UNIVERSITY OF CAPE TOWN

EEE3088F, 2022

INTERIM DESIGN REPORT:

LIGHT TRACKING AND TEMPERATURE SENSING HAT

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GROUP 18

JONATHAN APPS (APPJON001)

SHAMEERA CASSIM (CSSSHA020)

JAHAR PERSAD (PRSJAH002)

1. Executive Summary

The following report documents the design process and current design of a Discovery board HAT intended for use as a light tracking device. For reference, PCB design files are available in the following Gitlab repository:

https://gitlab.com/g5168/eee3088f-group-18-project

The report begins by introducing the HAT concept as well as its use case, design details, and key results. A block diagram is used to overview the final design, after which the specifications for each submodule are detailed (power, microcontroller interfacing, sensing). Power budget analyses for the submodules, as well as for the entire design are then given. The design processes are then overviewed, and lastly conclusions are made.
For further details, including licensing, reusing, and deploying, see the gitlab repository.

2. Introduction

The HAT was designed to operate a rotating frame which is intended to sense the direction in which the light is brightest. The HAT will be programmed to rotate the frame, using 2 motors, to point its face in the direction of maximum brightness. This design can be used for many applications, although its primary use case is intended to be to efficiently generate power through solar panels. A small solar panel could be connected to the face of the frame (this will be omitted from the design however, as solar panels will be connected to the frame by the user) and the rotation of the frame will allow for optimal sunlight to be provided to the panel at all times.

The HAT uses 2 sensor types (one digital, one analog) to support this design. The digital sensor is a temperature sensor (LM75B) which monitors the temperature of the HAT to check for overheating (which causes design/solar panel inefficiencies). The analog sensor is made up of 2 photoresistors (GL5549's), which enable the evaluation of brightness on both sides of the HAT. This in turn enables the controlling of the peripheral device's rotation.

The HAT's power module uses batteries to drive the operation of the sensors and the microcontroller interfacing. Under-voltage protection, battery polarity-protection, and input voltage polarity protection are some of the features that operate the HAT in a stable manner. The HAT includes microcontroller interfacing abilities, which enable the transmission of data to and from the STM32.

This design could be implemented for small-scale energy projects. Users who desire the powering of a small device (during load shedding for instance) could use the HAT to generate power for a load. It could also be used for small robots which need to track light.

For this to be a useful design, the power generated by the HAT must exceed the power consumed by the HAT. The power specifications for this design will thus be discussed later in this report. The total cost of the HAT was approximately $62.33, excluding shipping costs.

