IMPERIUM

STM32SenseHAT

Title – STM32SenseHAT Report [EN]

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Group 7 ♣

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1 Executive Summary

The STM32 EnviroSensing HAT is a sophisticated, multi-purpose sensing system designed to accurately measure, log, and transmit various environmental parameters. The system comprises three primary modules: Power, MCU, and Sensing, each of which is meticulously designed to ensure optimal performance and seamless integration.

The Power module controls the MCU and sensors' battery management, voltage regulation, and power distribution. It comprises a lithium-ion battery charger submodule that uses the TP4056 chip for precise charging control, a battery protection submodule incorporating the DW01 protection IC and dual MOSFETs for overcharge, over-discharge, and short-circuit protection, and a voltage regulator submodule utilizing the MCP1700T-3302ETT linear regulator for efficient voltage conversion.

The MCU module, built around the powerful and energy-efficient STM32F030F051C6T6 microcontroller, serves as the core processing unit. It is accompanied by an EEPROM (AT24C32) for non-volatile data storage, and multiple communication interfaces, including I2C, SPI, and UART, for seamless sensor data retrieval and transmission.

The Sensing module employs three high-precision sensors for direct interaction with the environment: a TMP102 temperature sensor with ± 0.5°C accuracy and 12-bit resolution, an LTR-303-ALS digital light sensor providing 0.01 lux to 64k lux dynamic range with a 16-bit ADC, and an LDR (Light Dependent Resistor) for measuring ambient light levels. These sensors are carefully selected to ensure accuracy and compatibility with the overall system.

2 Introduction

2.1 SenseHat Concept

The STM32 EnviroSensing HAT is a custom-designed, innovative solution that accurately and responsively senses environmental conditions in various applications, including home environmental monitoring, greenhouse climate control, and industrial automation systems. By incorporating both temperature and light monitoring capabilities, this advanced HAT (Hardware Attached on Top) empowers users to effectively manage and regulate critical parameters.

Seamlessly integrating temperature monitoring with ambient light sensing functionality, the STM32 EnviroSensing HAT ensures comprehensive environmental data collection. This combination of features is particularly useful in scenarios where maintaining optimal conditions is crucial, such as providing the perfect growing environment in a greenhouse. Additionally, the system can be implemented in smart home applications, offering adaptive temperature and lighting control based on real-time environmental data.

Key Sensor Specifications include a temperature sensor with a resolution of 0.0625, an accuracy of 0.5%, and a measurement range of -40°C to 125°C. The ambient light sensor boasts a 16-bit ADC resolution, an accuracy of 2%, and a detection range from 0.1 lux to 64k lux.

The HAT is powered by a 5V bus for battery charging and a 3.3V bus to supply power to the MCU and sensors. Communication interfaces include I2C for effortless sensor and EEPROM communication with the STM32 and UART for efficient data transmission to the host computer.

Data logging is a significant feature of the STM32 EnviroSensing HAT, with a consistent format that allows for easy analysis and integration into other systems. The logged data can trigger user-defined threshold-based actions such as temperature and light regulation, further enhancing the device's functionality.

In summary, the STM32 EnviroSensing HAT is a reliable and versatile environmental monitoring and control solution, making it ideal for a wide range of applications that require accurate and responsive sensing of temperature and light conditions.

