EEE088F 2022
Interim Design Report
Autonomous Plant Monitoring HAT for Discovery Board with STM32FC051

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1 Executive Summary [5]

The following report documents the design process and current design of a Discovery Board HAT (*Hardware Attached on Top*) for a STM32 Microcontroller. The use case for this HAT is for semi-autonomous indoor plant growing. All fianl PCB design files are available in a **GitHub repository at this link**.

This design was created for small scale agricultural setups. Appropriate user stories were applied to develop the **Specifications**. Given these use cases, the PCB is able to: Monitor the temperature around a plant, get precise readings of the light level a plant is receiving. These measurements can then be used to integrate with a control system that can adjust the temperature and light that a plant receives.

This device was thoroughly designed and the PCB has dimensions of: *96.01 mm x 70.01 mm,* weighs *~0.11kg* per board and costs *$14.576 per board* (*excl. Shipping from JLCPCB*). The device measures Temperature with an accuracy of (-10℃ to +85℃): ±1℃, at a 9-12 bit resolution. The device measures Light with an accuracy of < 3% Photocurrent Fluctuation versus Temperature Change (0℃ to 60 ℃) and the device operates at 5V via an input voltage from a USB or at 3.6V Input Voltage via 18650 Li-Ion Battery.

2 Introduction [15]

The use case for this project is autonomous and semi-autonomous indoor grow operations. This could be used in scenarios where someone would want to remotely monitor and control the environmental conditions of their growing operation or in scenarios where the operation is too large for the individual monitoring of environmental conditions and the system must self-monitor.

This sensing unit is designed to monitor two crucial factors in the growth of all crop-yielding plants: **Heat and Ambient Light**.
Most crop yielding plants grow in the temperature range of *15-30*℃ (the large majority being around 21℃). Thus both sensors will need to operate effectively in this temperature range. It is also important that the ambient light sensor be sensitive to the spectrum of light required to grow plants.The wavelength of light that plants predominantly use for photosynthesis ranges from 600–800 nm. Thus the light sensor should be sensitive to this range of light frequencies.

These sensor readings would then be used to control the cooling/heating system and lighting system of the grow environment. This would allow for correction in the case of heat or light being sub-optimal.

Temperature Sensor Resolution: 9-12 bit resolution
Temperature Sensor Accuracy (-10℃ **to +85**℃**):** ±1℃
Light Sensor Accuracy: < 3% Photocurrent Fluctuation versus Temperature Change (0℃ to 60 ℃)
Operating voltage: 5V Input Voltage via USB *OR* 3.6V Input Voltage via 18650 Li-Ion Battery
Typical Power Consumption: *32324.16 mW* = **32.32416 *W***
Cost:

- **$14.576** *per board*
- Shipping from JLCPCB ≈ *$26.53* for 5 Boards
- **~ $99.41** for 5 Boards (*incl. shipping*)