2.1. Project Subsystems Block Diagram

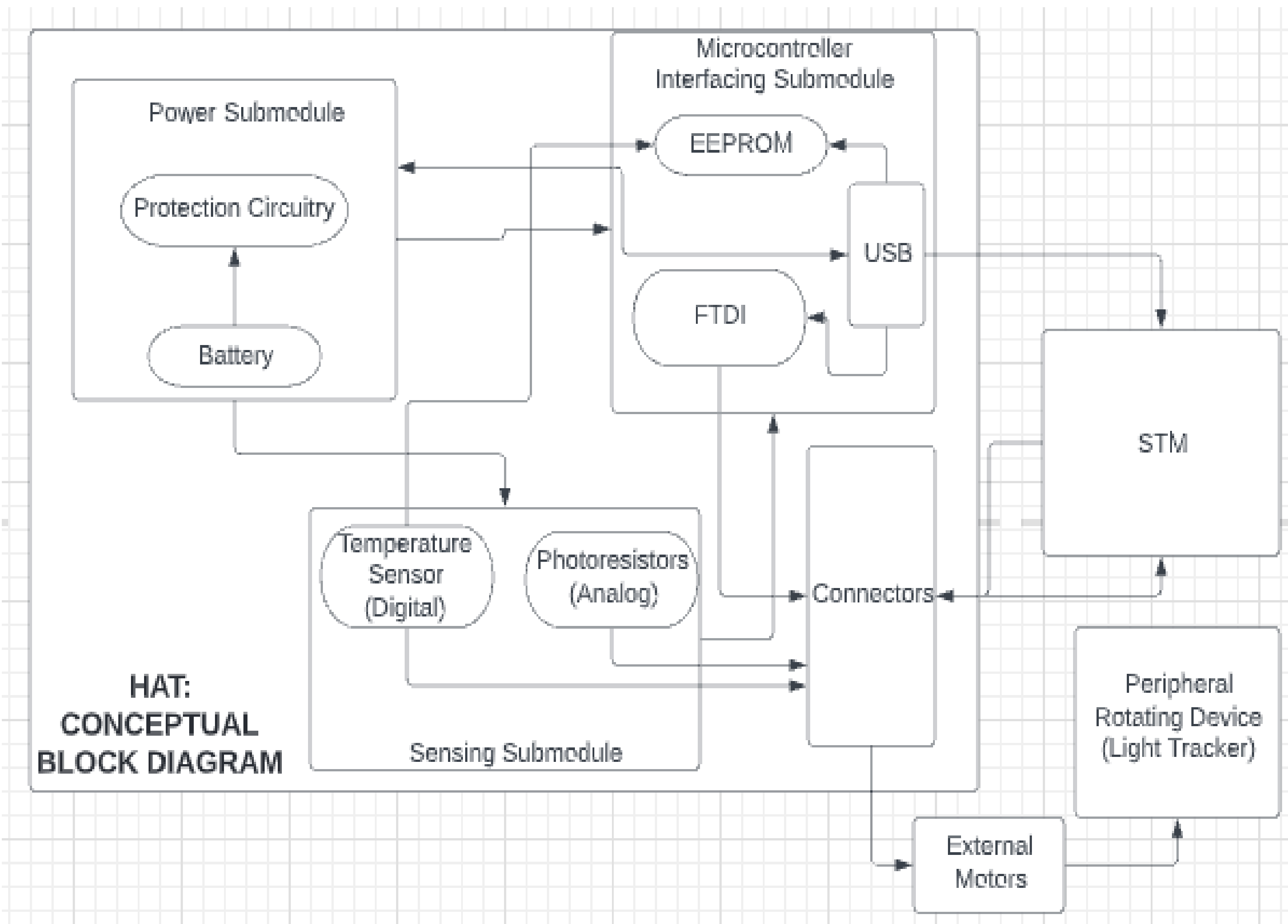

Figure 1: Projects Subsystem Block Diagram

3. Specifications

3.1 Power Subsystem Submodule

This submodule delivers 5V, and receives a voltage between 4.5 and 6V. The max current in the circuit is 22mA, the reason it was done this way is that anything above 30mA will blow the LED.

The circuit contains the following circuits/components:

1. A 18650 connector (DNP)
2. A Li-Ion battery charger
3. Input voltage polarity protection
4. Battery polarity protection
5. Battery Under-voltage cutout protection
6. This module will provide an output of 5V

There were 2 ICs used:

1. MT3608L - DC-DC converter, used to step up the voltage to a constant 5V to be outputted from the submodule
2. TP4054 - Used to charge the battery

Parts List

Part	LCSC	Datasheets
R1	C4177	https://datasheet.lcsc.com/lcsc/2110251730_UNI-ROYAL-Uniroyal-Elec-0603WAF1801T5E_C4177.pdf
R2	C22775	https://datasheet.lcsc.com/lcsc/2110252030_UNI-ROYAL-Uniroyal-Elec-0603WAF1000T5E_C22775.pdf
R3	C22775	
R4	C22775	
R5	C22765	https://datasheet.lcsc.com/lcsc/2110252030_UNI-ROYAL-Uniroyal-Elec-0603WAF1201T5E_C22765.pdf
R6	C25805	https://datasheet.lcsc.com/lcsc/2110260030_UNI-ROYAL-Uniroyal-Elec-0603WAF1103T5E_C25805.pdf
R7	C22809	https://datasheet.lcsc.com/lcsc/2110252030_UNI-ROYAL-Uniroyal-Elec-0603WAF1502T5E_C22809.pdf
Charging IC(TP4054)	C32574	https://datasheet.lcsc.com/lcsc/1809261814_TOPPOWER-Nanjing-Extension-Microelectronics-TP4054-42-

		SOT25R_C32574.pdf
DC-DC Converter(MT3608L)	C2932326	https://datasheet.lcsc.com/lcsc/2201121530_XI-AN-Aerosemi-Tech-MT3608L_C2932326.pdf
C1	C15849	https://datasheet.lcsc.com/lcsc/1811061822_FH-Guangdong-Fenghua-Advanced-Tech-0603CG6R0C500NT_C37474.pdf
C2	C45783	https://datasheet.lcsc.com/lcsc/1811151152_Samsung-Electro-Mechanics-CL21A226MAQNNNE_C45783.pdf
D1	C84256	https://datasheet.lcsc.com/lcsc/1810010213_Everlight-Elec-PT17-21C-L41-TR8_C100090.pdf
D2	C84256	
D3	C191023	https://datasheet.lcsc.com/lcsc/1810202112_Guangdong-Hottech-1N5819WS_C191023.pdf
L1	C383376	https://datasheet.lcsc.com/lcsc/1912111437_TDK-MLP2012V4R7MT0S1_C383376.pdf
Q1	C118536	https://datasheet.lcsc.com/lcsc/1912111437_Foshan-Blue-Rocket-Elec-2N2222A_C358533.pdf