2.2 Block Diagram

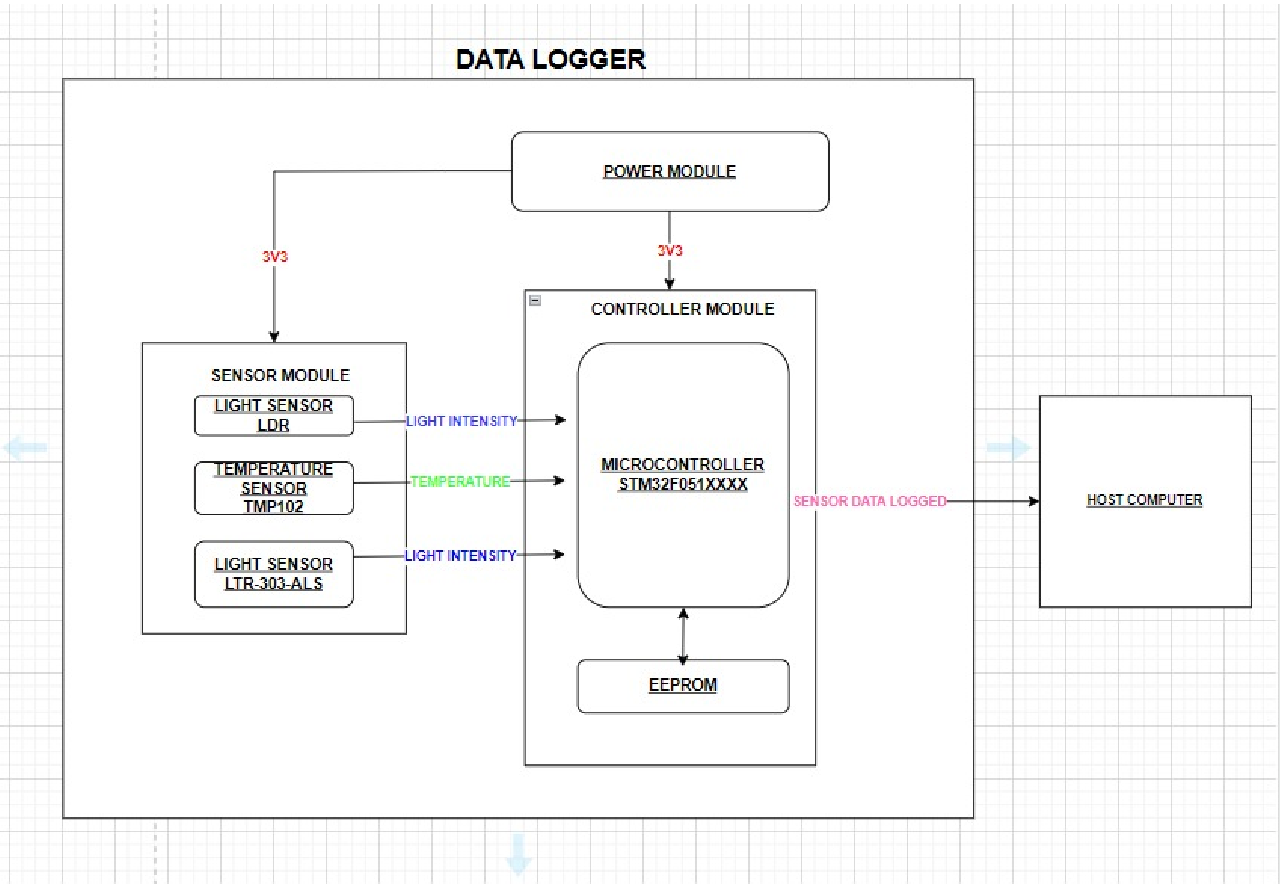

Figure 1: SenseHAT Block Diagram

3 Specifications

3.1 Power Module

The power module is designed to handle battery management and supply a stable 3.3V power source to all sensors and the MCU module from a 5V input provided by a USB bus.

3.1.1 Battery Charger Submodule

The battery charger submodule is responsible for managing the charging process for the 18650 battery. The specifications for this submodule are as follows: The chip used:**TP4056**

Table 1: Specifications of Battery Charger Submodule

Specification	**Description/Detail**
Input Voltage	VCC: 0.3-10 V TEMP,CE: 0-10 V
Charging current	1000mA
Charge Voltage	4.2V
Accuracy	1.5%
Trickle Charge threshold	2.9V
BAT Short Circuit duration	Continuous
BAT pin current	1200mA
PROG pin current	120uA
Operating Temperature	-45-85°C
Charge Status	Charging: RED LED-ON, GREEN-OFF Charge Termination: RED LED-OFF, GREEN-ON

Design Notes

1. Package: SOP-8
2. Rprog of 10k was used thus ibat is 130mA. This might be improved by changing the Rprog.

3.1.2 Battery protection submodule

This module protects the battery from under voltage, overvoltage, overcharging and overcurrent. Specifications are shown below: The chip used:**DW01A**

Table 2: Specifications of the Battery protection submodule

Specification	**Detail**
Input Voltage	0.3-10V
Supply current	3.0-6uA
OC output pin voltage	-24-0.3V
OD Output Pin Voltage	-0.-0.3V
CS Input pin voltage	-24-0.3V
Operating temperature range	-40-85°C
Starting charger Volatge	1.2V
Overcharge Protection Voltage	4.25-4.35V
Overcharge Release Voltage	4.05-4.15V
Over-discharge Protection Voltage	2.40-2.60 V
Overcurrent Protection Voltage	130-170mV
Short current protection Voltage	0.82-1.75V
Overcharge delay time	"Typ:100ms Max 200ms"
Over-discharge delay time	"Typical 55ms Maximum 200ms"
Overcurrent Delay Time	"Typical 7ms Maximum 20ms"

Design Notes

1. Package: SOT-23-6

3.1.3 Voltage Regulator Submodule

This module regulates 5V from the USB bus/battery to 3.3V, suitable for the MCU and sensor module. Its specifications are shown below: The chip used:**MCP1700T-3302ETT**

Table 3: Specifications of the Voltage Regulator Submodule

Specification	**Detail**
Input Voltage	2.3-6V
Input Quiescent Current	1.6uA
Maximum Output Current	250mA
Output Short Circuit Current	408mA
Output Voltage Regulation	"Min VR - 3.0%, VR - 2.0% Typ VR ± 0.4%, Max VR + 3.0%, VR + 2.0%"
VOUT Temperature Coefficient	50 ppm/°C
Line Regulation	"Min -1.0%, Typ 0.75%, Max 1%"
Load Regulation	"Min -1.5%, Typ 1%, Max 1.5%"
Dropout Voltage	350mV
Output Noise	3 µV/(Hz)1/2
Power Supply Ripple Rejection Ratio	44dB
Thermal Shutdown Protection	140°C

