ECE198 Design Document Outline - Group 15

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https://github.com/applesaucethebun/198Project

Needs Assessment

Client/Customer Definition

Our customer base will be **people living in Mexico with severe lupus erythematosus.** This is a section of autoimmune diseases in which the immune system of the body becomes hyperactive and starts to attack healthy tissues. Studies show that the number of patients with severe lupus erythematosus in Mexico is approximately 57,754 [1]. About 2/3rds of patients with this issue find that bad UV radiation aggravates their symptoms, usually from sunlight, and doctors often recommend to avoid sunlight as much as possible [2][3][4]. The problem is that people with this disease have no accessible way to tell what the UV radiation is around them. With a way to tell, affected people will be able to be safer in their surrounding area and have confidence in whether their symptoms will get worse, as UV levels can be bad both outdoors and indoors. Mexico in particular is an area with a very high average UV index, making the risk from sun damage especially high for those with lupus. Furthermore, Mexico has an average income of about 20,000 USD [5] so they most likely do not have access to quality healthcare. Due to this, our creation would have to be fairly affordable as this condition is more severe for people who cannot procure expensive treatment devices. Our solution is to create a device that communicates with these customers what the UV index is, so instead of guessing when it can be safe to go out they will have a measurable way to tell.

Competitive Landscape

1. Wearable Device for UV Monitoring [6]

The University of Minnesota has developed a wearable photodetector designed to monitor UV exposure in real-time, aimed particularly at assisting patients with photosensitive diseases such as lupus. This device combines a flexible, 3D-printed UV-visible photodetector array that is interfaced with the skin, allowing it to measure irradiance across the 310–650 nm spectrum. By incorporating a hybrid organic-inorganic material system, it enhances UV sensitivity and provides more precise, reliable irradiance data than basic sensors. This continuous monitoring ability can provide lupus patients with immediate feedback on their UV exposure levels.

The device does face limitations - particularly concerning accessibility and privacy. The device's high-tech materials and manufacturing requirements may make it cost-prohibitive, reducing accessibility for people in low-income regions where lupus is prevalent, such as Mexico. Finally, given the sensitive nature of the data collected, there are potential privacy concerns regarding data storage and handling, as the device would be collecting and storing real-time health information directly from the patient's skin interface.

2. Sensor + App (WearShade) [7]

WearShade, a startup product, offers a UV monitoring system tailored to help individuals, including lupus patients, manage sun exposure risks more effectively. The product combines a UV sensor with an app that provides real-time feedback, alerting users when UV levels are high and advising them to limit sun exposure. By tracking environmental data continuously, the system enables users to make informed decisions to avoid overexposure and reduce potential health complications related to photosensitivity. This functionality makes it a practical tool for patients seeking immediate, actionable insights on UV safety, particularly for managing conditions that are aggravated by sunlight.

Despite its advantages, WearShade faces challenges in its design and broader impact. As a startup, WearShade might encounter hurdles in scaling its production and ensuring consistent long-term support, which can impact users who depend on regular updates and reliability. Moreover, the accuracy of the device's UV sensor may be affected by environmental variations or limited internet connectivity, making it less reliable in rural or low-access areas. These factors present potential obstacles for maintaining device effectiveness and user trust, especially in underdeveloped regions.

3. LaRoche Posay MySkinTrack UV [8]

The My Skin Track UV sensor, while innovative, faces challenges in meeting the needs of lupus patients in Mexico, particularly in terms of affordability and accessibility. At a price point of $60, it may not be affordable for many individuals in Mexico. People with severe lupus erythematosus, often already burdened by medical expenses and limited healthcare access, may find this device prohibitively expensive. Furthermore, the sensor's reliance on NFC technology requires users to have compatible smartphones and the technical familiarity to operate both the sensor and its accompanying app, which may not be feasible for all users within this demographic.

In terms of UV sensitivity, the My Skin Track UV sensor has limitations that reduce its practicality for those with photosensitive conditions. The device works well in direct sunlight, but it struggles to detect UV exposure from indirect or diffuse light, such as on partly cloudy days. For individuals with lupus, who need constant, precise monitoring of UV radiation to avoid symptom aggravation, this lack of comprehensive sensitivity could compromise its effectiveness. Additionally, since it doesn't provide real-time alerts, users have to manually scan the sensor to check exposure, which might not offer the immediate feedback needed for safety in high UV environments, like those found frequently in Mexico.