3.1.1 Power Subsystem Schematic

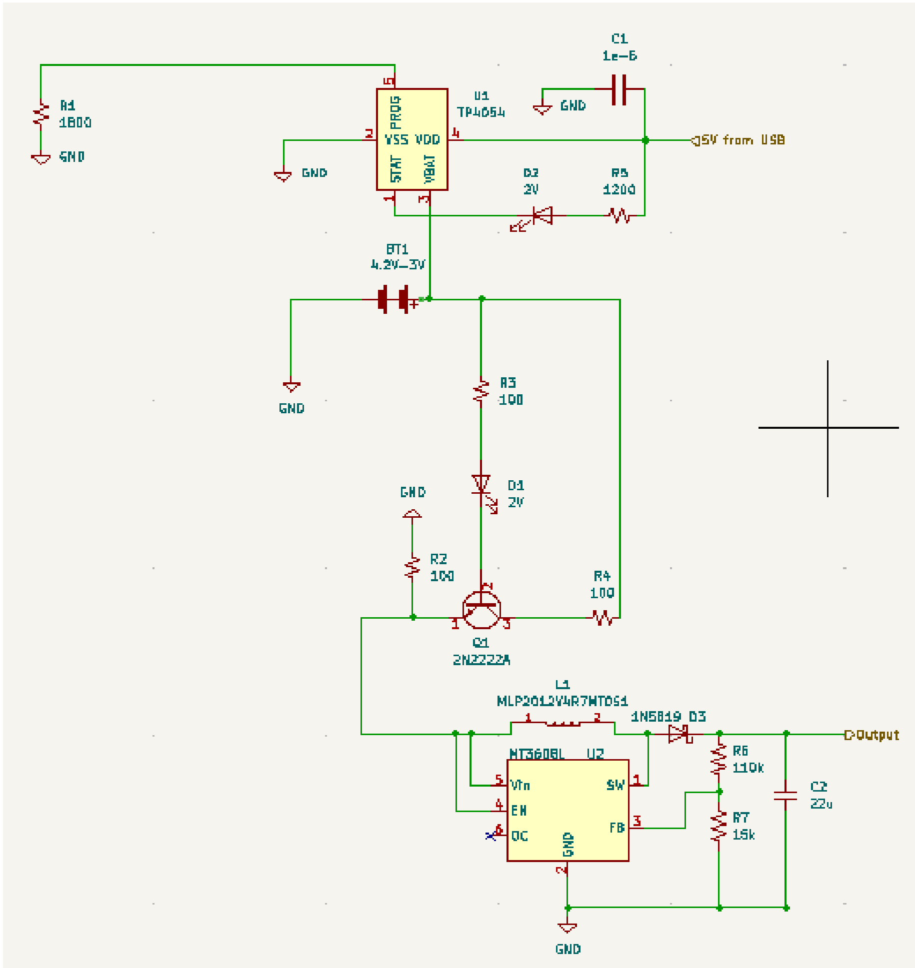

Figure 2: Power Subsystem Schematic

Location in git:
https://gitlab.com/g5168/eee3088f-group-18-project/-/blob/main/PCB/main/power.kicad_sch

3.1.2 Conclusion

This design is deemed safe, there is a bit of uncertainty when it comes to the calculations of how much current is flowing through this module, but otherwise it seems safe. It is not the most efficient design since a lot of parts that have a power dissipation associated were used. But the design should be able to perform its duties.