Design Notes

1. Package: SOT-23-6
2. Voltage Regulator (VR): 3.3V
3. The internal power dissipation of the MCP1700 voltage regulator is a function of input voltage, output voltage, and output current. The power dissipation from the quiescent current draw is negligible, given its low value of 1.6 µA multiplied by the input voltage (VIN). The following equation can be employed to calculate the internal power dissipation of the LDO:$1.6\mu A \times V_{IN}$

3.1.4 Schematic

Link:https://github.com/Travimadox/STM32SESNSEHAT/blob/main/PCB/STM32SENSEHAT/power.kicad_sch

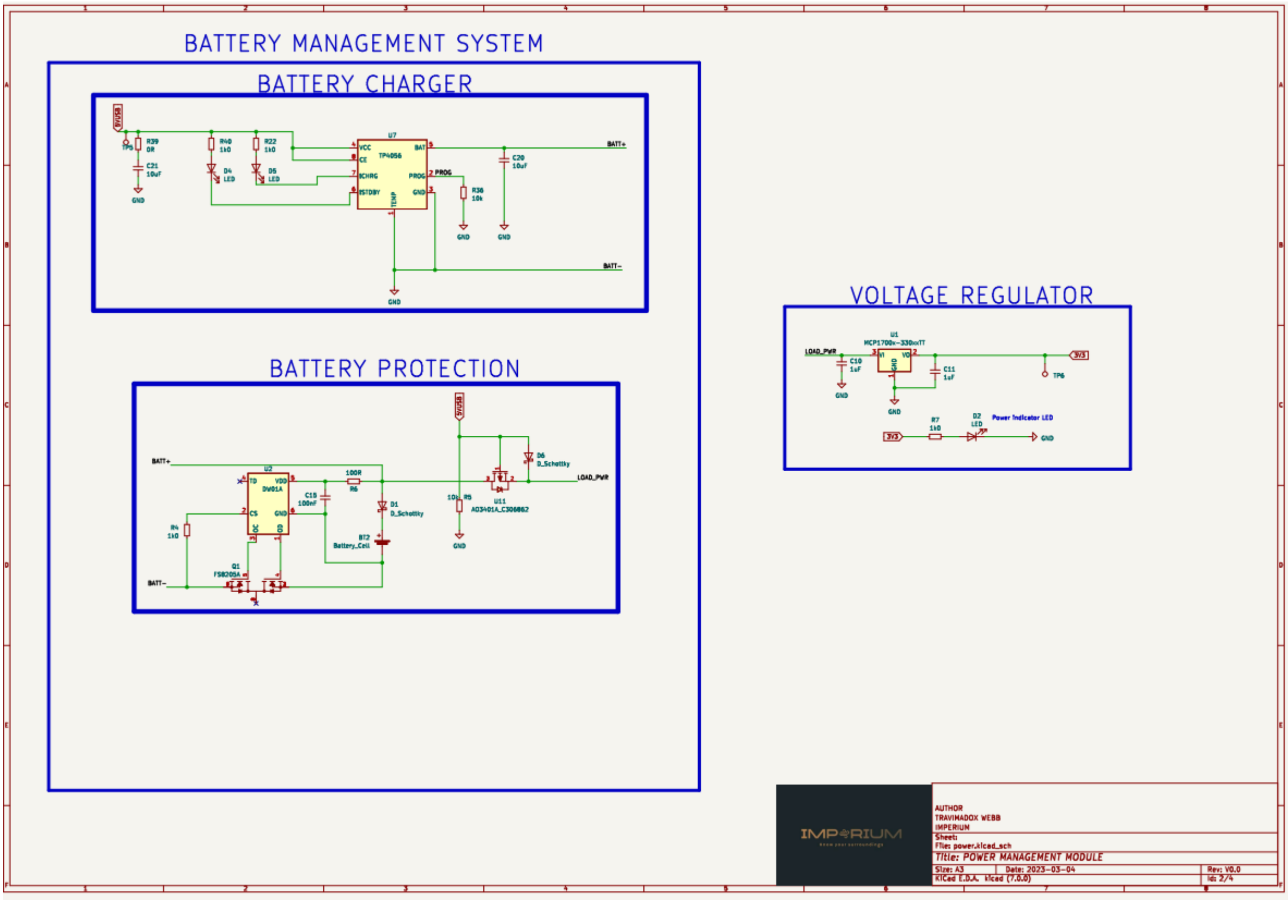

Figure 2: Power Submodule Schematic

3.1.5 Fit to Requirements

The current design meets the project requirements; however, there is potential for enhancements, particularly in the battery protection aspect. One possible improvement is modifying the battery charging mechanism. Adjusting the Rprog resistor can increase the charging current, eliminating the need to disconnect the battery when the USB is connected. This modification could streamline the charging process and provide a more user-friendly experience. Exploring this option and implementing it in future iterations of the STM32 EnviroSensing HAT could lead to a more refined and efficient design.

