Smart Beehive Monitoring System - Wiring Guide

System Overview

This IoT beehive monitoring system tracks multiple environmental parameters and bee activity to provide comprehensive hive monitoring. The system features:

- **Environmental monitoring** (temperature, humidity, pressure, VOCs)
- **Bee activity tracking** (IR-based entrance monitoring)
- **Weight monitoring** (load cell-based)
- **Predator/motion detection** (PIR sensor)
- **Location tracking** (GPS module)
- **Solar-powered operation** with battery backup
- **Real-time data** transmission to Firebase database
- **Web-based dashboard** for beekeepers

ESP32 Pin Assignments

ESP32 Pin	Connection	Component	Notes
3.3V	VCC	BME680, ADS1115s, HX711, NEO-6M	Total current should not exceed 500mA
5V	VCC	HC-SR501 PIR	Supplied from USB or voltage regulator
GND	GND	All components	Common ground point
GPIO 21 (SDA)	SDA	BME680, ADS1115 modules	I2C data line (shared)
GPIO 22 (SCL)	SCL	BME680, ADS1115 modules	I2C clock line (shared)
GPIO 16 (RX2)	TX	NEO-6M GPS	GPS TX connects to ESP32 RX
GPIO 17 (TX2)	RX	NEO-6M GPS	GPS RX connects to ESP32 TX
GPIO 25	OUT	HC-SR501 PIR	With 10kΩ pull-down resistor
GPIO 32	DT	HX711	Data line for load cell
GPIO 33	SCK	HX711	Clock line for load cell
GPIO 34	Voltage divider	Battery monitoring	Through 47kΩ/10kΩ voltage divider
GPIO 35	OUT	TCRT5000 direct #9	Analog input (optional)
GPIO 13	Gate	2N7000 MOSFET	Optional sensor power control

Sensor Connections

BME680 Environmental Sensor

BME680 Pin	Connection	Notes
VCC	ESP32 3.3V	**NEVER connect to 5V** - will damage sensor
GND	ESP32 GND	Common ground
SDA	ESP32 GPIO 21	Connect 4.7kΩ pull-up resistor to 3.3V
SCL	ESP32 GPIO 22	Connect 4.7kΩ pull-up resistor to 3.3V

> **IMPORTANT**: Add a 0.1µF ceramic capacitor between VCC and GND near the sensor for noise suppression

ADS1115 ADC Modules for IR Sensors

ADS1115 #1 (Address 0x48)

ADS1115 #1 Pin	Connection	Notes
VDD	ESP32 3.3V	Power supply
GND	ESP32 GND	Common ground
SCL	ESP32 GPIO 22	Shared I2C bus
SDA	ESP32 GPIO 21	Shared I2C bus
ADDR	GND	Sets address to 0x48
A0	TCRT5000 OUT1	First IR sensor
A1	TCRT5000 OUT2	Second IR sensor
A2	TCRT5000 OUT3	Third IR sensor
A3	TCRT5000 OUT4	Fourth IR sensor

> **IMPORTANT**: Add a 0.1µF ceramic capacitor between VDD and GND near the module

ADS1115 #2 (Address 0x49)

ADS1115 #2 Pin	Connection	Notes
VDD	ESP32 3.3V	Power supply
GND	ESP32 GND	Common ground
SCL	ESP32 GPIO 22	Shared I2C bus
SDA	ESP32 GPIO 21	Shared I2C bus
ADDR	VDD	Sets address to 0x49
A0	TCRT5000 OUT5	Fifth IR sensor
A1	TCRT5000 OUT6	Sixth IR sensor
A2	TCRT5000 OUT7	Seventh IR sensor
A3	TCRT5000 OUT8	Eighth IR sensor

> **IMPORTANT**: Add a 0.1µF ceramic capacitor between VDD and GND near the module