Interfaces: USB, UART, I^2C, 1-wire protocol

2.1 Project Subsystems Block Diagram [10]

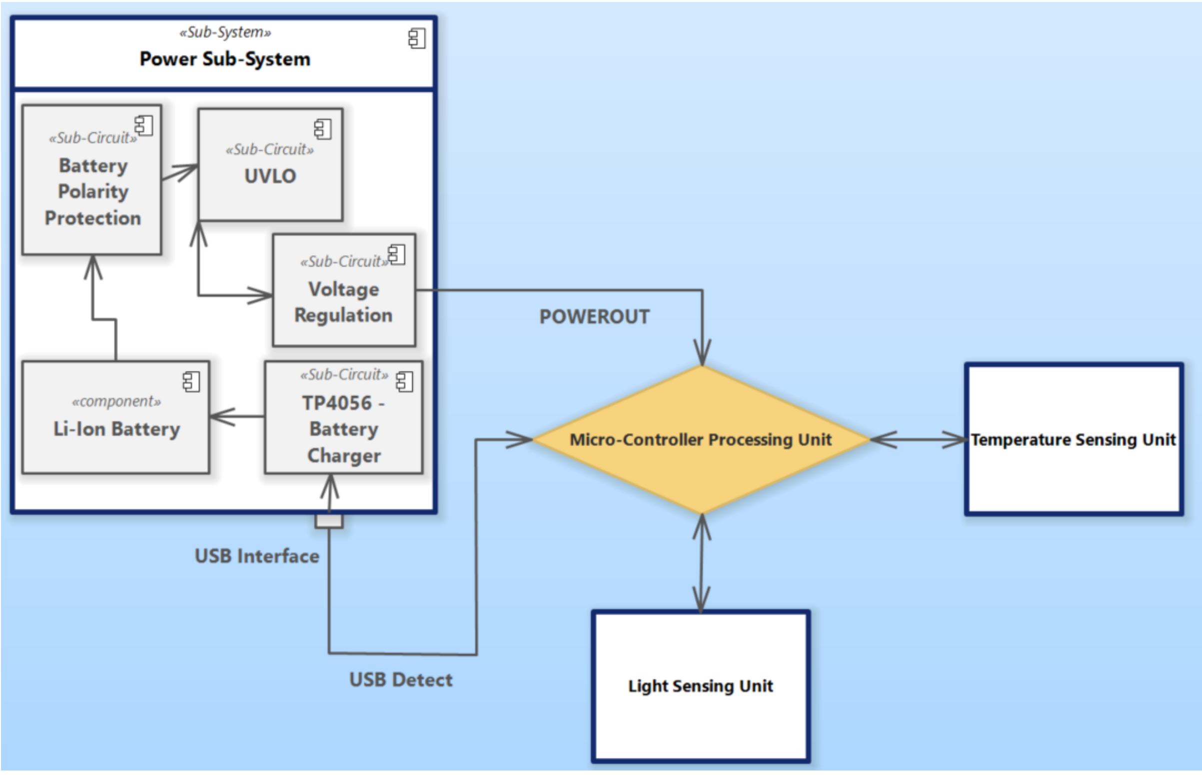

Figure 1: Project Sub-System Block Diagram

3 Specifications [15]

3.1 Power subsystem submodule [5]

Sub-Module Top Level Specifications:

- **Inputs:**
  - V_{CCIN} = 5V via USB Input at a maximum current of 4A
    - The typical current drawn will be ~2.5A
  - V_{BAT} = ~3.6V via an 18650 battery at a maximum current of 3A
    - The typical current drawn will be ~2.5A
- **Outputs:**
  - V_{OUT} = 3.3V
  - D+ & D- from USB to Microcontroller Sub-Module
- **Visual User Communication Interfaces:**
  - The charging circuit has two LEDs (**D5 & D6**) located below the battery holder in the locations shown below in Figure 2.

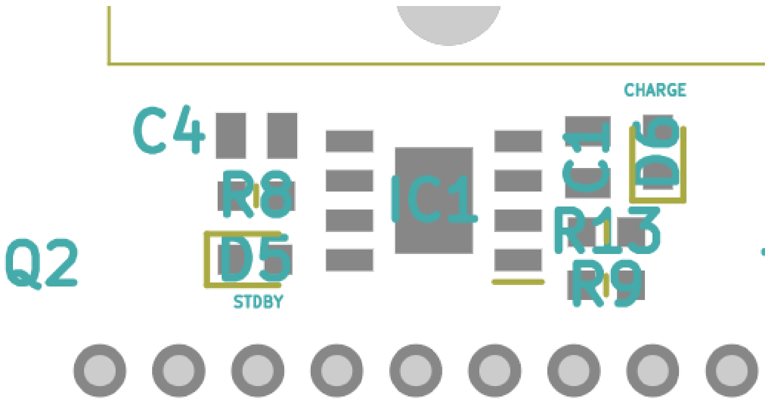

Figure 2: Location of *CHARGE & STDBY* LEDs on the PCB

Charge State	**Red LED** (*CHARGE*)	**Green LED** (*STBY*)
Charging	***ON***	***OFF***
Battery Fully Charged	***OFF***	***ON***
Vin too low	***OFF***	***OFF***
No battery connected	***OFF***	***OFF***

Figure 3: LED Charging State Table

- Furthermore, there is a Red LED located next to the USB input IC (*MICROXNJ*) that shows whether or not a USB has been detected using the following state table.