3.2 Microcontroller Module

The microcontroller interfacing submodule manages the communication between the microcontroller and the other components of HAT. It uses an STM32F0 microcontroller as the core processing unit, providing stable and efficient performance.

3.2.1 Microcontroller submodule

Its specifications are shown below: The chip used:**STM32F051C6T6**

Table 4: Specifications of the Microcontroller Board

Specification	**Detail**
Input Voltage Range	2.6V- 3.3V
Standard Operational Voltage	"Minimum: 2V Maximum: 3.6V"
External main voltage supply	"Minimum: -0.3V Maximum: 4.0V"
Backup Operational Voltage	"Minimum: 2.4V Maximum: 3.6V"
Input current	"Minimum- 0.5 uA Maximum-5mA"
MCU Family	STM32F051C6TX
External memory	Include an EEPROM to store data from sensors
Real-time clock	Includes an RTC for timestamping data
Internal Clock Frequency	Typically: 8MHz
Data logging	Automatically logs data when USB is plugged into a computing device, with specified transmission times and time-outs in case of sensor errors or missed data
Sensor interface	Interfaces with digital sensors through I2C and ADCs with GPIO pins
Operating Temperature	"Minimum- -40°C Maximum- 105 oC"
Storage Temperature Range	-65°C to 150°C
Flash Memory	32 KB
RAM	"32 KB Includes flash memory"
Clock Speed	Minimum- 48 MHz
Supported communication protocols	MCU should have interfaces of UART, I2C or SPI

Design notes

1. Package: LQFP48
2. The MCU in the STM32 EnviroSensing HAT is designed with additional headers to facilitate connections with external devices not included on the board. This feature provides increased flexibility and expandability, enabling users to interface with various peripherals for extended functionality and customisation options.

3.2.2 Memory Module

The AT24C256C-SSHL-T EEPROM is utilised in the STM32 EnviroSensing HAT for reading and writing logged data. This memory module's specifications ensure efficient data storage and retrieval, catering to the project's requirements. The following are the key specifications of the AT24C256C-SSHL-T EEPROM:

Table 5: Specifications of the EEPROM

Specification	**Detail**
Input Voltage	1.7-5.5V
Supply Current	"Typ 1mA Max 2mA"
Standby current	"Typ 1uA Max 6uA"
Interface	I2C
Compatibility	400kHz (1.7V) and 1MHz (2.5V, 2.7V, 5.0V)
Page Size	64-byte
Pages	512
Endurance	1,000,000 write cycles
Data retention	40 years
Operating temperature	55°C to +125°C
DC Output Current	5.0mA
Self-timed write cycle	5ms

Design Notes

1. Package: SOIC-8
2. The address of the EEPROM in the STM32 EnviroSensing HAT is set to the default configuration, as pins A0, A1, and A2 are grounded. Zero-ohm resistors are connected to the communication lines as a mechanism for error handling, enabling the lines to be disconnected in case of unprecedented errors. This design aspect ensures flexibility in addressing potential issues related to data transmission within the EnviroSensing HAT.

3.2.3 Communications with Host Computer

The FT234 chip is incorporated in the STM32 EnviroSensing HAT to manage data transmission between the board and the host computer. This FTDI chip transmits logged data to the user, ensuring efficient and reliable communication. The key specifications of the FT234 chip are as follows:

Table 6: Specifications of the USB-UART Interface

Specification	Detail
Input Voltage	5V
Data transfer rate	300 baud to 3 Mbaud
UART interface	"7 or 8 data bits, 1 or 2 stop bits and odd / even / mark/space / no parity UART signal inversion option *Synchronous and asynchronous bit bang interface options with RD# and WR# strobes."
Driver Support	"Royalty-free VIRTUAL COM PORT (VCP) DRIVERS Royalty-free D2XX Direct Drivers (USB Drivers + DLL S/W Interface) Refer to http://www.ftdichip.com/Documents/InstallGuides.htm"
Operating Temperature (Power Applied)	-40°C to 85°C
VCC Supply Voltage	-0.3 to +5.5
VCCIO IO Voltage	0.3 to +4.0
DC Input Voltage – USBDP and USBDM	-0.5 to +3.63
DC Output Current – Output	22mA
Data Retention	10 years
Write Cycle	2000 cycles
Read Cycle	Unlimited Cycles

Design Notes

1. Package: DFN-12
2. The STM32 EnviroSensing HAT utilises a USB self-powered configuration for a reliable power supply. A ferrite bead is incorporated to mitigate electromagnetic interference (EMI) and enhance signal integrity. These design aspects contribute to the HAT's efficient operation and performance stability.