3.2 Microcontroller Interfacing Submodule

3.2.1 Specifications

The specifications for this submodule have been tabulated below:

Item	Requirement	Specification	Additional Notes and Documentation Links
	Memory		
	This subsection includes communication protocols, both the ICs used for memory and their power specifications.		
M1	Key configuration data must be kept in a non-volatile medium and data from the temperature sensor must be time-stamped and stored alongside this throughout the operational period	EEPROM needs to be used to store configuration data and to read in and store data from the temperature sensor. The **AT24C256C-SSHL-T** is a 256-Kbit EEPROM chip with a SOIC-8_3.9x4.9x1.27P package. Memory can be retrieved from the line connected to the WP pin of the EEPROM. This IC operates between 1.7V and 5.5V with a maximum current of 2mA for reading data and 3mA for writing data at V=5V.	Datasheet: https://datasheet.lcsc.com/lcsc/1809151932_Microchip-Tech-AT24C256C-SSHL-T_C6482.pdf
M2	Translate USB to UART to be written to the STM	A **CH340C** chip can be used to interface between the USB and memory. The chip "translates" the data from USB to USART in the form of an array. The typical operating conditions for this IC is a 5V supply voltage and a 7mA current. It has a maximum current of 20mA.	Datasheet: https://www.mpja.com/download/35227cpdata.pdf
	Clock		
C1	Measure at a minimum of 1/60 Hz which is required to be soft-configurable.	PA8 connected to the STM32F051 will be used. The pin will be programmed to output the relevant clock signal.	

	USB		
U1a	Transfer data and provide power. The USB provides 5V (VCC_in).	A **MicroXNJ** USB Surface Mount Micro-B/USB Connector is used for power and data transfer.	Datasheet: https://datasheet.lcsc.com/lcsc/2204151400_SHOU-HAN-MicroXNJ_C404969.pdf https://gitlab.com/g5168/eee3088f-group-18-project/-/blob/main/Documentation/Datasheets/2204151400_SHOU-HAN-MicroXNJ_C404969%20TRANSLATED.pdf (both used in conjunction as translation is not fully clear)
U1b		A USB-MicroB cable is needed to connect the microcontroller to the HAT.	These may be reused from the equipment given out for EEE2046F.

Parts List

Component	LCSC	Datasheet
EEPROM - AT24C256C-SSHL-T	C6482	https://datasheet.lcsc.com/lcsc/1809151932_Microchip-Tech-AT24C256C-SSHL-T_C6482.pdf
FTDI - CH340C	C84681	https://www.mpja.com/download/35227cpdata.pdf
MicroXNJ	C404969	https://datasheet.lcsc.com/lcsc/2204151400_SHOU-HAN-MicroXNJ_C404969.pdf
R14	C25804	https://datasheet.lcsc.com/lcsc/2110260030_UNI-ROYAL-Uniroyal-Elec-0603WAF1002T5E_C25804.pdf
R15	C21190	https://datasheet.lcsc.com/lcsc/2110252030_UNI-ROYAL-Uniroyal-Elec-0603WAF1001T5E_C21190.pdf
R16	C21190	
R17	C21190	
R18	C23162	https://datasheet.lcsc.com/lcsc/2110252130_UNI-ROYAL-Uniroyal-Elec-0603WAF4701T5E_C23162.pdf

R19	C21189	https://datasheet.lcsc.com/lcsc/2110252030_UNI-ROYAL-Uniroyal-Elec-0603WAF0000T5E_C21189.pdf
R20	C21189	
D4 (SS14)	C2480	https://datasheet.lcsc.com/lcsc/2105061432_MDD-Microdiode-Electronics--SS14_C2480.pdf
C4	C14663	https://datasheet.lcsc.com/lcsc/1809301912_YAGEO-CC0603KRX7R9BB104_C14663.pdf