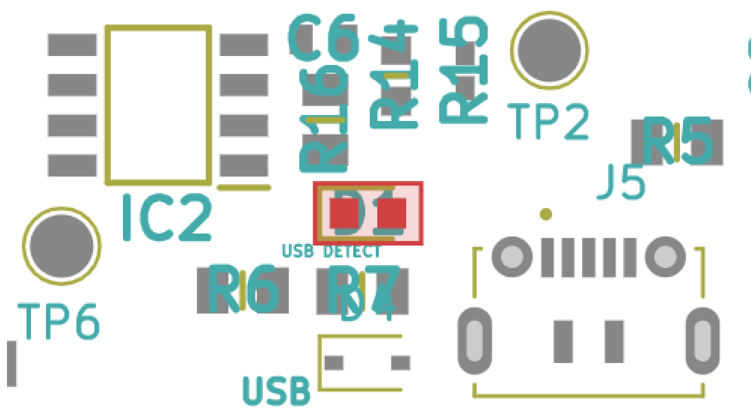

Figure 4: Location of *USBDETECT* LED on the PCB

<u>**USB Connection State**</u>	<u>**Red LED**</u> *(USBDETECT)*
NO USB Connected	***OFF***
USB Connected	***ON***

Figure 5: USB Connection State Table

- **Interfaces with other modules:**
    - 3.3V will be delivered by the Power Module to the 3V3 Pin (*Pin 1*) on the 32 pin connector (*J2)*. The other modules will access this power from the pin.
    - Within the sub-module, the ICs will connect to each other in as short a routing as possible. With this, before each power pin of each IC, a decoupling capacitor has been added to remove any noise in the power provided to the ICs.

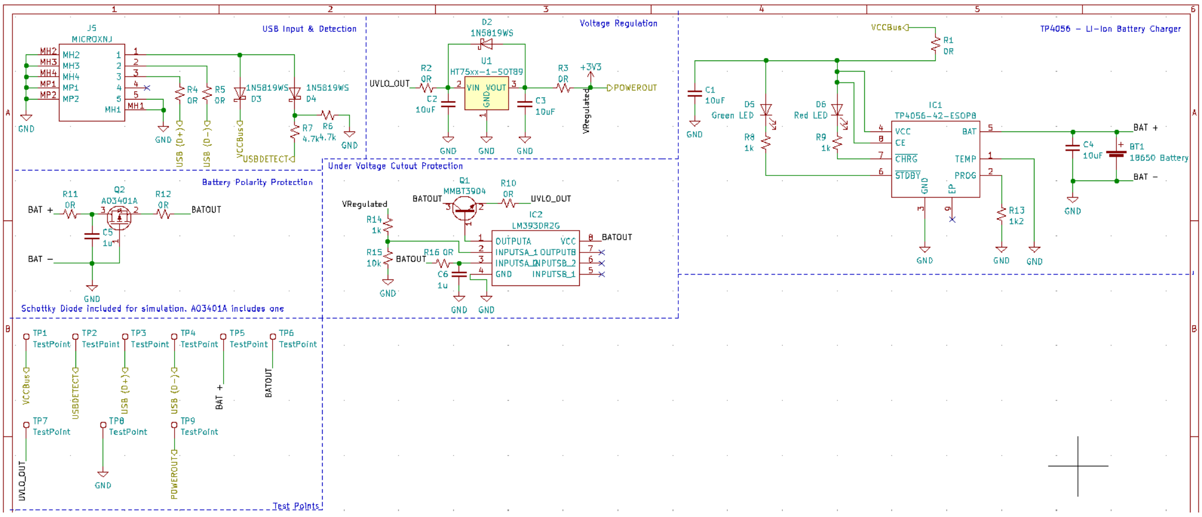

Figure 6: Power Subsystem Schematic v1.0

Full Size Image available on GitHub here (Better Quality)

GitHub Link to KiCad Schematic available here

Whilst the design has been meticulously thought through and improved throughout the design process, there are still uncertainties surrounding the functioning of the UVLO circuit. Other than this, the design is expected to function as intended. Should it not function as intended, there are test points located in between each sub-module of the power system. These test points will allow the parts of the circuit to be shorted. This will mean that if a sub-system is faulty, it can be ‘removed’ from the circuit. This process of introducing isolating within the module, as well as isolating the sub-system from the rest of the circuit using jumpers will allow any unexpected errors to be mitigated should they arise.

