

Hive Monitor System - Project Overview & Concept

Project Summary

The Hive Monitor project is an initiative led by GaiaForge to support grassroots beekeeping operations in regions with limited access to technology and infrastructure. The goal is to develop a modular, solar-powered hive monitoring system that provides critical insights into colony health and environmental conditions.

This system is being deployed to Kisuno village (2.7438° S, 31.2471° E), where 76 bee colonies are managed across two stationary apiary locations surrounded by forest and farmland. Most hives are Kenyan top-bar, with some traditional types. The community experiences significant flowering periods in July and September, and crop seasons from March-May and September-December.

Local challenges include colony absconding, predators, pests, disease, low honey yield, and limited access to beekeeping tools, hive management technology, and proper honey processing techniques. Data is currently recorded by hand in notebooks. There is no power or solar access at the sites, though mobile signal is moderately available.

A core group of three moderately experienced beekeepers is leading the project and is highly motivated to learn and implement new technology. Their broader vision is to establish a beekeeping learning center to train local youth and promote sustainable beekeeping throughout the region.

This system-featuring modular sensing, long-term data logging, and solar operation-aims to empower these keepers with actionable insights to improve hive health, increase honey yields, and develop local technical skills through open collaboration.

Hive Monitor - Microphone Sensing Concept Overview

1. Overview

This document outlines the microphone sensing subsystem of the hive monitor project.

It describes how acoustic data from the hive will be captured using the onboard PDM microphone on the Adafruit Feather nRF52840 Sense, processed using FFT, and analyzed to detect changes in hive activity.

2. Hardware

- Microcontroller: Adafruit Feather nRF52840 Sense
- Microphone: Built-in PDM MEMS microphone
- Sampling Rate: 16 kHz
- FFT Window Size: 512 samples
- Power Strategy: Wake every 10 minutes, sample audio, process FFT, return to sleep

3. Frequency Bands

- Band 1 (B1): 200-300 Hz - Normal hive hum
- Band 2 (B2): 300-600 Hz - Queen piping
- Band 3 (B3): 600-1000 Hz - Swarming agitation
- Band 4 (B4): 1000-3000 Hz - Alarm or disturbance

4. Default Classification Thresholds

- THRESH_B1 = 0.6 (Normal hum)
- THRESH_B2 = 0.4 (Queen activity)
- THRESH_B3 = 0.3 (Swarming)
- THRESH_B4 = 0.2 (Alarm/disturbance)
- THRESH_SILENT = 0.1 (Possible absconding)

5. Output Format

Each audio capture session logs:

- Timestamp
- Band Energy Values (B1-B4)
- Classification Result

Example:

2025-04-10T18:00:00Z | B1: 0.72 | B2: 0.14 | B3: 0.04 | B4: 0.01 | Status: Normal

6. Configurability

Threshold values can be updated through:

- Config file on SD card
- BLE command (future feature)
- Hardcoded overrides for testing

This allows fine-tuning during real-world deployment.

Hive Monitor - Environmental Monitoring Concept Overview

1. Overview

This document outlines the environmental monitoring subsystem of the hive monitor project.

It describes how temperature, humidity, and barometric pressure data will be collected using onboard sensors and logged at the same interval as the acoustic monitoring system.

2. Sensors and Hardware

- Microcontroller: Adafruit Feather nRF52840 Sense
- Primary Sensors:
 - SHT (Humidity + Temperature)
 - BMP280 (Pressure + Temperature)
- Interface: I2C
- Sampling Interval: Every 10 minutes (synchronized with microphone sensing)

3. Parameters Monitored

- Temperature (°C)
- Humidity (%)
- Barometric Pressure (hPa)
- Optional alert column (Nominal, Warning, Critical)

4. Output Format

Each environmental capture session logs:

- Timestamp
- Temperature (°C)
- Humidity (%)
- Pressure (hPa)
- Alert status

Example:

2025-04-10T18:00:00Z | Temp: 34.8C | Hum: 59.3% | Pressure: 1013.2 hPa | Status: Nominal

5. Alert Thresholds

Default thresholds for alerts:

- Temperature: $< 30^{\circ}\text{C}$ or $> 38^{\circ}\text{C}$ = Alert
- Humidity: $< 50\%$ or $> 70\%$ = Alert
- Pressure: Used for correlation only (no direct alerts)

Status Levels:

- Nominal: All values within range
- Alert: One or more values out of range

6. Configurability

Threshold values can be updated through:

- Config file on SD card
- BLE command (future feature)
- Hardcoded overrides for testing

This allows adaptive tuning during real-world deployment.