TCRT5000 IR Sensor Array

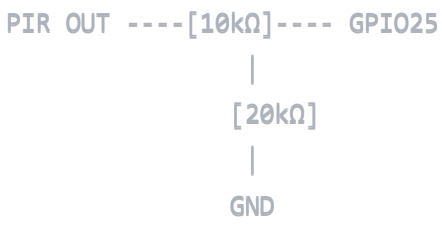
TCRT5000 Pin	Connection	Notes
VIN	ESP32 3.3V	Power for all sensors
GND	ESP32 GND	Common ground
OUT1-4	ADS1115 #1 A0-A3	First 4 sensors
OUT5-8	ADS1115 #2 A0-A3	Next 4 sensors
OUT9	ESP32 GPIO 34	Direct connection (optional)
OUT10	ESP32 GPIO 35	Direct connection (optional)

> **NOTE**: Add 100-330Ω current-limiting resistors for each IR LED emitter if not already on the module

HC-SR501 PIR Motion Sensor

HC-SR501 Pin	Connection	Notes
VCC	ESP32 5V	Requires 5V for reliable operation
OUT	ESP32 GPIO 25	Via voltage divider (level shifting)
GND	ESP32 GND	Common ground

Level Shifting Voltage Divider



> **IMPORTANT**: Add a 0.1µF ceramic capacitor between VCC and GND near the sensor

HX711 Load Cell Amplifier

HX711 Pin	Connection	Notes
VCC	ESP32 3.3V	Power supply
GND	ESP32 GND	Common ground
DT (Data)	ESP32 GPIO 32	Data line
SCK (Clock)	ESP32 GPIO 33	Clock line
E+	Load Cell Red	Excitation +
E-	Load Cell Black	Excitation -
A+	Load Cell White	Signal +
A-	Load Cell Green	Signal -

> **IMPORTANT**:
> - Use shielded twisted pair cable between load cell and HX711 module
> - Connect shield to GND at HX711 end only
> - Add a 0.1µF ceramic capacitor between VCC and GND near the module

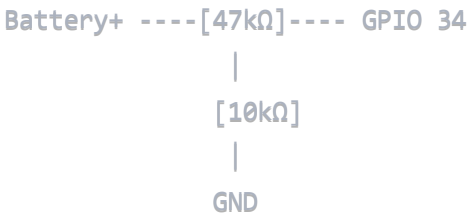
NEO-6M GPS Module

NEO-6M Pin	Connection	Notes
VCC	ESP32 3.3V	Power supply
GND	ESP32 GND	Common ground
TX	ESP32 GPIO 16 (RX2)	GPS TX connects to ESP32 RX
RX	ESP32 GPIO 17 (TX2)	GPS RX connects to ESP32 TX

> **IMPORTANT**: Add a 0.1µF ceramic capacitor between VCC and GND near the module

Power System

Battery Voltage Monitoring



> **IMPORTANT**: Add a 0.1µF ceramic capacitor in parallel with the 10kΩ resistor to filter noise

Solar Panel Connection

Component	Connection	Notes
Solar Panel +	1N5817 Schottky Diode Anode	For reverse polarity protection
Diode Cathode	TP4056 IN+	Connects to charging module
Solar Panel -	TP4056 IN-	Ground connection

TP4056 Charging Module

TP4056 Pin	Connection	Notes
IN+	Solar Panel + (via diode)	Input from solar panel
IN-	Solar Panel -	Input from solar panel
BAT+	Battery +	To 18650 positive terminal
BAT-	Battery -	To 18650 negative terminal
OUT+	MT3608 IN+	To boost converter input
OUT-	MT3608 IN- / System GND	Common ground

MT3608 Step-Up Module

MT3608 Pin	Connection	Notes
IN+	TP4056 OUT+	Input from battery/charger
IN-	TP4056 OUT-	Common ground
OUT+	ESP32 5V pin	Regulated 5V output
OUT-	System GND	Common ground