The issues with the UVLO are around the uncertainty of the functioning of the MOSFET and the comparator (*LM393DRG*). The suspected issue for the UVLO, is that the MOSFET will not operate in the correct mode when the comparator detects a low voltage coming into the circuit. Should this issue come to fruition, Test Point 6 can be connected to Test Point 7. This will cut the UVLO sub-system out of the Power system and hopefully mitigate any issues caused by the UVLO.

3.2 Microcontroller interfacing submodule [5]

Original Submodule Specifications:

Overall:

- This submodule will take 3.3V and draw a maximum of 50mA.
- This submodule will operate between 0°C and 40°C.

EEPROM:

- This submodule will contain 2kB of EEPROM with 16 bit pages that will be accessed through the I^2C protocol.
- This submodule will use a microcontroller to communicate with its EEPROM at a rate of 400kB/s.

USB to UART:

- This submodule will allow for microcontroller to computer communication through a USB to UART chip that will talk to the microcontroller at a Baud rate of 2400bps.

Sensing Connections:

- This submodule will convert two incoming analog sensor signals to binary data using an ADC and store both in its EEPROM.
- This submodule will store 8 bit samples in its EEPROM.
- This submodule will store incoming binary data from a digital sensor in its EEPROM.
- This submodule will have debugging capabilities in the form of female connectors that can be probed using an oscilloscope.

Current EEPROM Specifications (*AT24C256C*):

- 400kHz (1.7V) and 1MHz (2.5V, 2.7V, 5.0V) Compatibility.
- 2-wire Serial Interface (or I^2C)
- 256-Kbit with 64-byte pages.

Therefore this EEPROM satisfies the specifications and exceeds the specifications in terms of storage space.

Current USB to UART Specifications (*CH340G*):

- Baud Rate ranges from 50bps to 2Mbps.
- Allows for USB to UART communication with the STM microcontroller.

Current Sensing Connections Specifications:

- Many of this module's specifications will be done using code. Although the connections have been made such that it will be possible to store sensor data in the EEPROM and to sample the analog sensor using an ADC in the STM board.

Overall, this submodule meets the specifications for supply voltage and maximum supply current. Furthermore all components can operate within the specified temperature range. The specifications for each internal module have also been met.

The USB to UART module has some risk associated with the *TXS0108EPWR*, which might not be able to level shift the incoming USB 2.0 data at such high speeds. This might cause distortion of the USB signal and loss of information. There are test points which might be used to bypass the Level Shifter if required. Furthermore the entire USB to UART module can be disconnected from the STM board.

