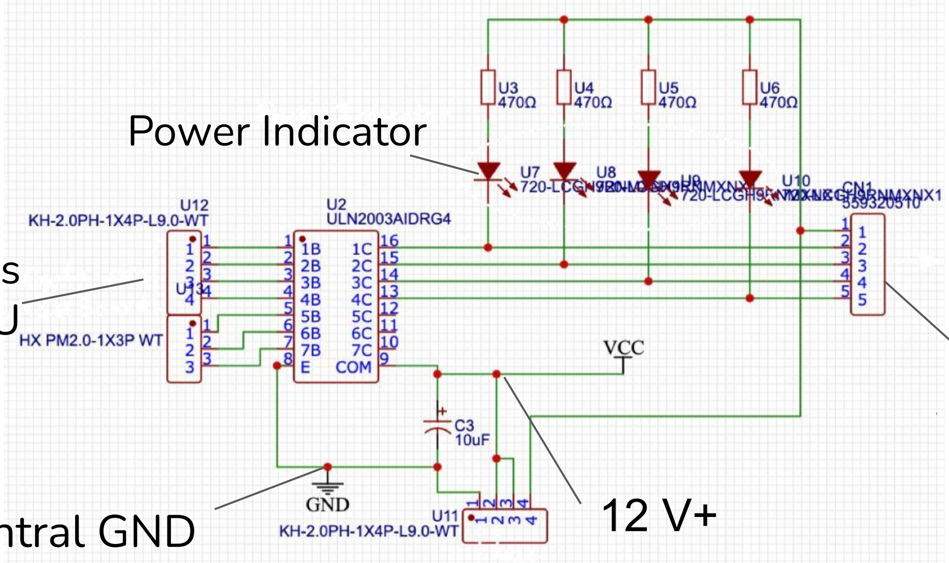


The MOSFETs are used as a high-current electronic switch, enabling the Arduino's low-power control signal to drive LEDs that require significantly more current than a GPIO pin can supply. By using a PWM pin, LED brightness can be controlled efficiently through rapid switching of the MOSFET.

Stepper Motor Control

ULN2003 Driver

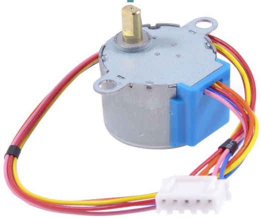
The ULN2003 driver is ideal because it prioritizes simplicity, low cost, and direct 5V compatibility. Unlike complex micro-stepping drivers (e.g., A4988), this basic Darlington array requires no configuration or voltage level shifting. This makes it the easiest solution, perfectly suited for the low-speed, precise indexing movements required by a filter wheel, minimizing overall design complexity.



4 I/O pins to MCU

Central GND

12 V+



Stepper Motor

The stepper motor's sole purpose in this system is to rotate the filter wheel. It provides the precise, controlled movements necessary by indexing the correct filter position.

Power System

Skin Lumina

LiFePO4	BMS
Long life cycle	Cell balancing
Thermal Stability	Short circuit protection
Long lasting charge	Overcharge/discharge protection

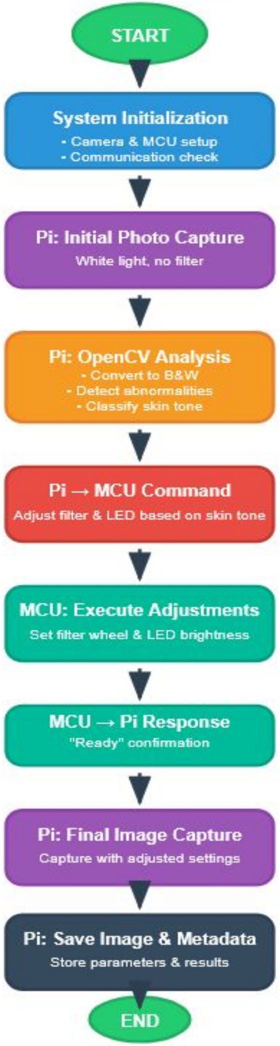
Component	Max Current (A)	Power (W)	Notes
Raspberry Pi 4	3.00 A	15.0 W	Peak draw
LED Driver Board	1.68 A	8.4 W	LED load
Stepper Motor	0.25 A	1.25 W	Motor circuit
ATmega Board	0.05 A	0.25 W	Logic power

Total Load: 4.98 A, 24.9 W

$LiFePO_4$

$LiFePO_4$ batteries were selected for their safety, long life, and stable voltage. They are more thermally stable and less prone to fire than Li-ion or LiPo batteries. Despite slightly lower energy density, their durability and steady 12.8V output make them a reliable long-term power source.

