Portable Environmental Tracker

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Objective:- Development of a portable environment tracker which acts as a NODE in a network of such devices spread across a large area transmitting data to a central receiver. (*Due to lack of info about post data collection phase I have taken the liberty to modify it a bit*)

Features:- We will be detecting ***Temperature, humidity, pressure, ambient light, Volatile Organic Compounds, air quality, noise and ambient noise.***

Power System

- **Battery:** Single-cell 3.7 V Li-Po. (400-500 mAh)
- **Power Conversion:** Buck converter generates regulated **3.3 V rail** for all digital, RF, and sensor blocks.
- **Charging & BMS:**
    - **BQ25170** Li-Ion charging IC.
    - Integrated **battery management circuitry (BMS)**.
    - Supports **USB and solar charging**.
- **Battery Voltage Monitoring:**
    - **Resistor ladder** + **MOSFET-gated sensing** to MCU ADC.
    - Allows **periodic SoC checks** without continuous current draw.

Environmental Sensors (I²C Bus)

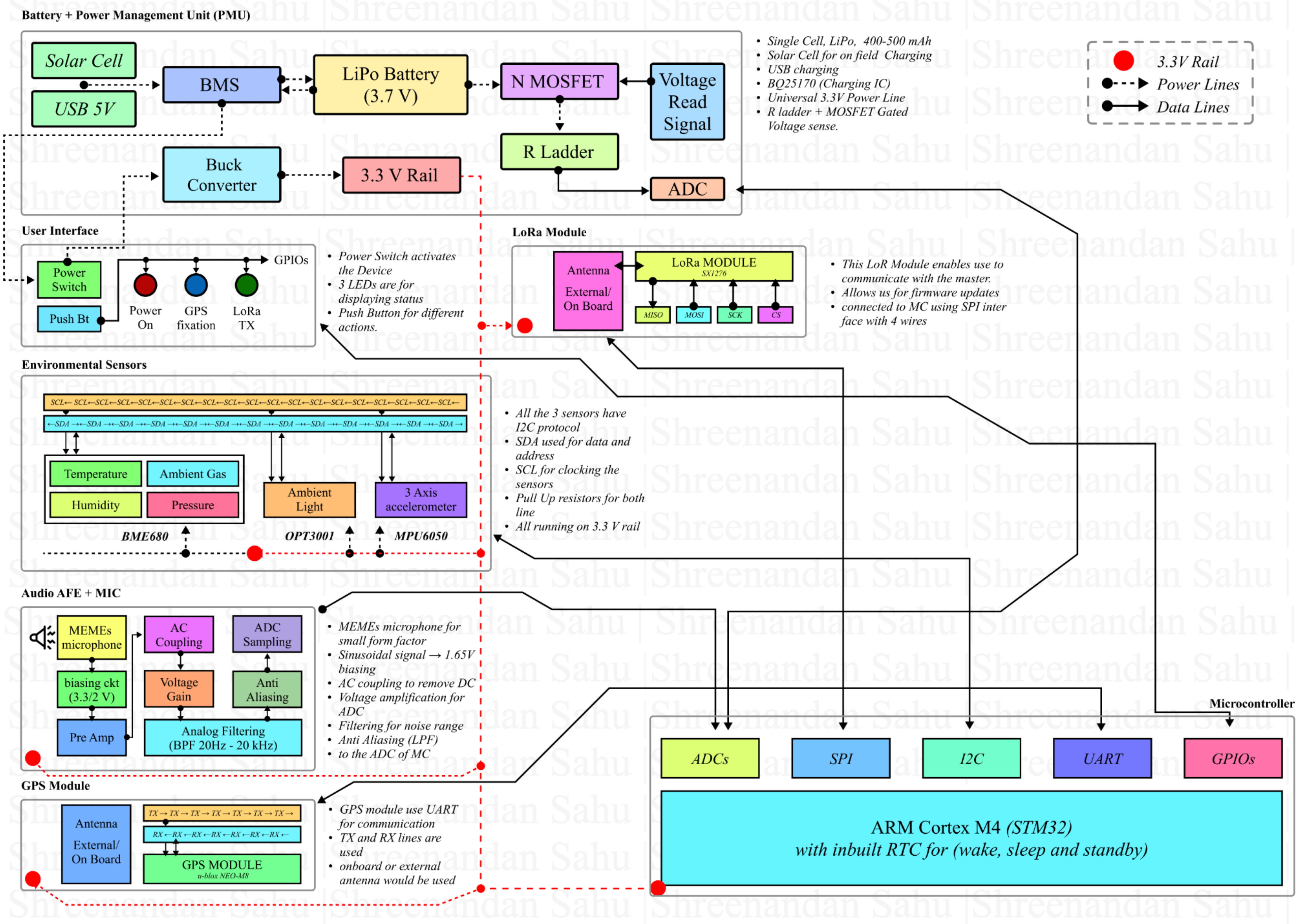
- All sensors powered from **3.3 V** and share the **SDA/SCL I²C bus with pull-ups**.
- **BME680:** Temperature, humidity, pressure, gas (IAQ).
- **OPT3001:** Ambient light measurement.
- **MPU6050:** 3-axis accelerometer (and gyro).
    - **Interrupt pin** used for **wake-on-motion** events.
- MCU controls I²C sampling rates for power efficiency.