Requirement Specification

Functional

The functional requirement our system must meet is detecting the UV rays in the area to ensure we can report what is safe and not. Studies show that the UV rays start to become harmful when the UV index range is 3 through 5 [9], so our sensor will need to, at the minimum, sense values around this range.

UV Measurement Accuracy

- Quantifiable: The UV sensor must measure the UV index within a range of 0 to 11+ with an accuracy of ±1 index point.
- Feasible: 1A engineering students can program the STM32 microcontroller to read data from the UV sensor and display the UV index.
- Measurable: UV readings can be compared with a calibrated reference UV sensor in controlled environments. Specifically, read with viewing angles to the display up to 100 degrees (from the ISO 13406-2) standard.
- Appropriate: This directly solves the problem of lupus patients needing accurate UV index readings.
- Citation: World Health Organization UV Index Standard.

In order to convert the UV sensor's detected values into an accurate UV index, there must be a constant of calibration for the area, as the UV index calculation is different for different areas of the world. For our example, we will be calibrating it to match the local UV index (Waterloo region). This is a practical method as the UV intensity is directly proportional to the UV index, so once the calibration constant is found, the UV index can be determined with the device alone.

The OLED display should be visible in both bright sunlight and darkness, ensuring the display is clear without being excessively bright, which could cause discomfort. Additionally, the OLED must consume minimal power to prevent unnecessary energy drain, supporting continuous operation.

Technical

The technical requirement our system must fulfill is being able to communicate with two STM32's from a distance of at least 1 metre, a requirement laid out in the project requirements. We must also ensure our system must not expend more than 30W of power at any point in time and cannot store more than 500 mJ of energy at any point in time. To ensure this, our system's output of energy is limited by the display of values produced.

Safety

We must ensure that no humans or animals are tested with the design. To ensure this, all testing and calibration processes will be conducted using controlled environmental simulations or sensors in safe conditions, without involving live subjects. All sensors and electronic components will operate within safe power and environmental ranges - avoiding overheating, electrical hazards, or malfunctions that could cause harm.

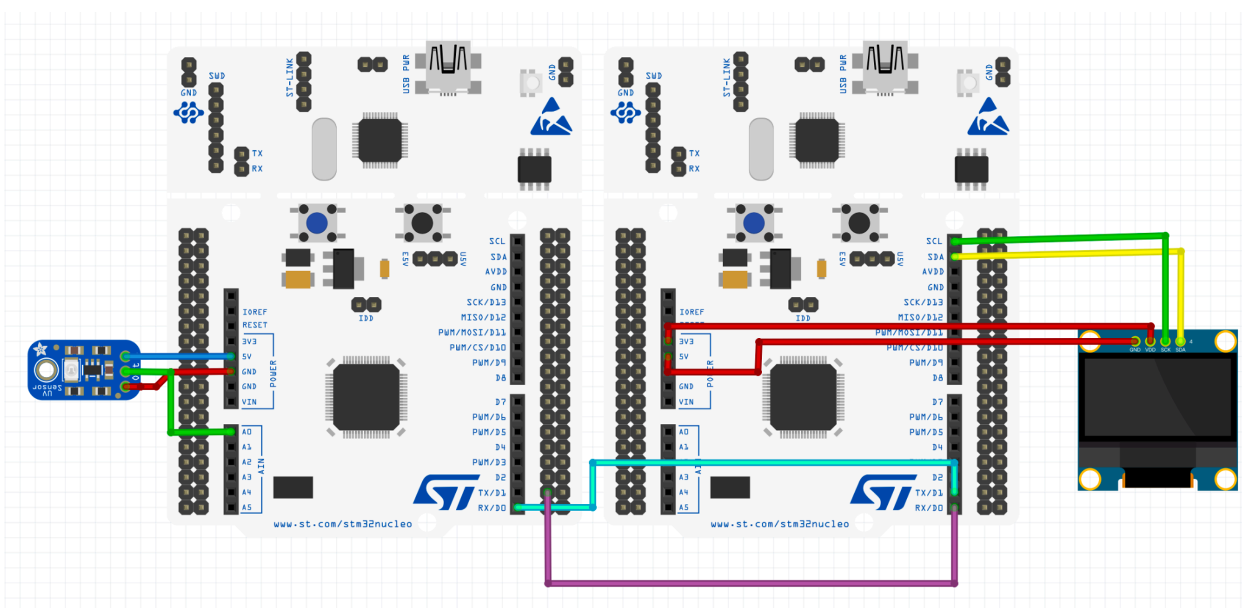
Design (Electrical, Physical, Firmware)

Electrical

Our design will contain two Nucleo STM32's, one OLED display, and one breakout UV sensor, and male-male wires as needed. The STM 32's will be two STM32F401REs as required in our technical requirements**.** Our OLED will be a GeeekPi OLED module (128x64) which meets our requirements of viewing standards in an outdoor environment. Finally, it will also contain a GUVA-S12SD Analog UV Sensor by Adafruit, as it can detect the 240-370 nm range of light [10], which effectively covers the UV spectrum for our needs of determining a UV Index. All these components should result in a low power system that can run for extended periods of time.