Software Design



The Raspberry Pi captures an initial reference image under white LED illumination.

The initial reference image is processed using a combination of OpenCV techniques.

Next, the software analyzes a central patch of pixels, converts them to a hexadecimal skin tone code, and classifies the skin into categories (e.g., fair, medium, dark).

This classification determines the LED intensity profile for subsequent scans.

Based on the category, the Pi communicates to the Arduino with LED intensity parameters.

Once LEDs are set, the Pi instructs the Arduino to begin filter cycling.

Once the scan cycle is complete, the Pi uploads both the image and its metadata to the MERN backend.

Raspberry Pi ⟷ Arduino Communication Protocol

UART Serial Link (9600 baud)

Wired TX/RX connection ensures stable, low-latency communication between Raspberry Pi and Arduino.

Custom Text-Based Commands

Pi sends simple ASCII commands:

```
LED RED 5
LED WHITE 10
STEP FIFTH
```

Arduino parses and executes each command.

ACK-Based Handshake

Arduino responds with structured acknowledgments:

```
ACK LED RED 5
```

Pi waits for ACK before sending the next command.

read_center_hex()

↓

compute_LED_adjustments()

↓

send_serial_command()

↓

wait_for_acknowledgment()

↓

capture_image()

↓

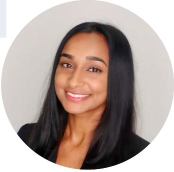
rotate_filter()

Why UART?

- Stable
- Human-readable
- Guaranteed timing
- Ideal for our real-time LED modulation and motor control

System Architecture Comparison

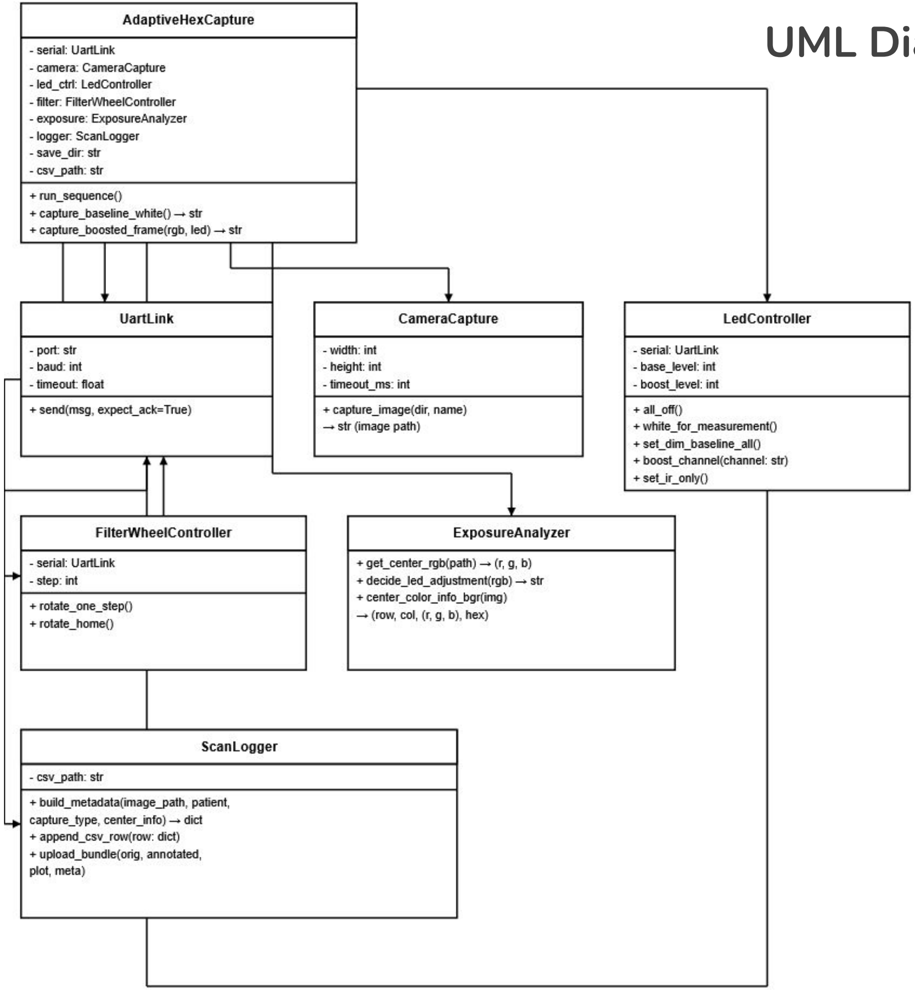
Architecture	Processing Power	Real Time Control	Ease of Development
Raspberry Pi 4 [Chosen Processor]	Quad-core Linux system optimized for CPU-intensive workloads; suited for our image capture, CLAHE preprocessing & contour analysis	Not suitable for timing-critical hardware control	*Easy:* Simple setup with Python, Linux, and OpenCV packages Strong documentation Fast iteration on image-processing code
Arduino Uno [Chosen Controller]	Very low (8-bit MCU)	Chosen for its precision for PWM LEDs + motor timing	*Easy:* Arduino IDE, simple C/C++, minimal setup required Perfect for LED and motor control prototyping
ESP32 [Alternative Controller]	Medium (dual-core MCU)	Good, but due to wifi/bluetooth interrupts it can steal CPU time causing delay in PWM output	*Medium:* WiFi stack, dual-core management Real-time tasks require careful timing and FreeRTOS familiarity
Jetson Nano [Alternative Processor]	Very high (GPU + quad-core CPU). Introduces unnecessary complexity, higher power consumption, greater heat output	Runs a full Linux OS, which cannot provide deterministic timing due to task scheduling and background processes.	*Hard:* CUDA installs, driver management, Linux configuration challenges Complex GPU toolchain setup