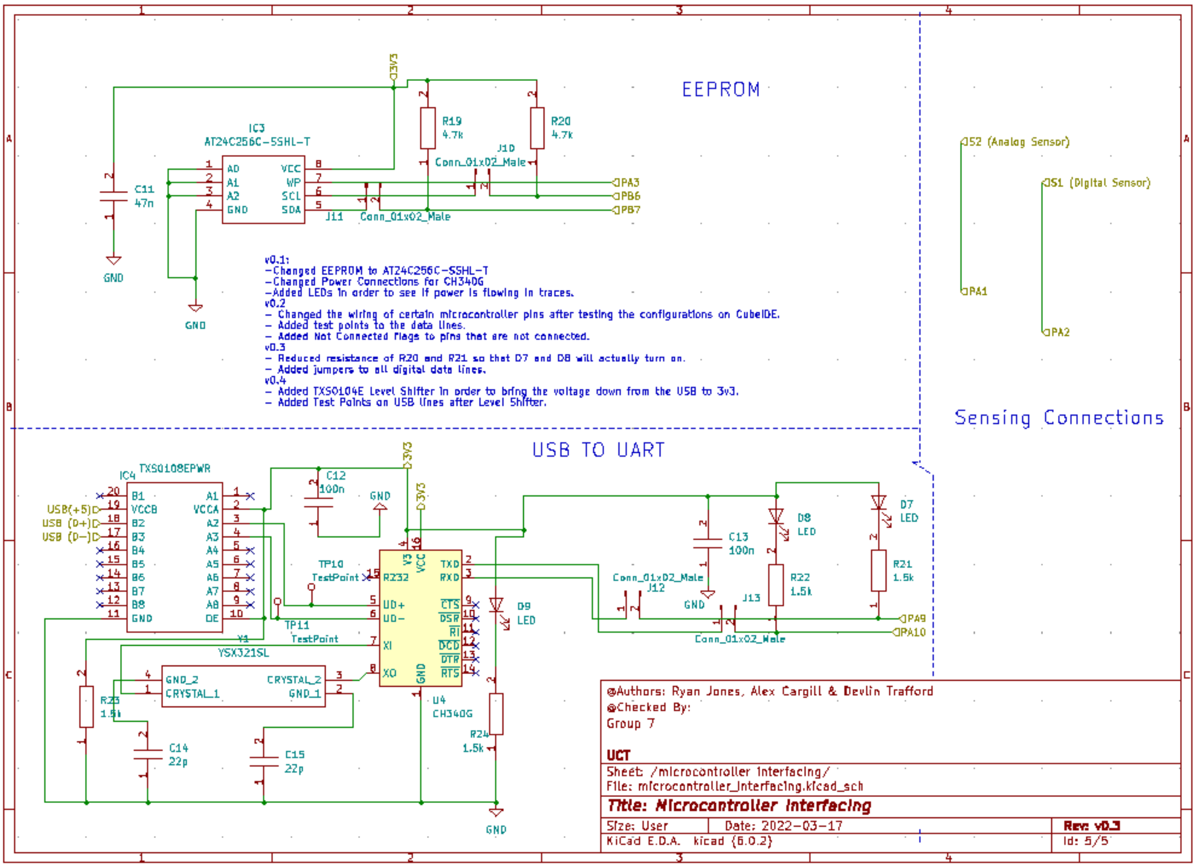

Figure 7: Microcontroller Subsystem Schematic v1.0

Full Size Image available on GitHub here (Better Quality)

GitHub Link to KiCad Schematic available here

3.3 Sensing submodules [5]

- **Digital Sensor Specification DS18B20:**
  - **V_{DD} (Operating voltage):** 3.3-5V
  - **I_{DD} (Active current) :**
  - **Standby current :** <1 uA
  - **Max Voltage Range on any Pin wrt Ground:** -0.5V to +6.0V
  - **Operating Temperature Range:** -55°C to +125°C
  - **Output data protocol:** 1-wire
  - **Accuracy :** ± 1 °C
  - **Resolution:** 9-12 bit (writeable)

- **Analog Sensor Specification ALS-PD15-21B-TR8:**
  - **V_{CCin} :** 1.8V to 5.5V
  - **Standby current:** <1 uA
  - **Operating temperature:**-40C to 85C
  - **VCCmax:** 0.5 ~ 6 V
  - **Output Voltage:** 0 ~ VCC-0.6 V
  - **Output Photo Current:** 0 ~ 5 mA

- This module should output an analogue voltage reading between 0V and 3.3V.
- Sensitive to the desired light spectrum for growing indoor plants (between 600 and 800 nm).
- Low photocurrent fluctuation versus temperature change (15 to 30 ℃).
- Operable at 3.3V

This a good design since both sensors will be operating in their recommended temperature and voltage range. The light sensing module is sensitive to the desired light spectrum and both sensors have a sufficient degree of accuracy. Additionally both sensors have a low standby current which means the module is also energy efficient in its idle mode.