3.2.2 Microcontroller Interfacing Subsystem Schematic

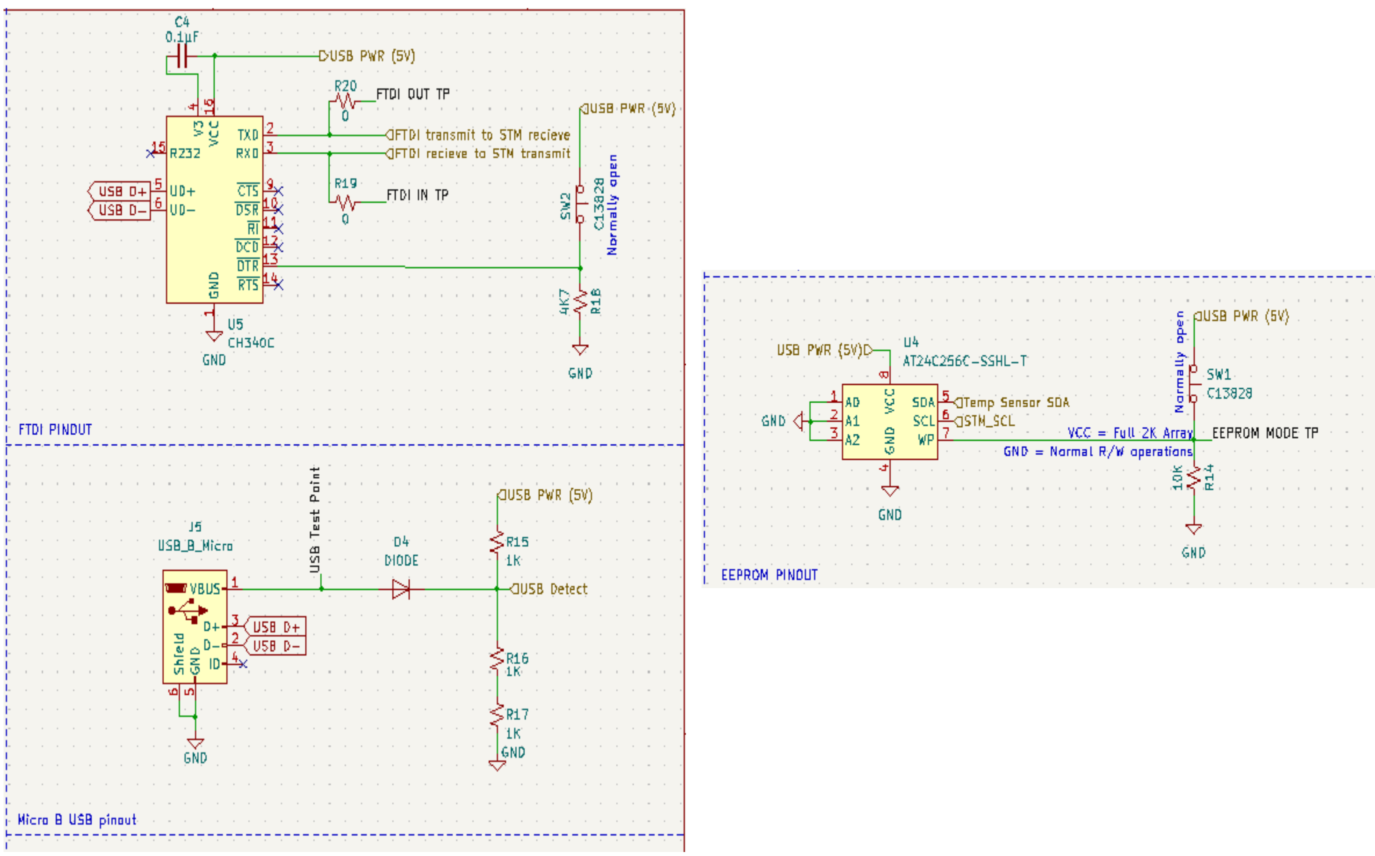

Figure 3: Microcontroller Interfacing Subsystem Schematic

Location in git:
https://gitlab.com/g5168/eee3088f-group-18-project/-/blob/main/PCB/main/microcontroller_interfacing.kicad_sch

3.2.3 Conclusion:

The design is safe, sufficient and largely should work. An outstanding issue that was picked up after submitting the gerbers was that the output of the EEPROM is not connected to an STM pin and hence is not writing to anything. Thus, the information being stored in the EEPROM cannot be seen. Fixing this will require the soldering of a wire to the PCB and using that to connect to the STM to write the data to I2C (this will be done when the PCB is returned). It has also been noted that the schottky diode used was replaced by an LED when gerbers and assembly documentation was uploaded to jlcpcb. This will also be rectified when the PCBs are returned. The documentation in this report takes into account the schottky diode and not the LED.

3.3 Sensing submodules

The specifications for this submodule have been tabulated below:

3.3.1 Digital Sensor Specification

Item	Specifications	Additional Notes	Datasheet Links
1	One LM75BD Temperature sensor is used.	This operates at 2.8V - 5.5V, and as such is perfect for the HAT as a digital sensor. Further operating conditions can be found in the attached datasheet.	https://datasheet.lcsc.com/lcsc/2110111830_UMW-Youtai-Semiconductor-Co---Ltd--LM75BD_C725792.pdf
2	One red LED (BL-HUE35A-AV-TRE) is used to indicate that the temperature is outside optimal functioning conditions.	This is connected to a pin which reads the LM75. The temperature data register will be polled to ensure that when the temperature exceeds a specified limit, the LED is lit up.	https://datasheet.lcsc.com/szlcsc/1809192334_BrtLed-Bright-LED-Elec-BL-HUE35A-AV-TRE_C138549.pdf
3	20mA of forward current through the LED must not be exceeded.	Thus, a resistor in place to ensure correct operation (see Item 4).	N/A
4	Items 2 and 3 necessitate the use of a 300Ω resistor. Unfortunately this was overlooked during the design process, and a 10kΩ resistor was used	Performing a KVL analysis on a 5V power supply in series with a 300Ω resistor (with a forward voltage	N/A