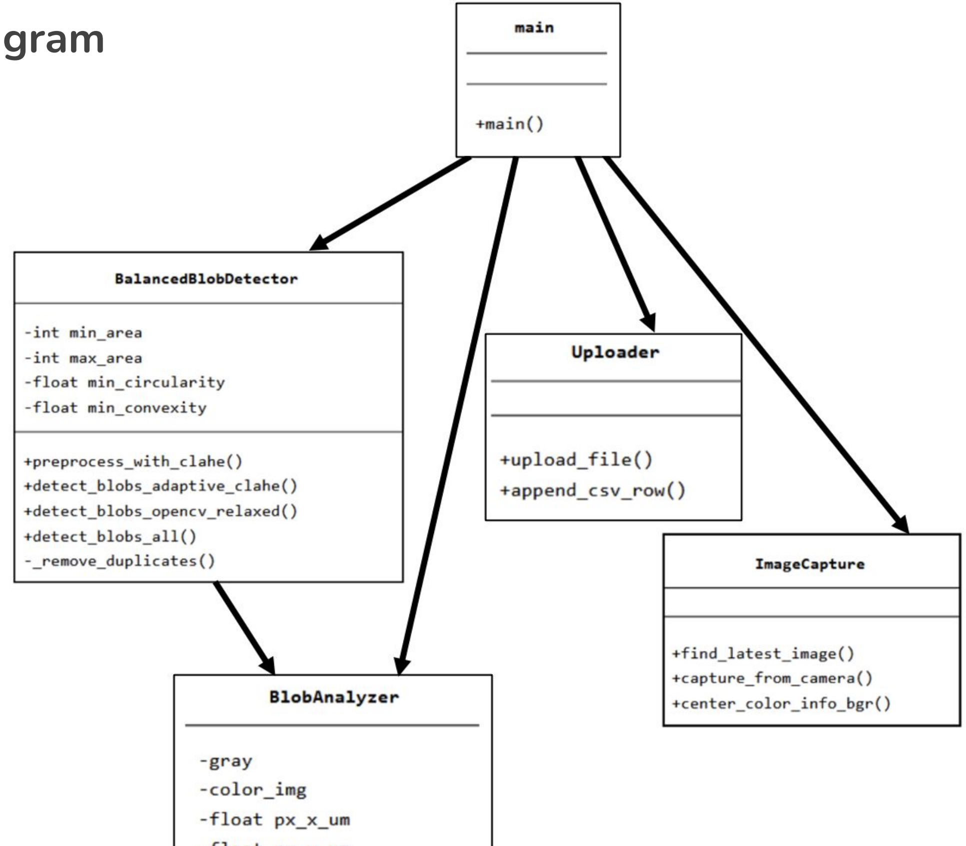
Website Stack Comparison

Stack	Backend (Host/Runtime)	Data layer (DB + Storage)	Front-End	Fit & Tradeoffs
MERN [Chosen]	Node.js / Express	MongoDB Atlas for metadata + Cloudinary for images	React	Clean, Scaleable Upload Pipeline Flexible Metadata
Serverless Jamstack: FastAPI (Render) + Supabase + Netlify	Fast API hosted on Render	Supabase Storage	Netlify	Low ops/low server maintenance More service coordination Learning Curve
LAMP	Apache + PHP	MySQL	HTML, CSS, JavaScript	Not as modern or scalable as MERN/Jamstack for heavy client-side application