3.2.4 Schematic

Link:https://github.com/Travimadox/STM32SESNSEHAT/blob/main/PCB/STM32SENSEHAT/mcu.kicad_sch

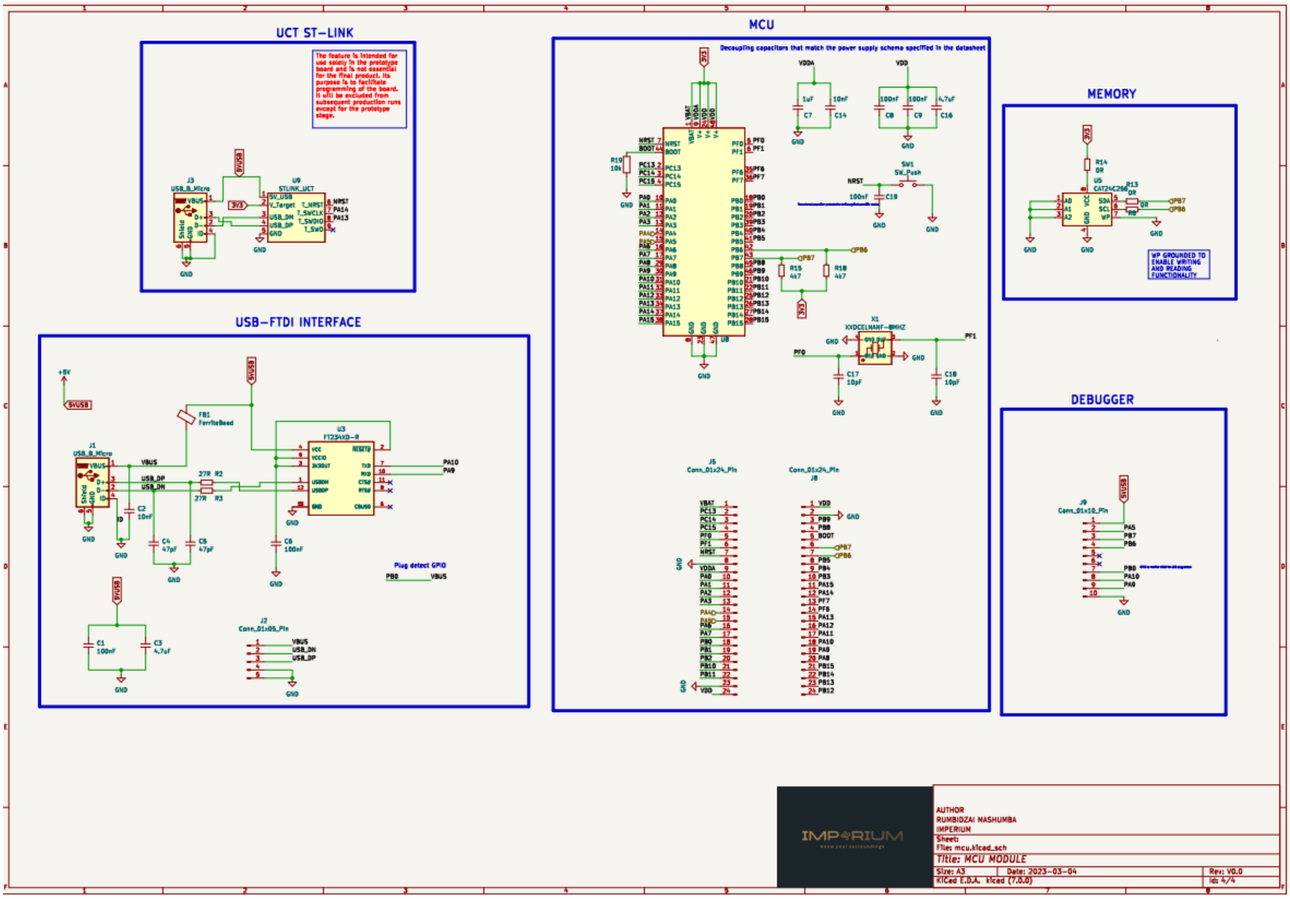

Figure 3: MCU Module Schematic

3.2.5 Fit to Requirements

The current design of the MCU module meets the basic requirements set forth by the client. However, several improvements can be considered for future iterations. For example, replacing the EEPROM with a higher-capacity variant or configuring the memory to use an SD card would enable longer data logging periods. Integrating an ESP32 module could also provide network connectivity for wireless data transmission and battery-level alerts. Furthermore, incorporating a dedicated CMOS battery for the internal RTC in the STM32 would prevent loss of time settings in the event of power loss. These enhancements would further refine the MCU module and expand its capabilities.