GPS Subsystem

- **u-blox NEO-M8 GNSS module** interfaced via **UART (TX/RX)**.
- MCU controls **GPS enable pin** to power the module only during fixes.
- MCU parses **NMEA messages** for latitude, longitude, time.
- External or onboard **GPS antenna** connected to RF input.

LoRa Communication

- LoRa radio based on **SX1276**.
- Interface: **SPI (MISO, MOSI, SCK, CS)** + **DIO interrupt pins**.
- External or PCB-based LoRa **RF antenna**.
- Used for:
    - **Periodic long-range telemetry**.
    - **Low-rate OTA firmware updates** through a bootloader mode.



Battery + Power Management Unit (PMU)
Solar Cell
USB 5V
BMS
LiPo Battery (3.7 V)
N MOSFET
Voltage Read Signal
R Ladder
ADC
Buck Converter
3.3 V Rail
• Single Cell, LiPo, 400-500 mAh
• Solar Cell for on field Charging
• USB charging
• BQ25170 (Charging IC)
• Universal 3.3V Power Line
• R ladder + MOSFET Gated Voltage sense.
3.3V Rail
Power Lines
Data Lines
User Interface
Power Switch
Push Bt
Power On
GPS fixation
LoRa TX
GPIOs
• Power Switch activates the Device
• 3 LEDs are for displaying status
• Push Button for different actions.
LoRa Module
Antenna External/ On Board
LoRa MODULE
SX1276
MISO
MOSI
SCK
CS
• This LoR Module enables use to communicate with the master.
• Allows us for firmware updates
• connected to MC using SPI inter face with 4 wires
Environmental Sensors
SCL← SCL←SCL←SCL←SCL←SCL←SCL←SCL←SCL←SCL←SCL←SCL←SCL←SCL←SCL←SCL←SCL←SCL←SCL←
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Temperature
Ambient Gas
Humidity
Pressure
Ambient Light
3 Axis accelerometer
BME680
OPT3001
MPU6050
• All the 3 sensors have I2C protocol
• SDA used for data and address
• SCL for clocking the sensors
• Pull Up resistors for both line
• All running on 3.3 V rail
Audio AFE + MIC
MEMEs microphone
AC Coupling
ADC Sampling
biasing ckt (3.3/2 V)
Voltage Gain
Anti Aliasing
Pre Amp
Analog Filtering (BPF 20Hz - 20 kHz)
• MEMEs microphone for small form factor
• Sinusoidal signal → 1.65V biasing
• AC coupling to remove DC
• Voltage amplification for ADC
• Filtering for noise range
• Anti Aliasing (LPF)
• to the ADC of MC
GPS Module
Antenna External/ On Board
TX → TX → TX → TX → TX → TX → TX →
RX ←RX ←RX ←RX ←RX ←RX ←RX ←
GPS MODULE
u-blox NEO-M8
• GPS module use UART for communication
• TX and RX lines are used
• onboard or external antenna would be used
Microcontroller
ADCs
SPI
I2C
UART
GPIOs
ARM Cortex M4 (STM32)
with inbuilt RTC for (wake, sleep and standby)
Shreenandan Sahu