UML Diagram



AdaptiveHexCapture
- serial: UartLink
- camera: CameraCapture
- led_ctrl: LedController
- filter: FilterWheelController
- exposure: ExposureAnalyzer
- logger: ScanLogger
- save_dir: str
- csv_path: str
+ run_sequence()
+ capture_baseline_white() → str
+ capture_boosted_frame(rgb, led) → str
UartLink
- port: str
- baud: int
- timeout: float
+ send(msg, expect_ack=True)
CameraCapture
- width: int
- height: int
- timeout_ms: int
+ capture_image(dir, name)
→ str (image path)
LedController
- serial: UartLink
- base_level: int
- boost_level: int
+ all_off()
+ white_for_measurement()
+ set_dim_baseline_all()
+ boost_channel(channel: str)
+ set_ir_only()
FilterWheelController
- serial: UartLink
- step: int
+ rotate_one_step()
+ rotate_home()
ExposureAnalyzer
+ get_center_rgb(path) → (r, g, b)
+ decide_led_adjustment(rgb) → str
+ center_color_info_bgr(img)
→ (row, col, (r, g, b), hex)
ScanLogger
- csv_path: str
+ build_metadata(image_path, patient,
capture_type, center_info) → dict
+ append_csv_row(row: dict)
+ upload_bundle(orig, annotated,
plot, meta)



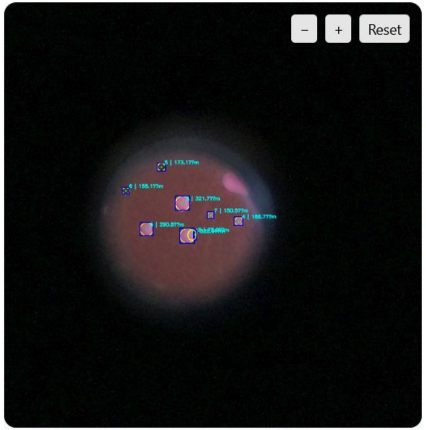
main
+main()
BalancedBlobDetector
-int min_area
-int max_area
-float min_circularity
-float min_convexity
+preprocess_with_clahe()
+detect_blobs_adaptive_clahe()
+detect_blobs_opencv_relaxed()
+detect_blobs_all()
-_remove_duplicates()
Uploader
+upload_file()
+append_csv_row()
ImageCapture
+find_latest_image()
+capture_from_camera()
+center_color_info_bgr()
BlobAnalyzer
-gray
-color_img
-float px_x_um
-float px_y_um
-float smooth_sigma
+analyze_blob()
-_empty_color()

Edge Detection Algorithm

Different wavelengths emphasize different skin features because each wavelength interacts uniquely with tissue, making certain abnormalities easier to visualize.

Accurate Scan

Image Details Close



Center Hex: **#B66492**

Resolution: 3280 × 2464

Anomalies: 8

Processing Time (ms): 1517.9

Detected Anomalies

ID	Location (x, y)	Diameter (µm)
1	(1665, 1323)	328.9
2	(1650, 1220)	321.7
3	(1537, 1302)	290.8
4	(1827, 1277)	188.7
5	(1583, 1106)	173.1
6	(1471, 1181)	155.1

Public ID: skinlumina/pi/s0mqiizg3rhdyyc7afbu
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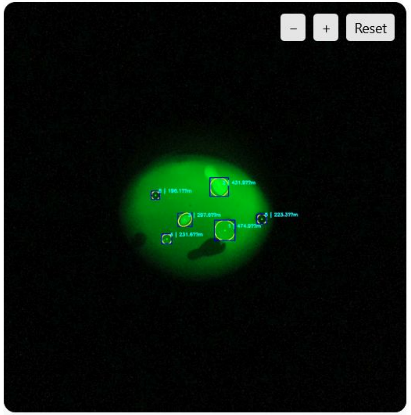
Almost Accurate Scan

Image Details Close



Center Hex: **#03AE0A**

Resolution: 3280 × 2464

Anomalies: 6

Processing Time (ms): 2746.0

Detected Anomalies

ID	Location (x, y)	Diameter (µm)
1	(1794, 1372)	474.9
2	(1776, 1230)	431.9
3	(1663, 1336)	297.6
4	(1604, 1400)	231.6
5	(1915, 1335)	223.3
6	(1567, 1257)	196.1

Public ID: skinlumina/pi/lj0ku0hh88hksbpjt3az
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We achieved an average processing time of 2.68 seconds, comfortably meeting our system requirement specification of staying under 5 seconds. Abnormality detection rate is at an 85% accuracy

Design Constraints

Economical – The project is designed to stay within a budget of \$500–750, utilizing off-the-shelf components along with 3D printing and laser cutting to keep costs manageable and the system affordable.