Our design will have the UV Sensor attached to ports 5V, GND, and A0 on the main board for the power, ground, and output respectively. We will then attach the OLED display to the respective outputs on the main board. Finally we attach two wires connecting the 2 STM32 boards, (TX/D1 -> RX/D0) and (RX/D0 -> TX/D1).

We have drawn an EDA diagram in Fritzing that simplifies our project, with the correct wire configurations. The two STM32s will be, at minimum, 1 metre apart, as required.

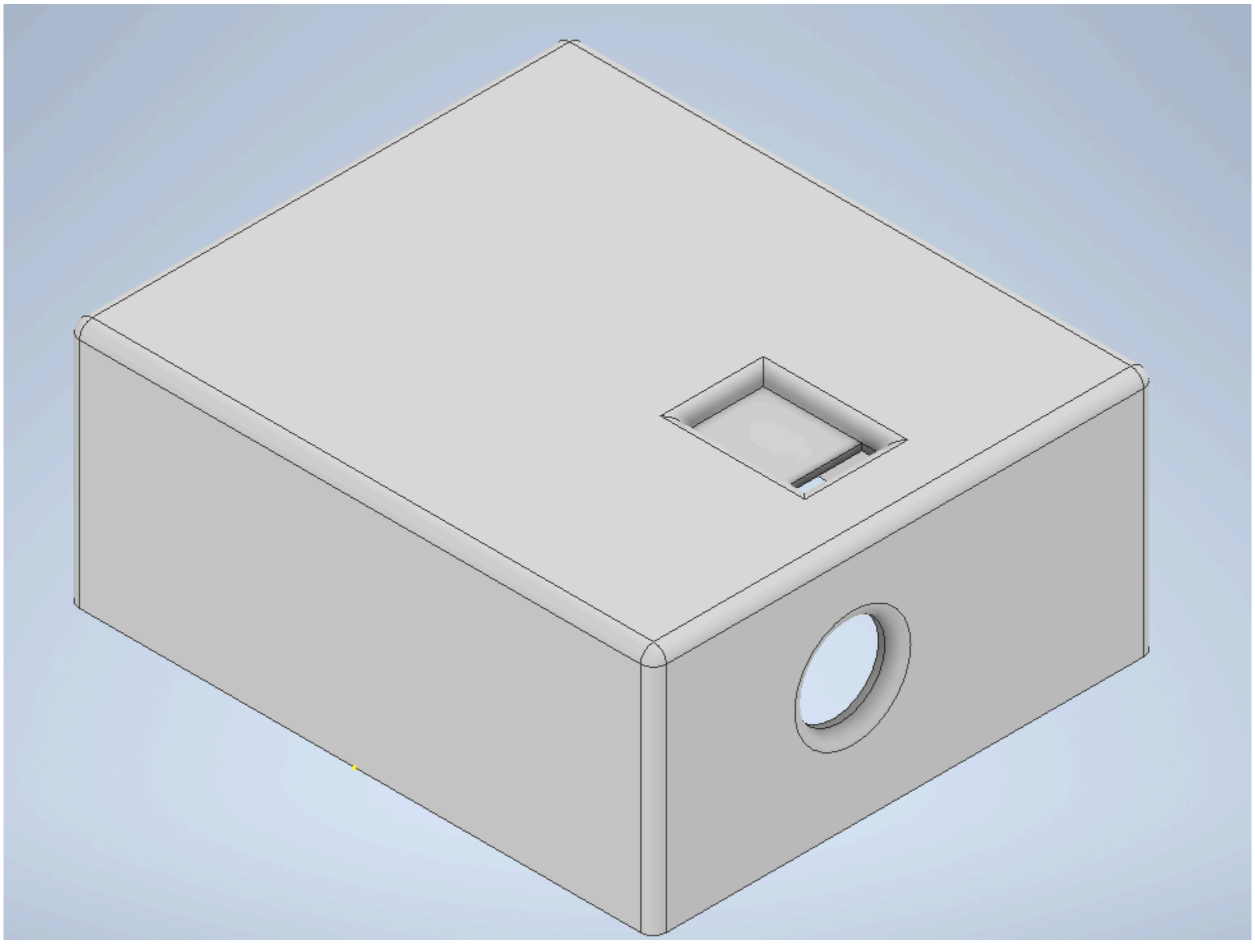


An alternative solution for our UV sensor was the Waveshare Digital LTR390-UV Ultraviolet Sensor [11]. However, with a higher cost of $30.50, it did not meet our budget requirements.