3.3 Sensing Module

Responsible for interacting with the environment directly and sensing environmental data

3.3.1 Temperature sensor

The temperature sensor used is TMP102. Its specifications are:

Table 7: Specifications of the Temperature Sensor

Specification	**Details**
Input Voltage	3.3V
Range	–40°C to 125°C
Accuracy (temperature error)	”–25°C to 85°C ±0.5 –40°C to 125°C ±1”
Resolution	0.0625
Operating temperature	–55°C to 150°C
Interface	”I2C Supports High Speed and Fast Mode”

Design Notes

1. Package: SOT-563
2. The alert pin is not connected in the current schematic, which may constrain certain chip functionalities. However, this design choice's core purpose of temperature measurement remains unaffected. Future iterations could consider wiring the alert pin to enhance the chip's overall capabilities without compromising the basic functionality.

3.3.2 Light Sensor

The sensor used is the LTR-303-ALS. The specifications are as follows:

Table 8: Specifications of the Light Sensor

Specification	**Details**
Input Voltage	3.3V
Operating temperature	–30°C to 70°C
Full dynamic range	0.01lux-64k lux
Effective Resolution	16 bits
Interface	”I2C Supports fast Mode”

Design Notes

1. Package: SOT-363
2. In the current schematic, the alert pin is not connected, potentially limiting some of the chip's features, though the basic functionality of ambient light measurement remains unaffected. The power pin of this chip is designed to be connected to Vcc only in the event of a TMP102 sensor failure. It should be noted that the sensor accuracy for this particular component is not explicitly stated in the datasheet. Future design iterations may address these aspects to optimize the chip's functionality.

3.3.3 LDR

An LDR (light-dependent resistor) has been incorporated into the design to supplement the digital light sensor, enhancing the system's overall light-sensing capabilities. The specifications of the LDR are as follows:

Table 9: Specifications of the Light-Dependent Resistor

Specification	**Details**
Input Voltage	"Typical:3.3V Maximum:10V"
Maximum Power Dissipation	90mW
Ambient Temperature	-30°C to 70°C
Spectral Peak	540nm
Light resistance	10-20k Ω
Dark resistance	2MΩ
Gamma Value	0.7
Response Time	"Rise Time: 30ms Decay Time:30ms"

Design Notes

1. The LDR employed in this design is a basic photoresistor, specifically, the model widely used in the first-year practicals of the EEE1006F course at the University of Cape Town. Utilising a familiar and accessible LDR, the design aims to leverage the team's existing knowledge and experience, ensuring ease of implementation and compatibility with other components.

3.3.4 Schematic

Link: https://github.com/Travimadox/STM32SESNSEHAT/blob/main/PCB/STM32SENSEHAT/sensor.kicad_sch