Time – The project is limited to two semesters, so both workload and design have been structured to align with this timeline.

Environmental – The system operates on low power with battery support, avoids disposable parts, and is designed to be energy-efficient and environmentally conscious.

Social / Ethical – The project addresses a critical health equity gap by providing inclusive skin analysis across all skin tones. As a non-invasive device, it avoids the regulatory burden of higher-risk FDA classifications.

Health & Safety – To remain non-invasive, LED power levels are limited to <10 mW/cm^2, and the system uses low voltages with no exposed mechanical parts to ensure user safety.

Manufacturability – By relying on commercially available components, the system is inherently scalable and reproducible, supporting long-term manufacturability.

Sustainability – The system is designed to be modular, allowing customization of lenses, apertures, and filters. It also leaves open pathways for integration with AI-based analysis in future software development.

Risk – The device is classified as low risk due to its conservative design, skin-safe operation, and thorough testing protocols. All human trials will undergo IRB review to ensure compliance and uphold ethical standards.

System Standards Table

Standard Name	Standard ID Number	Area of Application	Relevance to Skin Lumina Design
IEC Safety of Laser Products	IEC 60825-1	Laser & LED safety	Ensures that the LED system does not pose ocular hazards; confirms power levels are eye-safe.
ISO Medical Electrical Equipment	ISO 60601-1	Electrical and patient safety	Guarantees safety in electrical design, especially for skin contact or handheld usage.
ISO Skin Color Measurement	ISO/TR 26385:2008	Skin reflectance and colorimetry	Used for calibrating imaging across diverse skin tones.
IEEE Biomedical Engineering Standards	IEEE 11073 Series	Data and interoperability (future application)	Provides structure for future data standardization and communication with health informatics tools.
ANSI Standard for Imaging Devices	ANSI/NEMA PS3 (DICOM)	Image storage & medical interoperability	Applicable for integrating image formats with diagnostic platforms and EMRs.
ISO Optical Design Standards	ISO 10110	Lens and optical component specs	Applied during Zemax modeling and component selection to reduce aberrations and maintain alignment.

Safety Requirements

LED Exposure Safety: All LEDs operate under safe power thresholds (<10 mW/cm^2); device follows IEC 62471 LED safety guide

Thermal Control: Insulation and ventilation in the enclosure to ensure proper thermal regulation for electrical system

Electrical Safety: Powered by low-voltage (3V to 12V) regulated battery systems, reducing electrical shock risk.

Mechanical Safety: Filter wheel and optics are enclosed; no exposed moving parts.

Ergonomic Design: we are designing a lightweight-handheld device to reduce user strain whilst operating.

User Instructions: Clear documentation will guide proper use, including safe distances and durations.

Data Handling: Security protocols for patient data if cloud integration is implemented.

Project Challenges Faced during Development

CAD Challenge:
3D printer nozzle precision limited the ability to accurately fabricate small optical holders, such as the 5 mm lens mounts.

Optical Challenge:
Demonstrating NIR penetration depth and creating a clear proof of concept for subsurface imaging required extensive material testing.

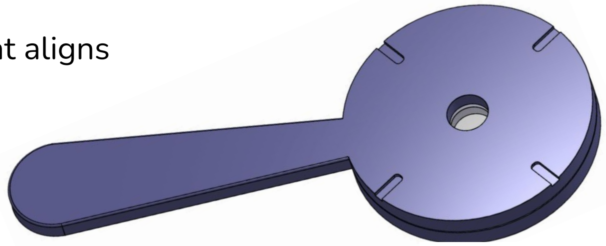
Testing Challenge:
Unable to test on live subjects due to IRB approval delays, so synthetic skin samples were created and used instead.

Electrical Challenge:
Designing and fabricating a PCB with a buck converter to reliably step down 12 V to 5 V required multiple layout revisions.

Software Challenge:
Edge detection algorithms struggled with spot accuracy and shape recognition, especially when differentiating light features on dark backgrounds.