	instead. This will be corrected when the PCB is returned.	drop of 3V) and a 2V LED, shows that the current through the LED will be: I = V/R = 3/300 = 10mA. This is a correct operating current for the LED.	
5	One C45783 capacitor was used, to decouple the signal at the Vcc pin.	This adds safety from undesirable noise signals.	https://datasheet.lcsc.com/lcsc/1809291518_TORCH-CT41G-0402-2X1-16V-0-1-F-K-N_C141382.pdf
6	Three RCT0310KJLF 0.1W, 10KΩ resistors are used. No more than 0.1W is dissipated by each resistor.	These act as pull-ups for the temperature sensors. Pull-up resistors are necessary for this temperature circuit configuration at the bus output and the interrupt line.	https://datasheet.lcsc.com/lcsc/1810161330_HKR-Hong-Kong-Resistors-RCT0310KJLF_C177337.pdf

3.3.2 Analog Sensor Specification

Item	Specifications	Additional Notes	Datasheet Links
1	The HAT uses 2 GL48516 photoresistors (LDRs).	These assume values of 5-10 KΩ at 10 LUX, and approximately 0.2 MΩ in the dark.	https://datasheet.lcsc.com/lcsc/2009121137_JCHL-Shenzhen-Jing-Chuang-He-Li-Tech-GL48516_C779572.pdf
2	Two RCT0310KJLF 0.1W, 10KΩ resistors were used. No more than 0.1W is dissipated by each resistor.	These were placed in series with the LDRs in 2 separate voltage divider configurations.	https://datasheet.lcsc.com/lcsc/1810161330_HKR-Hong-Kong-Resistors-RCT0310KJLF_C177337.pdf
3	The LDRs were placed on opposite sides of the HAT to ensure that the light on each of them is slightly different.	The photoresistors cannot be placed very closely together on the final HAT pcb.	N/A
4	The outputs from the voltage divider configurations operate between 2.4V and 3.6V.	GPIO pins in analog mode operate between 2.4V and 3.6V. ADC pins will be	N/A

		needed when the software is implemented.	
5	Item 4 implies that the input voltage should lie at around 5V. Thus the input voltage to the photoresistor voltage divider configuration was connected to the STM32F0's 5V pin.	This was an important design decision for the pcb's routing.	N/A