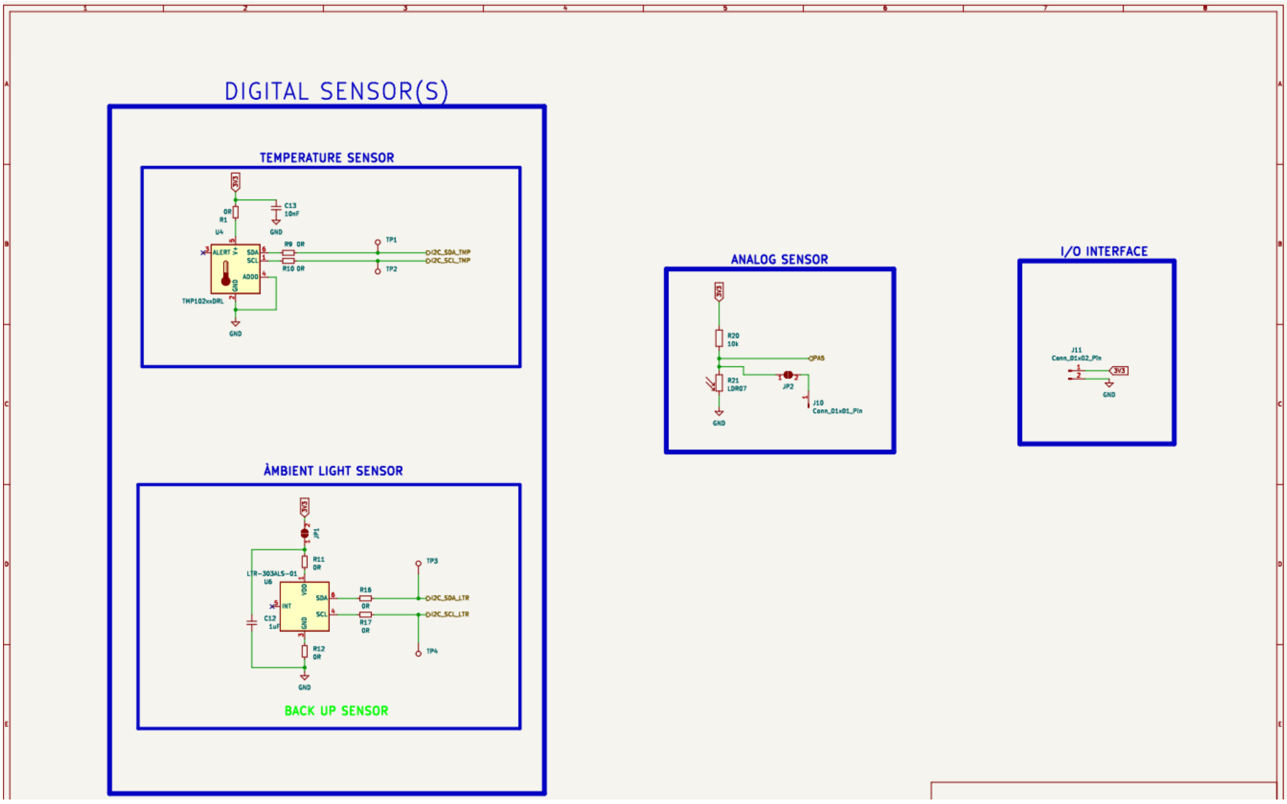

Figure 4: Sensing Module Schematic

3.3.5 Fit to Requirements

The current sensor configuration is suitable for the specified use cases; however, potential modifications could be considered for expanding functionality. Although the analog LDR may exhibit limited sensitivity (approx. 100 lux) and accuracy ($\pm 10\%$), it is sufficient for this board's intended applications, such as basic ambient light monitoring. For higher lux ranges, the digital light sensor (LTR-303_ALS) with a range of 0.1 lux to 64,000 lux and an accuracy of $\pm 2\%$ should be utilised. The decision to leave the alert pins of the digital sensor unconnected also limits the sensor's capabilities, such as interrupt-based alerts. Furthermore, the sensors remain powered on even when not recording data, leading to unnecessary power consumption, which could be up to 10% of the total power budget. Addressing this concern and implementing power-saving strategies, such as sleep mode or power gating, will be a priority in the next iteration of the board design—the board's efficiency and overall performance.

4 Power Budget

4.1 Power Module

Table 10: Power Module Power Pudget

Component	Supply Voltage	Minimum Current	Typical Current	Maximum Current	Minimum Power	Typical Power	Maximum Power
TP4056	5	0.95	1	1.05	4.75	5	5.25
DW01A	3.6	0.000003	0.000003	0.000006	0.0000108	0.0000108	0.0000216
MCP1700X-330XXTT	5	0.000016	0.000016	0.000004	0.00008	0.00008	0.00002
Resistors					1	1	1
				Total Power	**5.7500908**	**6.0000908**	**6.2500416**

Notes:

1. For the DW01A and MCP1700X-330XXTT, minimum current values were not provided in the datasheets. Therefore, the typical current values were used in their place.
2. The power budget accounts for 8 resistors, each with a power rating of 125mW, for a total power dissipation of 1W.
3. Capacitors were not included in the power budget, as their power consumption was approximated to be negligible.
4. The ferrite bead is not included in the power budget. However, based on its specifications (300mA, 68nH $\pm$ 5%, 850mΩ, 0603 SMD, ROHS), its power consumption can be approximated using $P = I^2R$, where I is the current and R is the resistance.
5. The AO3401A MOSFET was not included in the power budget due to insufficient information in the datasheet. However, its rated specifications (20V, 6A, 1.5W, 23mΩ@4.5V) can be used to approximate power consumption using $P = I^2R$, where I is the drain current and R is the on-resistance at the specified gate voltage.
6. The Schottky diode was not included in the power budget, as there was no direct power consumption information provided in the datasheet. However, based on its specifications (30V, 800mV@100mA, 200mA, SOT-23, ROHS), its power consumption can be estimated using $P = IV$, where I is the forward current and V is the forward voltage drop. Additionally, reverse recovery characteristics can be considered for dynamic power estimation.

4.2 Microcontroller Module

The power budget for the microcontroller interfacing module is shown below:

Table 11: Microcontroller Module Power Budget

Component	Supply Voltage (nominalV)	Minimum Current	Typical Current	Maximum Current	Minimum Power	Typical Power	Maximum Power
STM32F051C6T6	3.3	0.05	0.1	0.1	0.165	0.33	0.33
FT234XD-R	3.3	0.0065	0.008	0.0083	0.02145	0.0264	0.02739
CAT24C256	3.3	0.001	0.001	0.002	0.0033	0.0033	0.0066
Resistors					1	1	1
				Total Power	**1.18975**	**1.3597**	**1.36399**

Notes:

1. The power budget accounts for 8 resistors, each with a power rating of 125mW, for a total power dissipation of 1W.

4.3 Sensing Module

The power budget for the sensing module is shown below:

Table 12: Sensing Module Power Budget

Component	Supply Voltage (nominalV)	Minimum Current	Typical Current	Maximum Current	Minimum Power	Typical Power	Maximum Power
TMP102XXDRL	3.3	0.000001	0.00001	0.00001	0.0000033	0.000033	0.000033
LTR-303ALS-01	3.3	0.000005	0.00022	0.00022	0.0000165	0.000726	0.000726
Resistors					1	1	1
				Total Power	**1.0000198**	**1.000759**	**1.000759**