Skin Lumina

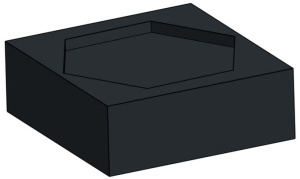
Prototyping: Design Implementation

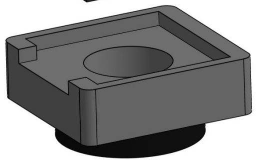


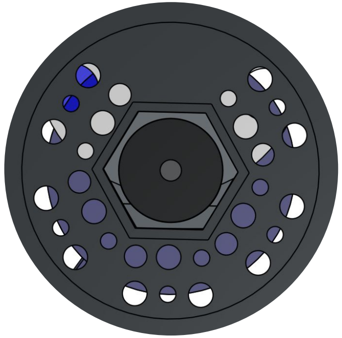
Objective: Create a portable, modular housing for the SkinLumina system that aligns all optical, electrical, and mechanical components for consistent imaging performance.

Design Process:

- Designed in Onshape to ensure precise optical alignment and easy assembly.
- The main housing securely holds the optical stack, PCBs, and wiring within a single compact shell.
- LED holes were 3D printed at 30° angles toward the imaging point to provide uniform illumination.
- A polarizer holder with a manual adjustment handle allows users to control polarization during imaging.
- Thermal management was integrated by adding ventilation holes near the battery and Raspberry Pi, the system's main heat sources.







Outcome: The 3D-printed design ensures stability, alignment, and portability, forming a robust prototype optimized for testing and future clinical adaptation.

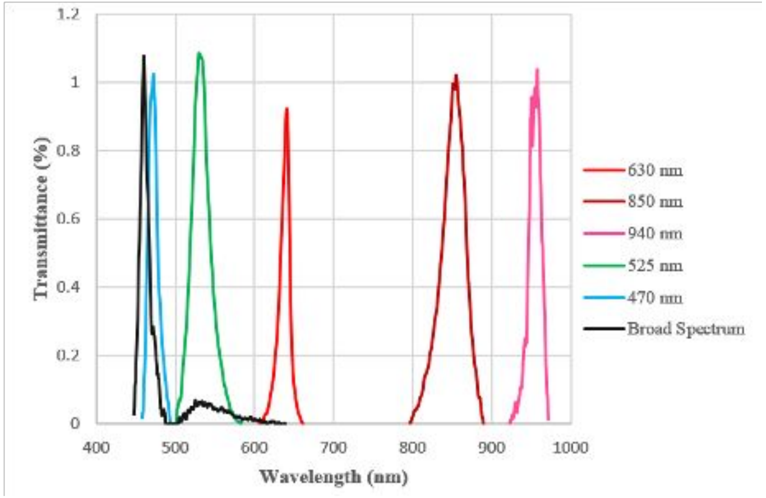
Testing: Experimental Methods using Phantom Skin

- **Base Material:** Smooth-On Dragon Skin 20 silicone used as the primary medium.
- **Absorption Agent:** Higgins India Ink added to simulate melanin and hemoglobin absorption.
- **Scattering Agent:** Titanium dioxide (TiO_2) powder introduced to model tissue scattering behavior.
- **Layer Composition:**
  - *Dermis:* 100 g silicone + 0.46 g ink
  - *Epidermis:* 20 g silicone + 0.092 g ink
- **Purpose:** To replicate the optical properties of real human skin and study wavelength-dependent light behavior.

10 of our created phantom skin samples.

These multilayer silicone phantoms simulate realistic absorption and scattering, allowing accurate optical testing for SkinLumina's imaging validation.

Testing: LED Profile Characterization



Measured spectral emission profiles confirming distinct LED wavelength peaks across the visible and NIR ranges.

Objective:

Confirm spectral accuracy and stability of SkinLumina's LED array across visible and near-infrared ranges.

Method:

Each LED (470, 525, 630, white, 850, 940 nm) was powered at its correlated current and the the profile was tested with an Ocean Optics HR2000CG-UV-NIR spectrometer. A polarizer and aperture reduced saturation during visible LED testing.

Results:

All LEDs emitted at expected wavelengths with stable intensity and minimal spectral overlap. The white LED showed a broad 430–650 nm band (peak ≈ 450 nm), while NIR LEDs at 850 nm and 940 nm used for deeper imaging.

The LED array produced distinct, stable emission bands, confirming accurate multispectral illumination for surface and subsurface skin imaging.