> **IMPORTANT**: Adjust MT3608 output to exactly 5V using its potentiometer

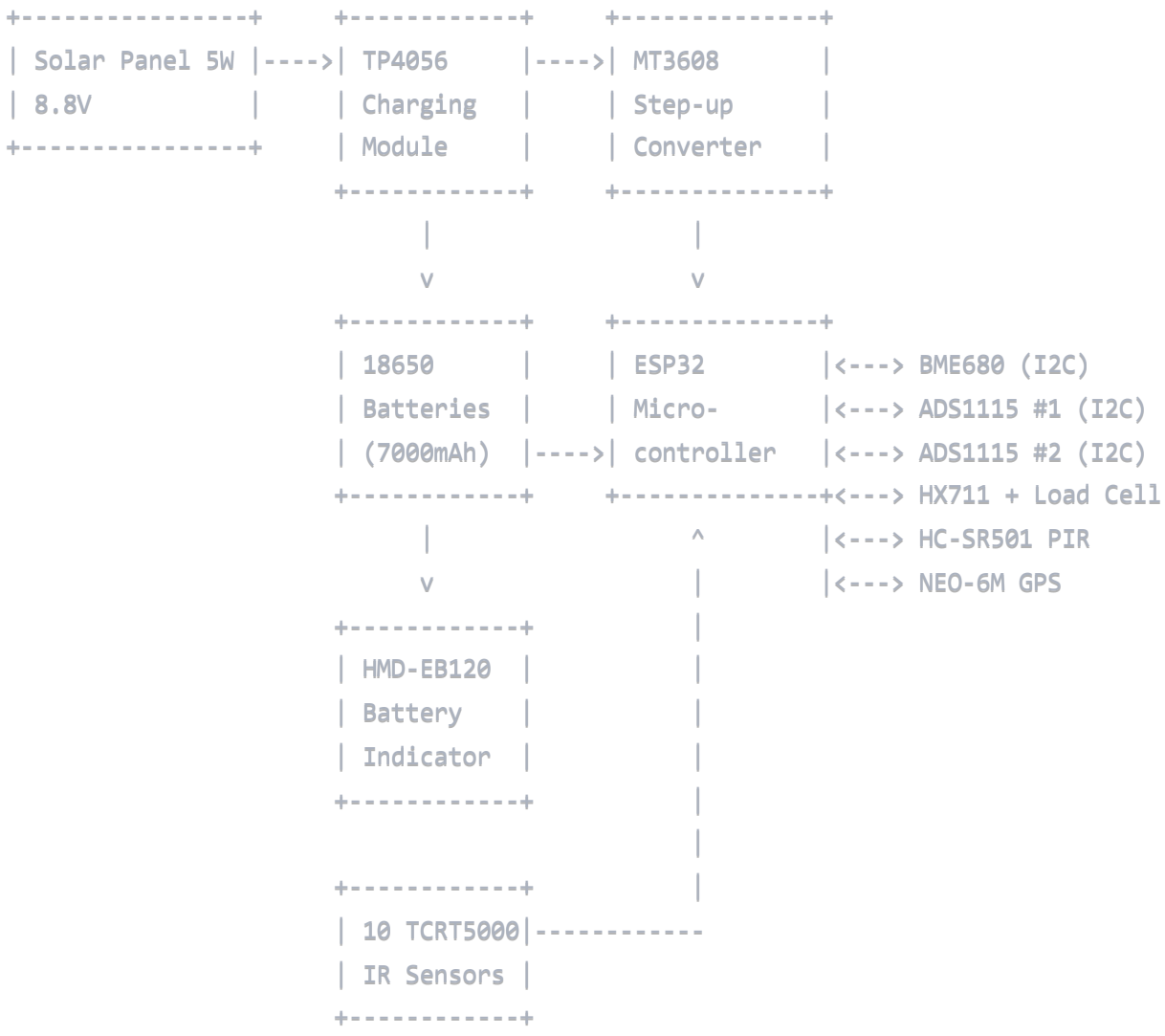
HMD-EB120 Battery Indicator

HMD-EB120 Pin	Connection	Notes
VCC	Battery +	Direct connection to battery
GND	Battery -	Direct connection to battery