Notes:

1. The power budget accounts for 8 resistors, each with a power rating of 125mW, for a total power dissipation of 1W.

4.4 System Total

The system power budget is shown below:

Table 13: SenseHAT Power Consumption

Submodule	Minimum Power	Typical Power	Maximum Power
Power Module	5.7500908	6.0000908	6.2500416
Sensing Module	1.0000198	1.000759	1.000759
MCU Module	1.18975	1.3597	1.36399
Total	**7.9398606**	**8.3605498**	**8.6147906**

5 Design Process

The design process for the STM32 EnviroSensing HAT was characterised by several critical decisions and inflexion points that ultimately shaped the final product. This section describes these vital moments, the rationale behind each choice, and supporting details and numbers.

5.1 Selection of Microcontroller

The STM32F051C6T6 was selected as the primary microcontroller due to its availability during design. This ARM Cortex-M0-based MCU features 32KB Flash memory, 4KB SRAM, and a 48MHz maximum frequency, ensuring compatibility with other microcontrollers from the same family if needed in the future.

5.2 Sensor Selection

Initially, the BME280 sensor was considered for its compactness and rich feature set. However, due to budget constraints, we opted for the more affordable TMP102 ($1.50/unit) and LTR-303_ALS ($0.65/unit) sensors as alternatives to the BME280 ($3.00/unit). This decision led to a slight reduction in accuracy compared to the BME280. It resulted in the loss of approximately 10% of the available board space, necessitating adjustments in the overall layout and component placement.

5.3 Choice of Power Supply Regulator

We selected Texas Instruments' MCP1700 low-dropout (LDO) linear regulator for our design, considering its compatibility with our 5V supply, budget constraints, and performance requirements. The MCP1700 delivers a stable 3.3V output at up to 250mA with an input voltage range of 2.7V to 6V, providing a 1V headroom for voltage fluctuations. To ensure the MCP1700's proper thermal performance, we calculated power dissipation and evaluated the junction-to-ambient thermal resistance, verifying that the maximum junction temperature would not be exceeded during operation. This approach allowed us to implement the MCP1700 effectively, meeting our project's technical and budgetary requirements.

5.4 Data Storage and Retrieval

A 512KB (4Mbit) EEPROM, such as the CAT24C256 by Atmel, was utilised as the only available option for data storage during the design process. This capacity limits data collection to approximately two days before the EEPROM becomes full, assuming a data logging rate of one sample per second. Another reason for choosing the CAT24C256 was its low cost, at just $0.50 per unit, which further contributed to meeting the project's budget constraints.

5.5 Communication Protocols

I2C was chosen as the primary communication protocol due to the team's familiarity with I2C devices, facilitating firmware development. The FTDI FT234XD-R UART bridge chip was selected for data transmission to the host computer because of previous experience with the component and project requirements. The FT234XD-R supports data transfer rates of up to 3 Mbaud, ensuring efficient communication between the STM32 EnviroSensing HAT and the host computer.

5.6 PCB Layout and Design

The PCB layout was iteratively improved to minimise signal interference, reduce electromagnetic noise, and enhance manufacturability. Critical component placement and proper heat dissipation were prioritised, utilising thermal vias and copper pour areas. The final PCB dimensions were 100mm x 100mm.

5.7 Testing and Debugging

Several simulations were performed to ensure the robustness of the design, including schematic Design Rule Checks (DRCs) and sensor testing with breakout boards, breadboards, and the STM32 microcontroller to validate the concept in real-world conditions. The testing involved measuring temperature and light levels under various environmental conditions to ensure accuracy and reliability.

5.8 ST-Link Inclusion

The decision to include the ST-Link debugger was debated until the last minute, and it was ultimately incorporated into the prototype board. The ST-Link V2 debugger has an SWD interface.

6 Conclusion

In conclusion, the STM32 EnviroSensing HAT is a highly capable and efficient board providing an excellent environmental sensing application platform. The current design meets the client's basic requirements, and there is potential for further enhancements to expand the board's capabilities.

The power module, battery charger submodule, battery protection submodule, voltage regulator submodule, MCU module, memory module, and sensing module have all been designed to meet the project's specific requirements. The components' specifications have been carefully considered to ensure optimal performance and efficient operation.

However, several areas for improvement have been identified in the design. For instance, modifying the battery charging mechanism by adjusting the Rprog resistor could streamline the charging process and provide a more user-friendly experience. Incorporating an ESP32 module could provide network connectivity for wireless data transmission and battery-level alerts. Power-saving strategies, such as sleep mode or power gating, could reduce unnecessary power consumption and enhance the board's efficiency.

By refining these aspects and incorporating additional functionalities, the STM32 EnviroSensing HAT could become an even more capable platform for environmental sensing applications. The team is committed to further developing and refining the design, incorporating user feedback and incorporating new technological advancements to ensure that the board remains a leading solution for environmental sensing.

Appendices