Testing: Wavelength Penetration Depth Analysis

Goal: Validate the calculated penetration depths of visible and NIR wavelengths using fabricated silicone skin phantoms. The layered phantoms (epidermis, dermis, hypodermis) were imaged under each LED wavelength.

Observations:

- Shorter visible wavelengths (470-530 nm) illuminated the surface layer (epidermis).
- Mid-range wavelengths (530-630 nm) reached the dermis, enhancing pigment and vessel visibility.
- Near-infrared wavelengths (850–940 nm) penetrated into the deepest layer, showing subsurface features that the other wavelengths could not pick up.

$\lambda\,(nm)$	$\mu_a\,(mm^{-1})$	$\mu_s'\,(mm^{-1})$	[calculated] $\delta\,(mm)$	[tested] $\delta\,(mm)$	Difference (%)
470	0.115	2.5	1.05	~1.0	4.88
530	0.083	2.0	1.39	~1.5	7.61
630	0.046	1.5	2.17	~2.75	23.5
850	0.012	1.0	5.26	~5.15	2.11
940	0.009	0.9	6.37	~6.0	5.98

Phantom sample penetration depth and imaged depth test % accuracy.

Distinct image contrast was observed for each wavelength, visually confirming the calculated penetration depths and proving that NIR reached past the predicted 4mm depth.

Testing: Buck Converter Efficiency

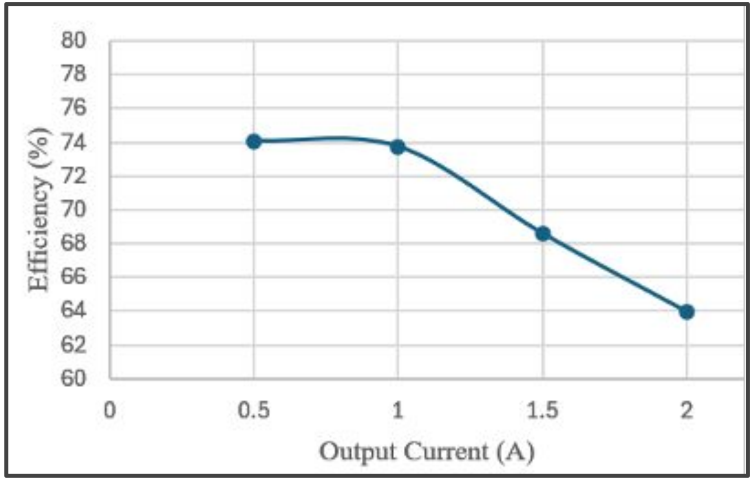
Objective:
Verify the stability and efficiency of the LM2678 buck converter, which powers key components of the SkinLumina system, including the LEDs, camera, and microcontroller.

Why This Test Matters:
Reliable voltage regulation is essential to prevent flickering LEDs, image noise, and sensor errors during imaging. Testing ensures consistent optical output and protects components from voltage or thermal instability.

Testing Overview:
The converter was evaluated using a DC electronic load to simulate varying power demands while monitoring voltage and current behavior under each condition.

Results:
The LM2678 maintained stable 5 V output and efficiency across all loads without overheating or fluctuation.

Buck Converter Efficiency vs. Output Current



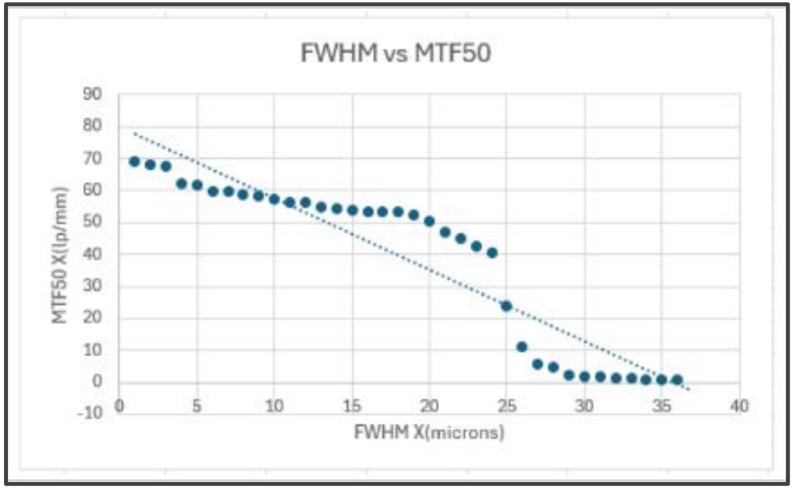
The measured data was used to generate the converter efficiency profile as a function of output current.