Additional Components

Component	Quantity	Purpose	Placement
0.1µF ceramic capacitors	8	Noise suppression	One near each sensor's power pins
4.7kΩ resistors	2	I2C pull-up	Between 3.3V and SDA line, and 3.3V and SCL line
10kΩ resistor	1	Level shifting	Between PIR output and ESP32 GPIO25
20kΩ resistor	1	Level shifting	Between ESP32 GPIO25 and GND
47kΩ resistor	1	Voltage divider	Between battery positive and GPIO34
10kΩ resistor	1	Voltage divider	Between GPIO34 and GND
Shielded twisted pair cable	0.5m	Load cell connection	Between load cell and HX711 module
10µF electrolytic capacitor	1	Power stabilization	Across battery power input to ESP32
1N5817 Schottky diode	1	Reverse protection	In series with solar panel positive lead

System Connection Diagram



Important Notes

1. **I2C Bus Configuration**:
   - The 4.7kΩ pull-up resistors on SDA and SCL lines are critical for reliable I2C communication
   - All I2C devices (BME680, both ADS1115 modules) share the same SDA/SCL lines
   - Different I2C addresses allow multiple devices on same bus (0x48 and 0x49 for ADS1115s)

2. **Power Management**:
   - ESP32 3.3V pin can provide up to ~500mA - be careful of total power budget
   - Use the MT3608 step-up converter to provide clean 5V for the PIR sensor
   - Consider using GPIO13 to control power to sensors when not in use

3. **Voltage Level Considerations**:
   - ESP32 GPIO pins are NOT 5V tolerant - always use level shifters when needed
   - PIR sensor requires level shifting (10kΩ/20kΩ voltage divider)
   - ADS1115s safely bridge between analog sensors and digital ESP32

4. **Grounding**:
   - All components MUST share a common ground

- Star grounding topology helps minimize ground loops and noise

5. **Noise Reduction**:
   - Keep analog sensor wires away from power lines
   - Use decoupling capacitors (0.1µF) near each sensor's power pins
   - Use shielded cable for load cell signals to reduce noise
6. **Environmental Protection**:
   - All components should be mounted in a weatherproof enclosure
   - Protect against condensation with silica gel packets
   - Consider conformal coating for outdoor electronics
7. **Cable Routing**:
   - Route signal cables away from power cables
   - Minimize cable lengths where possible
   - Use cable strain relief at enclosure entry points

Calibration Notes

1. **Load Cell**:
   - After connecting, run calibration code with a known weight
   - Default calibration factor (424.9) will be adjusted during calibration
   - Store calibration factor in EEPROM for persistence across reboots
2. **TCRT5000 IR Sensors**:
   - Test with no bee activity to establish baseline readings
   - Set appropriate thresholds in software for accurate bee detection
   - Mount 2-3cm above hive entrance for optimal detection
3. **Battery Voltage**:
   - Verify actual battery voltage with a multimeter
   - Adjust the voltage divider ratio in software if needed
4. **GPS**:
   - Allow up to 5 minutes for first GPS fix
   - Place antenna with clear sky view for best reception

Troubleshooting

1. **Poor I2C Communication**:
   - Verify pull-up resistors are installed correctly
   - Check I2C addresses match in code and hardware

- Keep I2C cables short (<30cm ideally)

2. **Load Cell Errors**:
   - Check shielding connection (ground at HX711 end only)
   - Verify correct color-coded wire connections
   - Ensure stable mounting to prevent mechanical noise
3. **Intermittent Operations**:
   - Check power supply stability under load
   - Monitor battery voltage for drops during transmission
   - Verify all capacitors are installed correctly
4. **No GPS Signal**:
   - Check antenna connection and placement
   - Verify UART pins match in code and wiring
   - Allow sufficient time for first fix
5. **Low Solar Charging Rate**:
   - Verify solar panel produces expected voltage in sunlight
   - Check diode orientation and voltage drop
   - Ensure TP4056 is configured for correct battery type