3.3.3 Sensing Submodule Schematic

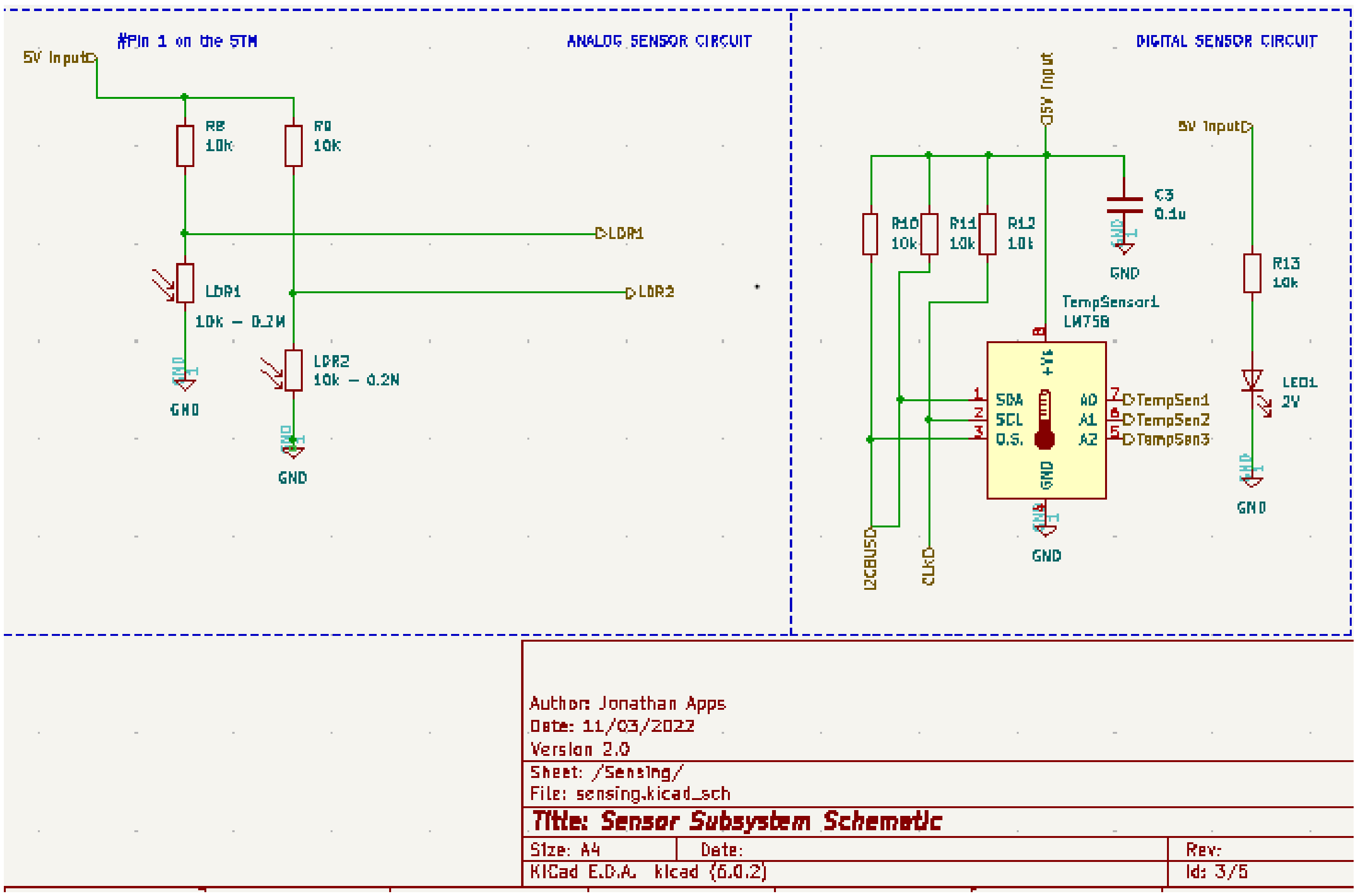

Figure 4: Sensing Subsystem Schematic

Location on git:
https://gitlab.com/g5168/eee3088f-group-18-project/-/blob/main/PCB/main/sensing.kicad_sch

3.3.4 Conclusion

This module relies heavily on the power and microcontroller interfacing modules to function. Provided that those modules function correctly, the sensing submodule should function correctly as it is very simple in terms of design and components. The sensors are adequately designed and thus sufficient for the purposes they are needed for. There is one clear error in the design of this module, which is the use of a 10kΩ resistor in place of the necessary 300Ω. The 10kΩ resistor will be replaced with the 300Ω resistor once the pcb is returned.

4. Power Budget Analysis

4.1 Power Submodule Budget Analysis

Component	Supply Voltage (nominal V)	Min Current (mA)	Typical Current (mA)	Max Current (mA)	Min Power (mW)	Typical Power (mW)	Max Power (mW)
TP4054	5	90	100	110	450	500	550
R1	3-4.2	10	22	30	36	79.2	108
R2	3-3.5	10	22	30	32.5	71.5	97.5
R3	3-4.2	10	22	30	36	79.2	108
R4	5	10	22	30	50	110	150
R5	5	10	22	30	50	110	150
R6	5	10	22	30	50	110	150
R7	5	10	22	30	50	110	150
C1	5	10	22	30	50	110	150
C2	5	10	22	30	50	110	150
D1	3-4.2	10	22	30	36	79.2	108
D2	5	10	22	30	50	110	150
D3	5	10	22	30	50	110	150
L1	5	10	22	30	50	110	150
MT3608L	0.01-1.5	-	1.6	2.2	-	2.4	3.3
Total					**998.5**	**1709.1**	**2198.8**

4.2 Microcontroller Interfacing Submodule Budget Analysis

Component	Supply Voltage (nominal V)	Min Current (mA)	Typical Current (mA)	Max Current (mA)	Min Power (mW)	Typical Power (mW)	Max Power (mW)
EEPROM - AT24C256C -SSHL-T (read/write)	5.0	-	1	2	-	5	10
	5.0	-	2	3	-	10	15
FTDI - CH340C	3.3	-	7	20	-	23.10	66
R14	5	10	22	30	50	110	150
R15	5	10	22	30	50	110	150
R16	5	10	22	30	50	110	150
R17	5	10	22	30	50	110	150
R18	5	10	22	30	50	110	150
R19	5	10	22	30	50	110	150
R20	5	10	22	30	50	110	150
D4 (SS14)	5	10	22	30	50	110	150
C4	5	10	22	30	50	110	150
Total					**450.00**	**1028.10**	**1441.00**