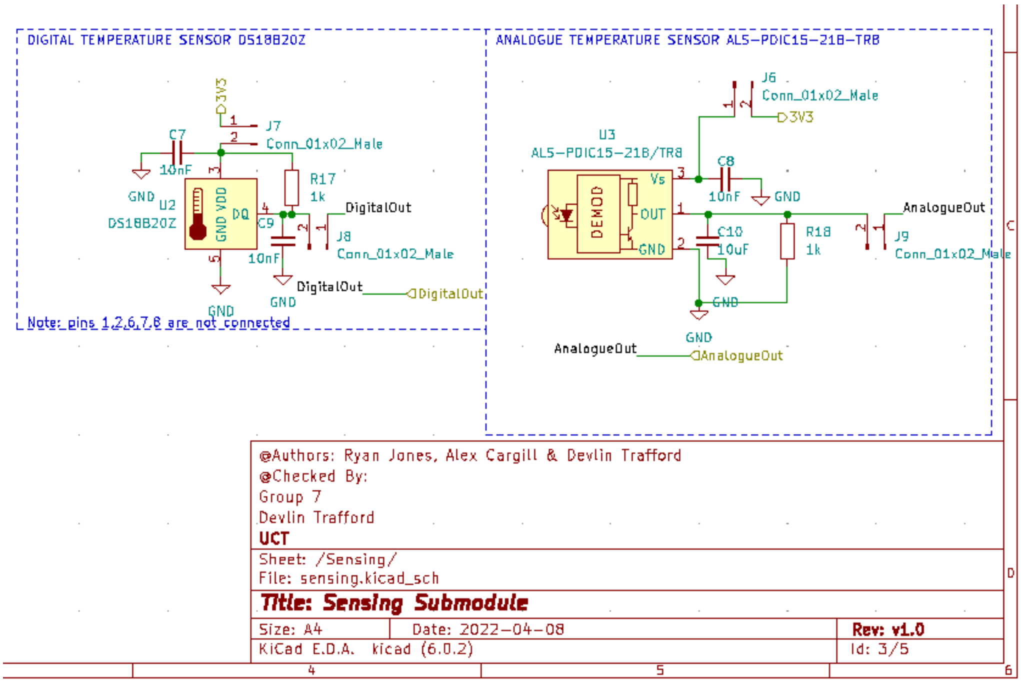

Figure 8: Sensing Subsystem Schematic v1.0

Full Size Image available on GitHub here (Better Quality)

GitHub Link to KiCad Schematic available here

4 Power Budget Analysis [20]

4.1 Power submodule [6]

For the **TP4056**, there are multiple conditions that determine the Charging Current. The decision to set $R_{PROG} = 1.2k\Omega$ means that the datasheet shows values for the charging current (I_{BAT}) and trickle charge current (I_{TRIKL}). According to the **datasheet**, I_{TRIKL} exists when $V_{BAT} < V_{TRKL}$, where V_{TRKL} is the threshold voltage for trickle charging. This voltage is in the range $2.8V - 3.0V$. That means that when the voltage across the battery is less than this value, the current value supplied to the battery is lower than that of when the threshold has not been reached.

For the Power Budget, this trickle current was ignored, as I_{BAT} will always be higher, so for the sake of over estimating, the power will be calculated using I_{BAT} rather than I_{TRKL} and I_{BAT} at different stages of charging.

Also note, that both LEDs will not have a minimum current, as regardless of the current that flows through, light will be emitted - it just may not be visible to the human eye.

NOTE 1: All ICs' values are for when $Temperature$ = 25℃.
NOTE 2: If no Maximum Power value available, the Typical value was used in the Maximum Power Total. If no Minimum Power value as well, the Typical Power Value was used.