Audio Subsystem

- **Analog MEMS microphone**.
- Biasing network: **3.3 V with mid-rail (1.65 V) reference**.
- **Pre-amplifier** + **AC-coupling**.
- **Analog band-pass filter**: 20 Hz–20 kHz.
- Additional **low-pass anti-aliasing filter** before MCU ADC.
- MCU samples conditioned mic signal for audio/event analysis.

User Interface

- **Power switch**.
- **Push button** for mode select / manual logging.
- **3 status LEDs:**
  - Power
  - GPS fix
  - LoRa transmission
- All connected to **MCU GPIOs**.

Microcontroller – ARM Cortex-M4 (STM32 family)

- Cortex-M4 with **DSP + FPU** for sensor fusion, FFT audio processing and small ML models.
- Typical specs: **256–512 kB Flash**, **64–128 kB RAM**—sufficient for code, model weights, buffers.
- Integrated peripherals: **ADC**, **I²C**, **SPI**, **UART**, **GPIOs** match all sensor, GPS, LoRa interfaces.
- Supports **deep sleep / stop / standby** modes with **sub-µA current** for aggressive duty cycling.
- Enough compute while remaining low-power and field-friendly.

GPS Module – u-blox NEO-M8

- Multi-GNSS support: **GPS, GLONASS, Galileo** → robust fixes in difficult environments.
- **Configurable update rates** and **low-power modes** for duty-cycled operation.
- **UART + NMEA** output simplifies firmware parsing and integration.
- **Fast cold/warm start** → shorter on-time → lower energy per fix.

Microphone – Analog MEMS + AFE

- Compact **SMD analog MEMS microphone** suited for rugged environmental devices.
- Uses MCU **ADC** to avoid high-speed digital audio interfaces (I²S/PDM).
- Dedicated **pre-amp**, **AC-coupling**, and **20 Hz–20 kHz band-pass filter** for environmental sound analysis.
- Analog path allows **tunable gain** and bandwidth matched to ADC range and target frequencies.

Battery – 3.7 V LiPo (400–500 mAh)

- Provides good balance of **size, weight, and multi-day uptime**.
- High energy density suitable for portable field systems.
- Charged via **BQ25170** from **USB 5 V** or **solar panel**.
- Battery voltage sensed through **MOSFET-gated resistor divider** to avoid constant leakage.
- Buck converter efficiently generates **3.3 V** system rail.

Wireless Module – LoRa SX1276

- Long-range, low-bitrate LoRa PHY ideal for **small telemetry packets** (sensor summaries, GPS coords).
- Simple interface: **SPI** + a few digital **DIO** interrupt lines.
- Supports **deep sleep** and **very low TX duty cycle**, keeping average power ultra-low.
- Enables **remote monitoring**, **over-the-air configuration**, and low-rate firmware updates.

Environmental Sensors – BME680, OPT3001, MPU6050

- **BME680:** Temp, humidity, pressure, gas (TVOC) in one I²C package → minimal PCB area.
- **OPT3001:** Calibrated ambient light for day/night detection and illumination profiling.
- **MPU6050:** 3-axis accelerometer enabling wake-on-motion, orientation checks, vibration anomalies.
- All share **I²C bus**, reducing pin count and routing complexity.