Another alternative we considered was using a simple LED indicator instead of an OLED display. We chose the OLED display because it allows us to convey more relevant information to the user compared to a single LED, which may not communicate sufficient details about the system's status. With an OLED display, we can show critical information clearly and precisely without overwhelming the user. Additionally, an OLED is cost-effective in providing more communication power for the application, with typical OLED costs around $4.8 compared to a minimal LED solution which, while cheaper, lacks necessary functionality.

Physical

The housing for the UV sensor will be designed as a durable 8.2 cm by 7.2 cm by 3 cm 3D-printed enclosure in ABS filament with a dedicated mounting point for secure placement of the sensor. A strategically placed opening will allow for the wire connection to pass through while minimizing exposure to external elements. This design ensures that the UV sensor is optimally positioned to measure ambient UV levels while maintaining a weather-resistant seal to guard against dust, moisture, and other environmental factors. Similarly, the OLED display will be housed in a separate 8.2 cm by 7.2 cm by 3 cm 3D-printed box. The display housing will feature a clear, fitted window area on the side of the housing, enabling visibility of the OLED display while protecting it from scratches, impacts, and weather-related damage. This window will allow users to view readings directly on the display - away from direct sunlight, which can significantly reduce visibility - while maintaining the box's integrity against rain, dust, and physical wear.



Both housings are crafted with cost-effective and readily available 3D printing materials, providing an affordable solution without compromising durability. Together, they offer weather resistance and reliable protection, extending the lifespan of the UV sensor and OLED display in a variety of environmental conditions.

Firmware

To transmit data within our system, we are using two communication protocols tailored to specific components and requirements. The two STM32 boards communicate via UART, providing a robust, low-latency connection between them. Meanwhile, we selected I2C for the OLED display due to its simplicity, minimal wiring - requiring only two connections, making it ideal for interfacing, as well as extensive documented use with this specific display.

The UV sensor we've chosen is analog-based, delivering a straightforward voltage output that simplifies integration. This sensor does not require an I2C setup procedure, making it suitable for our project's streamlined requirements. The sensor is a 'true' UV sensor with an analog output linked directly to UV intensity. To operate, the sensor's power (V+) is connected to 2.7–5.5V DC, with the ground connected to power ground. The analog signal from the OUT pin directly corresponds to the UV intensity:

- Output voltage (Vo) formula: $V_0 = 4.3 \times Diode\ Current\ (uA)$

For instance, if the photocurrent is 1 μA (corresponding to 9 mW/cm^2), the output voltage will be 4.3V.

- UV Index calculation: Convert the output voltage to a UV Index by dividing by 0.1V. For example, a 0.5V output corresponds to a UV Index of about 5.

This approach allows us to deliver UV measurements with simplicity and accuracy, leveraging UART and I2C for effective data transmission across our system.

Technical Analysis

Engineering is the application of established scientific or mathematical principles to solve or address problems. 10 points are granted for each scientific or mathematical principle applied successfully in the design, up to a maximum of 30 points. Each principle applied is assessed according to the following 10-point rubric.

Principle - Fundamental theorems of arithmetic [12]:

- We will be using mathematical operations such as addition and multiplication to obtain our output, as the sensing device returns voltages and we seek a corresponding UV index.
- To convert the sensor input into a readable output, we will have to use arithmetic to change the electrical input (in volts, units of voltage) from the UV sensor into a UV index input.
- We can consider the documentation of the sensor itself to find the calculation to consider the voltage conversion to UV index, likely a linear scaling factor (as the UV index itself is linear and directly proportional to UV intensity).

The formula we will employ to convert the input voltage into UV Index is given by:
$(Input\ Voltage)\ *\ c\ *\ 1\ UV\ Index\ =\ UV\ Index$
*c is a calibration factor to account for geographical and sensing variances affecting UV index.

We will implement this principle through our programming by finding the UV Index from a given input voltage. We will use the above formula to generate the index. We will find our calibration factor through testing and research, and then implementing it in our code to make accurate conversions from voltage to UV index.