Component	Supply Voltage (nominal V)	Minimum Current (mA)	Typical Current (mA)	Maximum Current (mA)	Minimum Power (mW)	Typical Power (mW)	Maximum Power (mW)
MICROXNJ	5	-	1800	-	-	9000	-
HT7533-1	3.6	70	100	-	252	360	-
AO3401A	3.6	0.25	2500	4000	0.9	9000	14400
TP4056 - ESOP8	5	950	1000	1050	4750	5000	5250
1N5819WS	5	-	1000	3000	-	5000	15000
	3.3	-	1000	3000	-	3300	9900
LM393DR2G	3.6	6	16	-	21.6	57.6	-
Red LED	5	-	20	25	-	100	125
Green LED	5	-	20	25	-	100	125
Totals					22524.5	31917.6	54217.6

Therefore, the total Power for:

- Minimum Power = 22524.5 *mW* = **22.5245 *W***
- Typical Power = 31917.6 *mW* = **31.9176 *W***

- Maximum Power = 54217.6 *mW* = **54.2176 *W***

4.2 Microcontroller interfacing submodule [6]

Component	Supply Voltage (nominal V)	Minimum Current (A)	Typical Current (A)	Maximum Current (A)	Minimum Power (W)	Typical Power (W)	Maximum Power (W)
AT24C256C-SSHL-T	3.3	6u	2m	3m	19.8u	6.6m	9.9m
CH340G	3.3	0.08m	4.8m	12m	0.264m	15.84m	39.6m
YSX321SL (Level of Drive)	N/A	N/A	N/A	N/A	1u	100u	200u
TXS0108EPWR	V_a=3.3 V_b = 5	-	-	8u	-	-	39.6u
Pull-Up Resistor for OE Pin	3.3	0.314m	0.33m	0.347m	1.04m	1.089m	1.15m
I2C Pull-Up Resistors	3.3	0m	0.7m	1.4m	-	2.31m	4.62m
UART Line LEDs	3.3	0m	3m	4.5m	4.95m	9.9m	14.85m
Totals		0.4m	10.83m	21.255m	6.275m	35.84m	70.36m

- For *AT24C256C-SSHL-T*, minimum supply current is given for V_{cc}=5V and for no read or write operations.
- For the *CH340G*, minimum current is given for the USB Suspended state only.
- *YSX321SL* is a crystal oscillator which doesn't have a supply voltage or current specified, although power dissipation is specified.
- Only a maximum supply current specified for *TXS0108EPWR*, the chip has two supply voltages and therefore the maximum current is the sum of the current drawn by each supply.
- The Pull-Up Resistor has a tolerance of 5%. This gives the minimum and maximum current values.
- The UART and I^2C LEDs will only turn on during transmission so the maximum represents the case where all the lines are pulled low and all the LEDs are conducting while the minimum represents the case where no data is being actively transmitted.

4.3 Sensing submodules [6]

Component	Supply Voltage (nominal V)	Minimum Current (mA)	Typical Current (mA)	Maximum Current (mA)	Minimum Power (mW)	Typical Power (mW)	Maximum Power (mW)
DS18B20 (Digital temperature sensor)	3.3	0.005	1	1.5	0.0165	3.3	4.95
ALS-PD15-21B-TR8 (Analog sensor)	3.3	0.001	0.2[1] (Note 1)	5	0.0033	0.66	16.5
Totals	3.3	0.006	1.2	6.5	0.0198	3.3	21.45

4.4 System Total [2]

Submodule	Supply Voltage (nominal V)	Minimum Current (mA)	Typical Current (mA)	Maximum Current (mA)	Minimum Power (mW)	Typical Power (mW)	Maximum Power (mW)
PSU	5	70	2500	4000	22524.5	31917.6	54217.6
Sensor1	3.3	0.005	1	1.5	0.0165	3.3	4.95
Sensor2	3.3	0.001	0.2	5	0.0033	0.66	16.5
Memory	3.3	0.006	2	3	0.0198	6.6	9.9
Microprocessor	3.3	-	-	120	-	-	396
Totals					22920.54	32324.16	54644.95

- Microprocessor has only a maximum current that it can draw from the supply, depending on the function the board is fulfilling at a particular time the power usage can be much lower than this.

[1] Typical current at ~3.3V and 1000 Lux

5 Design process [10]

Decided to use temp and light sensors because other sensors were unavailable and extended parts. Temperature and light sensors are easier to test due to being able to manipulate both of those environmental conditions. In the microcontroller subsystem, the *CH340G* was chosen for its very low price. The FTDI is far too expensive to be considered for this project.