Miniaturization and Design Constraints

PCB Design

- Use a **4-layer PCB** with a continuous ground plane for stability and reduced noise.
- Keep **buck converter switching nodes short** and place decoupling capacitors close to IC pins. To avoid high frequency switching noise
- Share **I²C bus** for sensors to minimize routing and pin coins for different sensors
- Physically separate **analog audio traces** from high-speed digital and RF lines to avoid cross talk.

Antenna Design

- NEVER DONE and have no idea and would love to learn

Audio Path Noise Reduction

- Place MEMS mic + pre-amp **far from power converters and RF circuits**.
- Use a dedicated **analog ground region**, tied to digital ground at a single point.
- Apply shielding and clean routing of the **band-pass filter** components.
- Shielding from EM and RF waves.

Thermal & Enclosure Considerations

- Add **copper pours + thermal vias** under power components for heat spreading.
- Use an **acoustic mesh** for microphone opening.
- Ensure mechanical robustness: secure PCB mounting, battery strain relief, ventilation. Using 3D printed casing to protect as well as to mount the solar panel.

Performance vs Power

- Higher sampling/GPS rates → better accuracy but higher power drain.

Failure Mode: GPS Signal Loss

- GPS fails in areas with foliage/buildings.

- **Mitigation:**
    - Use **last known location** when fix unavailable.

I dont have proper knowledge of the ML and DSP so I have not touched that aspect of the device and due to tight schedule I could not read and understand about it and will love to work on it in future.

Projects- https://shreenandansahu.netlify.app/

GitHub: https://github.com/shreenandansonu

Youtube: https://www.youtube.com/@shreenandansahu

Figure: Collage of different Projects done by me

Power Calculation

$\dfrac{\text{Once in 20 minute}}{\text{for 1 minute.}}$

Source = 500mAh Lipo battery

$$\boxed{\text{average Current} = \text{Active Current (Duty Cycle)} + \text{Sleep Current (1- Duty Cycle)}}$$

Microcontroller

Active = 10 mA →
Sleep = 20 µA

if we operate for 1 minute for collecting & Sending data & then for 20 minutes

$\frac{1}{21} \times 100 \approx \underline{5\%}$ (Active) & 95% (Sleep)

So Current drawn = $0.05 \times 10\,mA + 0.95 \times 20\,\mu A$
$0.05 \times 10000\,\mu A + 0.95 \times 20\,\mu A$
$500\,\mu A + 19.5\,\mu A$
$\approx 520\,\mu A.$
$= 0.5\,mA$

GPS

Active = 25mA . Sleep = 0 mA
if we operate for 2 minutes every 20 minutes.

$\frac{2}{20} \times 100 = 10\%$ duty cycle

Current drawn = $0.1 \times 25\,mA$
$= 2.5\,mA$

All Sensor (Assume)

Active = 5 mA.

if we operate for 2 minutes every 20 mins

$\frac{2}{20} \times 100 = 10\%$ duty cycle.

Current = $0.1 \times 5\,mA$
$= 0.5\,mA$

LORA

While transfering (TX) = 40mA

So for every 20 mins there will be 100 mS transfering so

$\frac{\cancel{100}}{20 \times 60 \cancel{\times 1000}} \cancel{\times 100} = \frac{1}{120} = 0.01\,\%$

So Current = $0.01 \quad 40\,mA = 0.4\,mA$

So in total the current drawn is

Sensor → 0.5 mA
LORA → 0.4 mA
GPS → 2.5 mA
micro control → 0.5 mA.

$\approx \underline{3\,mA}$ Average Current

So for 500 mAH : $\frac{500\,mAH}{3\,mA} = 166.6 \approx 160$ HRS

So the device will run upto $\frac{160}{24} \approx$ 7 days.

→ This is worst case if we charge it once & there is no solar board charging.