Hive Monitor - Motion Sensing Concept Overview

1. Overview

This document outlines the motion sensing subsystem of the hive monitor project.

The onboard 9-DoF motion sensors (accelerometer, gyroscope, and magnetometer) will be used to detect hive disturbances, monitor orientation, and log subtle changes in movement.

These readings can provide valuable insights into behavioral patterns, environmental events, or unauthorized tampering.

2. Sensors and Hardware

- Sensor: LSM6DS33 (accelerometer + gyroscope)
- Sensor: LIS3MDL (magnetometer)
- Interface: I2C
- Sensor Type: 9-DoF motion tracking
- Device: Integrated into Adafruit Feather nRF52840 Sense

3. Use Cases

- Detect sudden motion or impact (e.g., hive knock or tampering)
- Monitor hive orientation over time (tilting or shifting due to weather or handling)
- Record subtle motion trends (activity levels)
- Correlate with acoustic and environmental data for behavioral analysis

4. Sampling Strategy

- Motion data will be captured every 10 minutes, synchronized with audio and environmental logs
- Only minimal averaging or RMS will be computed to conserve power
- Optional: Wake from sleep on motion/tilt interrupt for future versions

5. Output Format

Each motion capture session logs:

- Timestamp

- Acceleration vector (X, Y, Z)
- Gyro rates (optional)
- Orientation or tilt
- Motion status classification (e.g., Nominal, Movement Alert)

Example:

2025-04-10T21:45:00Z | X: 0.03g Y: -0.02g Z: 0.98g | Orientation: Stable | Motion Status: Nominal

6. Future Applications

- Behavioral analysis and anomaly detection
- Feature fusion with acoustic and environmental data
- Dataset for AI training or collaboration with researchers
- Swarm prediction using multivariate motion patterns

Hive Monitor - Light Sensing Concept Overview

1. Overview

This document outlines the light sensing subsystem of the hive monitor project.

The onboard APDS-9960 sensor will be used to monitor ambient light levels, enabling detection of hive lid removal, unusual light exposure, and possible tampering events.

2. Sensor and Capabilities

- Sensor: APDS-9960
- Interface: I2C
- Measures:
 - Ambient light (lux-level approximation)
 - RGB color values (optional)
 - Proximity and gesture detection (not used for this project)

3. Use Cases

- Detect when the hive lid is removed or opened
- Measure duration of lid-open events
- Detect unexpected daylight exposure (e.g. hive moved, disturbed)
- Correlate light events with motion, sound, or environmental changes

4. Sampling Strategy

- Light levels are sampled every 10 minutes in sync with other sensors
- Optionally monitored more frequently or on interrupt if needed
- Alert condition if light level exceeds a defined threshold

5. Output Format

Each light reading includes:

- Timestamp
- Ambient light level (lux-like units)

- Alert status (e.g., Enclosed, Lid Removed)

Example:

2025-04-10T18:00:00Z | Light: 3 lux | Status: Enclosed

2025-04-10T18:20:00Z | Light: 420 lux | Status: Lid Removed

6. Future Applications

- Correlate light level with bee activity and stress
- Detect seasonal lighting trends or anomalies
- Enable timed logging when light changes occur

Hive Monitor - Weight Sensing Concept Overview

1. Overview

This document outlines the weight sensing subsystem of the hive monitor project.

Using a load cell and HX711 ADC amplifier, this system will measure and log the hive's weight at regular intervals to monitor honey accumulation, colony behavior, and environmental effects.

2. Hardware and Configuration

- Load Cell: Strain gauge-based weight sensor
- Amplifier: HX711 24-bit ADC module
- Interface: 2-wire digital (DT and SCK)
- Wiring:
 - VCC: 3.3V or 5V from Feather
 - GND: Ground
 - DT: GPIO pin (e.g., D6)
 - SCK: GPIO pin (e.g., D5)

3. Use Cases

- Track honey accumulation over time
- Detect swarming or absconding events
- Monitor diurnal weight fluctuations
- Identify rain ingress or moisture retention
- Flag sudden changes (theft, removal, environmental events)