Revisions:

v0.1:

- Changed EEPROM to *AT24C256C-SSHL-T* because there is more programming support for this chip through better documentation. The chip is slightly more expensive, but is also higher specification.
- Added LEDs in order to see if power is flowing in traces. These are for debugging purposes. One can see when the UART or I^2C lines are pulled low by the open drain.
- The initial temperature sensor (*TMP117AIDRVR*) had leads which were too small to accommodate efficient testing.
- The next temperature sensor (*DS18B20Z+T&R*) was too expensive (***$9.32***) so the cheaper version (*DS18B20Z*) of the same chip was chosen

v0.2:

- Changed the wiring of certain microcontroller pins after testing the configurations on CubeIDE. It was discovered that the STM only supports UART and I^2C on very specific pins.
- The initial light sensor chosen (*DY-PD204-6B*) was through-hole and since the group wished to only have SMT parts, this sensor was replaced by the *ALS-PD15-21B-TR8* which also had markedly better accuracy and temperature stability.
- Removed the Schottky Diode from the Power Circuit in the Battery Polarity Protection sub-circuit as the AO3401A includes one as a barrier diode. This was an unnecessary inclusion in the circuit and the cost of the components could be reduced.

v0.3:

- Reduced resistance of R20 and R21 in the microcontroller subsytem so that D7 and D8 will actually turn on.
- Added jumpers to all digital data lines. These allow the isolation of the EEPROM and USB to UART modules as well as being testing points.

v0.4:

- Added *TXS0104E* Level Shifter in order to bring the voltage down from the USB to 3v3. The 5V data lines will likely break the CH340G unless level shifting is implemented.
- Added Test Points on USB lines after Level Shifter. These are to ensure that the signals are being level shifted correctly.
- Removed a logic system which would determine whether to use battery power or power from a USB. Removing this freed up budget for the rest of the circuit. Instead, the 5V USB line will always be run through the battery circuitry.

v1.0:

- All the jumpers initially chosen were through-hole so the design was revised to use SMT jumpers.
- Removed the Input Polarity Protection sub-circuit, as the USB detection circuit included Schottky Diodes which would prevent a negative input voltage, so a whole circuit was unnecessary and increased the circuit cost.
- Changed the Voltage Regulator IC from the *AMS1117-3.3* to the *HT7533-1*. This was due to the *AMS1117-3.3*'s dropout voltage of 1.1V. This would make the *AMS1117-3.3* not regulate voltage in scenarios where the board still required power and didn't need to cutout the supply voltage.

6 Conclusion [10]

The sensors were chosen such that they operate effectively in the desired environmental conditions of 15-30 ℃ and light with a spectrum of 600-800 nm. Additionally both sensors have been chosen to be operable with a 3.3V input and low standby current. The design process of the sensing unit required fewer design iterations since fewer parts were required. The primary difficulty associated with the sensing unit was finding sensors which were inexpensive, SMT and had datasheets with the necessary information. The data from the light sensor is an analogue voltage signal and will be processed by the microcontroller's ADC. The temperature sensor will give out digital using 1-wire serial data protocol. This microcontroller module has been designed to operate in conditions below 40℃ and with a maximum current draw of less than 50mA. The module facilitates the storage of sensor data in the EEPROM. Furthermore, it implements a USB to UART interface that can be used to interact with the HAT from a computer. The module features 3 LEDs which light up when the UART data lines are communicated properly. The main issues during design regard the USB to UART module, which required the interfacing with 5V USB data lines while using a power supply of 3.3V. The solution was determined to be a level shifting chip that will shift the incoming USB data to 3.3V and prevent the USB to UART chip (*CH340G*) from breaking. In order to use the USB to UART module from a computer, CH340 drivers must be installed on the USB host machine. Finally, the Power module made design decisions that reduced the need for extended parts, by making use of basic parts and attempting to most things from first principles rather than using expensive ICs. Throughout the design process, the priority was to make the circuits as simplistic, functional and cheap as possible. This was achieved through the removal of a seperate input polarity protection circuit , and rather using a singular diode.