Standard - Statistical distribution:

Statistical distribution refers to the analysis of the distribution of data points recorded by an input [13].

- In our application, we will be using principles from statistical distribution to calculate the average UV levels over a given timeframe, with input values taken from the UV sensor. The Global Solar UV Index[14], for example, developed by the WHO, specifically uses averaged values to represent exposure levels safely and effectively for public health advisories.
- The arithmetic mean of the intensity of ultraviolet radiation values sensed [$\mu W/cm^2$] will be calculated over a given timeframe, refreshed periodically, to alert users of the average UV index.

  $Average\ UV = (UV_1 + UV_2 + \ldots + UV_n)/n$

  Where n is the number of UV values taken each second.

This principle will be implemented through our programming as we will take the average of the past second of data and divide it by the number of data points received. In other words, we will display the average UV index value every second to the user, which we will calculate using principles of statistical distribution. We therefore convert the instantaneous UV to become an average UV so it isn't constantly changing.

Standard - Metrology:

Metrology refers to the science of measuring quantities. By employing a metrological standard, we will calculate and communicate data with the user in standard, well-known units.

- We will represent our values in the UV index, which is the standard metrology for reporting UV [14][15].
- Using the UV Index, we can alert users with lupus whether or not it is safe to be exposed in the sun.
- Many scientific reports about sun exposure and skin conditions utilize the UV Index, so using the standard metrology will allow us to provide accurate and relevant data for health purposes.

We will implement our standard by taking our input data of UV in wavelength (measured through nanometers) and convert the value into a UV index.

Manufacturing and Implementation Costs

Bill of Materials (198) ECE198 Installation & User Manual

(Chassis will be printed at the Rapid Prototyping Center for $0.04/g of PLA filament)

Energy Analysis

Reference Standard and Baseline Power Levels

To ensure compliance with power limits, we reference the IEEE 802.3af [16] standard for low-power devices. This standard sets a power consumption baseline for low-energy electronic devices, capping the maximum power at 15.4 W over a 3.3V supply, which aligns with our STM32, OLED display, and UV sensor components' voltage requirements, and is well under the 30 W power supply limit imposed by the course.

Appropriateness of Reference Standard

The USB 3.0 power standard is appropriate for this design, as it provides a reliable baseline for low-power devices powered via USB, with an output of up to 5V and 900 mA [17] (4.5 W maximum). Our design operates at 3.3V, which is safely below the 5V output from a USB 3.0 port, ensuring that the connected components—the STM32 microcontroller, UV sensor, and LCD display—are well within safe power limits.

Analysis of Potential for Energy Storage in the Design

Our design includes 2 STM32 microcontrollers, UV sensor (with a direct voltage reading), and OLED display (connected via I2C). According to the specification sheet [18], the single display draws 0.04W during normal operation, with the full screen lit at 0.08W.

The UV sensor and OLED display do not include capacitors or components specifically designed for energy storage, and the STM32 MCU draws minimal current. Given the small geometric size and low energy capacities of these components, any energy storage within the system is negligible. Additionally, the enclosure for the device is 3D-printed using PLA (polylactic acid), a material with non-conductivity at room temperature and high geometric stability, reducing the risk of heat buildup.

Energy Stored in the System

The maximum energy stored within the system primarily comes from capacitive components on the PCB and within the STM32 microcontroller, which are designed for signal stabilization rather than storage. Calculations for maximum stored energy show that even under peak operation, energy does not exceed 0.01 J, considering each component's capacitive properties and low current draw. For the OLED display, the power consumption will be 0.08 Watts at full brightness, or 0.08 J per second. Additionally, no chemical or mechanical storage devices (like batteries or springs) are integrated, keeping the total energy stored well within safe limits. Given the 3.3V voltage, each Nucleo64 STM32 uses a maximum of 0.1 W for operation.

Verification of Compliance with Project Limits

Parameters of Concern: System Voltage (V) & Energy Consumption (W)

Given the details above, the net voltage in the system is given by **3.3 V**. Each STM32 draws no more than 3.3 V for their respective system, therefore there will be 3.3 V flowing throughout the circuits. ***As the IEEE standard voltage for low-power devices is 3.3 V, our device complies exactly with the criteria.***

The energy consumption in Watts is given by the following equation:

$$\boldsymbol{\Sigma} P = \boldsymbol{\Sigma} P_{STM} + P_{DISPLAY} + P_{SENSOR}$$

Summing all the power drawn from the device, we get:

$$\boldsymbol{\Sigma} P = (2 * 0.1W) + 0.08W + \sim 0.001W = 0.281W$$

As the IEEE standard power consumption for low-power devices is 15.4W, our device easily complies with the criteria, capping at 0.281W at peak brightness.