4. Sampling Strategy

- Take weight readings every 10 minutes, aligned with other sensor modules
- Collect multiple samples (e.g., 5-10) and average them for noise reduction
- Optional: implement a smoothing filter or rolling average
- Calibration required with known reference weights

5. Output Format

Each log entry includes:

- Timestamp
- Calculated weight (kg)
- Status (e.g., Stable, Alert, Weight Drop Detected)

Example:

2025-04-10T18:00:00Z | Weight: 42.78 kg | Status: Stable

2025-04-11T02:10:00Z | Weight: 39.15 kg | Status: Weight Drop Alert

6. Calibration and Configurability

- Calibration requires measuring known weights and adjusting gain factor
- Gain factor can be stored in EEPROM, SD card config file, or hardcoded
- Adjustable thresholds for triggering alerts on sudden weight changes

Hive Monitor - Power Management Concept Overview

1. Overview

This document outlines the power management subsystem of the hive monitor project.

It details how the system will use solar charging, battery management, and deep sleep cycles to operate for extended periods in remote, off-grid environments.

2. Power Sources and Configuration

- Battery: 2S LiFePO4 battery pack (nominal 6.4-7.2V)
- Charging: BQ24650 MPPT solar charge controller
- Solar Panel: 12V, 10W
- Regulator: DC-DC converter (e.g., 5V Pololu step-down) to power Feather
- Power routed to Feather VBAT or USB input, depending on regulator

3. Power Management Strategy

- All sensors and peripherals powered down or disabled when not in use
- nRF52840 enters deep sleep mode between readings
- Adjustable wake/sensor interval: 1 min, 5 min, 10 min, 30 min, or 1 hour
- Optional power gating via MOSFETs for SD card, amplifier, or HX711
- Battery voltage and solar current can be monitored (if desired) via ADC or INA219

4. Low Power Sleep/Wake Behavior

- Deep sleep current target: <10 uA between readings
- Wake from RTC, onboard timer, or external ESP32 RTC pulse
- Runtime duration per cycle: ~1-2 seconds total for all sampling and logging
- Configurable wake intervals allow fine-tuning power vs data frequency
- Optionally enter extended sleep if low battery detected

5. Optional Features and Alerts

- Low battery warning via log file or BLE packet

- Suspend logging during rain (if rain sensor added)
- Runtime voltage monitoring for diagnostics
- Add status LED blink (disable in field mode to conserve power)

6. Wiring and Safety

- All power lines fused (battery, solar, and logic)
- Use Schottky diodes or OR-ing logic to prevent backfeed from solar
- Mount MPPT and battery in weather-resistant compartment
- Ensure clean ground between modules to avoid noise and brownouts

Hive Monitor - Communication and Data Logging Concept Overview

1. Overview

This document outlines the communication and data logging subsystem of the hive monitor project. It describes how sensor data is stored, retrieved, and optionally transmitted via Bluetooth or other interfaces. This enables remote monitoring, system updates, and historical analysis.

2. Data Storage

- Primary storage: microSD card (FAT32)
- Format: plain text or CSV logs for compatibility
- Each entry includes timestamp, sensor data, and optional classification/alerts
- Modular logs per subsystem (e.g., audio, environment, motion, weight)

3. Communication Interfaces

- BLE (Bluetooth Low Energy) for:
 - System status and last readings
 - File preview or selective retrieval
 - Configuration updates (e.g., wake interval, thresholds)
- USB serial (optional for debugging or local access)
- Future optional support for LoRa or mesh networking

4. File Structure and Format

- Files named by date or subsystem, e.g., env_20250410.csv
- Example log entry:

2025-04-10T18:00:00Z, Temp: 34.7C, Hum: 62.1%, Pressure: 1012.3 hPa, Status: Nominal

- Log files rotated daily or weekly to prevent overflow
- Optional compression or deletion based on storage capacity

5. Configuration and Updates

- Config file stored on SD card or updated via BLE

- Editable parameters:
 - Wake interval (1, 5, 10, 30, 60 minutes)
 - Alert thresholds (temp, humidity, etc.)
 - Logging options (frequency, format)
- Optional OTA update pathway using BLE or USB serial

6. Data Retrieval and Future Expansion

- BLE app for basic interaction and download (planned)
- SD card may be removed and accessed via PC or uploader
- Future expansion:
 - Web dashboard with chart visualizations
 - Upload pipeline for researchers to central database
 - MQTT or HTTP push from gateway (if connectivity is added)