4.3 Sensing Submodules Budget Analysis

Component	Supply Voltage (nominal V)	Min Current (mA)	Typical Current (mA)	Max Current (mA)	Min Power (mW)	Typical Power (mW)	Max Power (mW)
R8	5	0.025	0.2	0.25	0.125	1	1.25
R9	5	0.025	0.2	0.25	0.125	1	1.25

R10	5	0.14	0.2	0.5	0.7	1	2.5
R11	5	0.14	0.2	0.5	0.7	1	2.5
R12	5	0.14	0.2	0.5	0.7	1	2.5
R13	5	9	10	11	45	50	55
C3	5	0	0.2	0.5	0	1	2.5
LED1	2	9	10	11	18	20	22
LDR1	2.4-3.6	0.025	0.0476	0.25	0.06	0.14	0.216
LDR2	2.4-3.6	0.025		0.25	0.06	0.14	0.216
LM75B	5	0.004	0.28	0.4	0.02	1.4	2
Total					**65.49**	**77.68**	**91.932**

4.4 System Total

Submodule	Minimum Power(mW)	Typical Power(mW)	Maximum Power(mW)
Power	984.50	1678.30	2156.80
Sensing	65.49	77.68	91.932
Microcontroller Interfacing	450.00	1028.10	1441.00
Totals	**1499.99**	**2784.08**	**3689.73**

5. Design process

The design process for this board was as follows:
Each team member developed a design for their respective submodule, after which the team met and discussed whether the designs would work well in conjunction with each other and revisions of each submodule were made. The design process was iterative, it started off with a base design which was improved each week to get the final product.

Key decisions relating to the schematics that were made include:

- The removal of the operational amplifier after the first revision as it would drain the battery even after the under voltage cut out protection kicked in (power module).
- The step down dc-dc converter was swapped out for a step up dc-dc converter as this mitigated the need to amplify the voltage after the transistor before entering the previously used step down dc-dc converter. This also resulted in the final design of the power submodule using less components overall. (power module)
- The initial EEPROM chosen was changed to match that suggested by the lecturers. This EEPROM IC matched the specifications of the project better and there are more resources available on how to use it effectively. (microcontroller interfacing module)
- The FTDI chip was chosen specifically to include an internal crystal oscillator so that one would not have to be included on the board. This allows for the design of an individual oscillator to be avoided (microcontroller interfacing module).
- Initially, there were 4 photoresistors, 2 of which enabled the HAT to rotate the peripheral module based on the light strengths on it. This, along with a push button controlling whether on-HAT or on-peripheral LDRs would be used to sense light, was removed. This removal was done to save power and remove complexity from the design (sensor module).

Key decisions that were made with regards to the PCB include:

- The GND plane was chosen to be on the front copper layer(top) and the +5V plane on the back copper layer(bottom), as this allowed for more efficient tracing (more components required ground connections than power connections)
- The LDRs were specifically chosen to be on opposite sides of the board to ensure that light could be tracked from multiple directions.
- Distance was intentionally put between the pushbuttons and the temperature sensor to avoid the user's body heat affecting the sensor's output.
- The MicroXNJ USB port was chosen to be on the opposite side of the board as the STM USB port to avoid the two being on top of each other and preventing the HAT and STM from connecting as they should.

6. Conclusion

The HAT is intended to control the rotation of an external frame based on the direction of the light detected. This could be used in several contexts but this design largely focused on the use case of rotating solar panels to optimize the amount of energy produced. The design process was iterative and in some parts components were chosen and tested via trial and error.

The iterative nature of the decisions made contributed to the simplicity of the final design. Many design paths could have been taken, but the choices made minimized the complexity and inefficiencies in the final PCB. Although some errors remain, these will be mitigated or fixed by soldering additional components to the HAT when it is returned.

Overall, the completed design was under-budget both in terms of cost (before shipping) and power. The expected power consumption of the HAT is approximately 2.8W and the price of the 5 PCBs is expected to be $62.33 excluding shipping and customs. In theory, the individual modules are all expected to work and therefore it is expected that they will work well in conjunction with each other in reality.