Testing: Spatial Resolution

Objective: Evaluate optical performance and image sharpness to confirm SkinLumina's ability to resolve fine skin features.

Method:

- Custom Python GUI with OpenCV used to analyze test images.
- Defined circular ROIs and extracted horizontal and vertical line profiles.
- Measured key metrics:
  - **FWHM** – feature sharpness
  - **Edge Width (10–90%)** – transition clarity
  - **MTF50** – contrast preservation



Results: The analysis showed that as image blur increased, the measured FWHM values widened while MTF50 decreased, meaning the image lost fine detail and sharpness. Across the entire image field, resolution stayed consistent from the center to the edges, showing that the optical system maintained accurate focus, alignment, and minimal distortion during imaging.

Testing: Hexadecimal Detection Accuracy

Objective:

Use HEX color codes to measure skin reflectance and adjust the individual LED brightnesses for consistent imaging across skin tones.

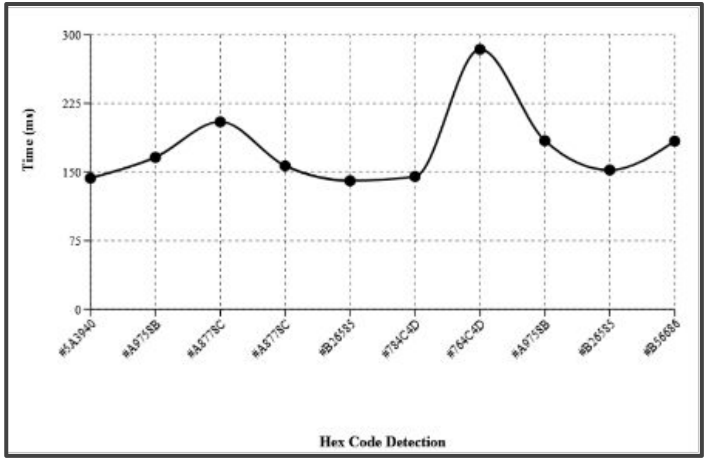
Method:

- Used OpenCV and NumPy to extract the image’s center pixel and nearby region.
- Averaged RGB values to reduce noise and converted them into a six-digit HEX color code.

Results:

- Detection times ranged from 140–280 ms with 95% consistency across ten trials.

Detection Time vs. HEX Code Detection



The chart shows detection time and consistency of HEX color extraction across captured images.

HEX color detection allows real-time LED calibration, ensuring balanced illumination and accurate imaging for all skin tones.

Administrative Content

Distribution of Work		
Task	**Responsibility (Primary)**	**Responsibility (Secondary)**
Visible Imaging System	Tatiana C.	Ryan R.
NIR Imaging System	Ryan R.	Tatiana C.
LEDs and Filters	Tatiana C.	Ryan R.
Camera + Optical Stack	Ryan R.	Tatiana C
Power System	Abdullah A.	Tiffany T.
PCB Layout	Abdullah A.	Ryan R.
Other Necessary Circuits (motor, LED, etc.)	Abdullah A.	Tiffany T.
Software Development	Tiffany T.	Abdullah A.
Camera Interfacing and Control Logic	Tiffany T.	Abdullah A.
Image Capture + Data Processing	Tiffany T.	Abdullah A.

Current Bill of Materials as of 9/12/25

	ITEM	Quantity	Price/Unit Cost	Cost (USD)
1	OD4 Filter 470 nm	1	182.32	182.32
2	OD4 Filter 532nm	1	182.32	182.32
3	OD4 Filter 632 nm	1	182.32	182.32
4	6.25mm fl ACH Lens	1	79.38	79.38
5	5mm fl ACH Lens	1	95.58	95.58
6	LED Red	12	.194	2.33
7	LED Blue	12	.19	2.28
8	LED Green	12	.273	3.28
9	LED 850nm	12	.99	11.88

	ITEM	Quantity	Price/Unit Cost	Cost (USD)
1	LED 940nm	12	.34	4.08
2	LED Cool White	24	.277	6.55
3	Raspberry Pi 4 Kit	1	110	110
4	Elegoo 1.75mm Filament	2	12.5	25
5	PCB Order	1	24	24
6	Arduino	1	27	27
7	Motor + Driver (5pack)	1	15.55	15.55
8	Shipping + Tariff Costs (Estimate)	1	160	160
Total	$1,114.87			

Thank you!

SkinLumina: Inclusive Multispectral Skin Analysis Device