This analysis confirms that the design does not exceed specified project energy limits with two main parameters, voltage in the system and power consumption. The IEEE standard baseline, combined with the low-power nature of our selected components, ensures that our device is safe and efficient for continuous use without exceeding power or energy constraints, including the course's< 30 W power supply constraint.

Risk Analysis

1. Negative Consequences on Safety or the Environment from Intended Use

When used as intended, the device could inadvertently increase exposure to UV radiation if the sensor provides inaccurate or delayed readings. Users relying solely on the device may be at risk if they spend extended periods in high UV conditions without sufficient protection. Manufacturing components like microcontrollers and sensors contribute to electronic waste, potentially impacting the environment if not disposed of responsibly.

2. Negative Consequences on Safety or the Environment from Incorrect Use

If the device is improperly assembled or connected—such as incorrect wiring or undervoltage protection—the UV sensor or display may fail, leading users to underestimate UV levels. This could result in serious health risks for photosensitive individuals who need accurate data to avoid flare-ups. Environmental risks include possible overheating or short-circuiting of components, which may pose fire hazards if the device is not designed with sufficient protection circuits.

3. Negative Consequences from Misuse or Unintended Use

Using the device in ways it was not designed for, like exposing it to water or using it as a sensor for UV flashlights, could damage internal components, potentially leading to electrical shocks or component failure. Misuse may also cause UV sensors to give erroneous readings, which could lead to prolonged, unintended exposure to UV rays.

4. Potential Design Malfunctions

The device could malfunction if the sensor, display, or communication between the STM32 microcontrollers fails. Communication errors may prevent data transfer, causing the user to miss critical information on UV exposure levels. Furthermore, exposure to environmental wear-and-tear, such as degradation of the STM32 from rain or prolonged UV exposure can lead to a malfunctioning device. We will contain the device in a 3-D printed chassis to prolong its lifespan.

5. Consequences on Safety or the Environment for Each Failure Mechanism

Failure mechanisms—such as UV sensor inaccuracies, STM32 communication errors, or display malfunctions—pose risks to user safety, as inaccurate data might increase UV exposure without sufficient protection. From an environmental perspective, if users discard the device after a malfunction rather than repair it, it could contribute to electronic waste.

Test Plan

	Test 1:	Test 2:	Test 3:	Test 4:	Test 5:
Test Setup	Test of UV sensor with high UV rays: We will take the UV sensor in a location that will have UV rays over 3 and test to see if our values match	Test of UV sensor with low UV rays: We will take the UV sensor in a location that will have UV rays under 3 and test to see if our values match	Test of OLED brightness and signal, and readability: We will ensure that our OLED outputs an appropriate light readable from an angle of	Communication between the STMs: We will test to see if the two modules can communicate to each other by running a simple program that takes a chosen input of true or false and then shows the output on the other STM32	UV Index Calculation and Average test: We will input a manual amount of nanometer measures and see if the output is the average of the values and properly converted to index form

Environmental Parameters	A location with UV levels of over index 3 with space to put the sensor and the main board 1 metre away	A location with UV levels of under index 3 with space to put the sensor and the main board 1 metre away	An area to accurately see OLED	Space to put the sensor and the main board 1 metre away to test communicatio n	None specific
Test Inputs	Under index 3 UV rays	Over index 3 UV rays	True/False readability	True/False manual input	Manually input 5 data points [2,5,3.1,4.5,2.3]
Quantifiable Measurement Standard	Display will show the UV Index	Display will show the UV Index	Viewing angle (in degrees).	1 Output from the STM	UV Index average
Pass Criteria	**Pass**: Display shows the UV index is over 3 and shows it is unsafe **Fail**: Display shows the UV index is under 3 or icon for being unsafe is not present	**Pass**: Display shows the UV index is under 3 and shows it is safe to go out **Fail**: Display shows the UV index is over 3 or icon for being unsafe is present	**Pass**: Readable within 100 degrees **Fail**: Not readable within 100 degrees	**Pass**: Manual input in one STM32 gets displayed on the other STM32 **Fail**: Manual input in one STM32 does not get displayed or gets displayed incorrectly on other STM32	**Pass**: Output on OLED displays 3.38 index **Pass**: Output on OLED displays wrong index

Sources

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