Julian Imperial – Hardware Production Report

Table of Contents

Contents

1.0 Introducing the Broadcom development platform and existing functionality

The Broadcom development platform that was used was the Raspberry Pi 4 Model B board, here are some of its features and specifications, along with the Sense hat that it comes with.

It is built around the Broadcom BCM2711 System on Chip (SoC), which integrates a quad-core ARM Cortex-A72 (ARM v8) 64-bit processor operating at 1.5 GHz. Compared to its predecessors, this model delivers significantly higher processing performance, expanded memory options, and enhanced connectivity, making it a suitable platform for projects requiring real-time data processing, hardware interfacing, and multimedia support.

Key hardware features of the Raspberry Pi 4 Model B include:

- Quad-core ARM Cortex-A72 CPU @ 1.5 GHz
- Variants with 2 GB, 4 GB, or 8 GB LPDDR4-3200 SDRAM
- Broadcom VideoCore VI GPU with support for OpenGL ES 3.0 and dual 4K video output
- Gigabit Ethernet, dual-band 802.11ac Wi-Fi, and Bluetooth 5.0

- Two USB 3.0 ports and two USB 2.0 ports for peripheral connectivity
- Dual micro-HDMI ports supporting up to 4Kp60 video output
- 40-pin GPIO header supporting digital I/O, I^2C, SPI, UART, and PWM
- Camera Serial Interface (CSI) and Display Serial Interface (DSI) ports
- microSD card slot for operating system and file storage
- USB-C power input (5V DC, 3.0A recommended)

The **Raspberry Pi Sense HAT** includes:

- **9-DOF IMU (Inertial Measurement Unit):**
    - Gyroscope
    - Accelerometer
    - Magnetometer (compass)
- **Environmental sensors:**
    - Temperature
    - Humidity
    - Barometric pressure
- **8×8 RGB LED matrix** for display output
- **Joystick** for basic input

2.0 Added functionality

In addition to the Raspberry Pi 4 Model B and Sense HAT, a custom printed circuit board (PCB) was incorporated into the project to improve compatibility with external sensors. The PCB was designed using **KiCad**, where the schematic was developed, signal connections were defined, and the Raspberry Pi GPIO pin configurations were assigned.

The purpose of this PCB was to integrate the **SEN0189 turbidity sensor** and the **ADS1015 analog-to-digital converter** into a stable and reproducible hardware platform. Since the Raspberry Pi does not feature native analog input, the ADS1015 was required to digitize the SEN0189 sensor's analog voltage output. The custom PCB consolidated these components into a single board, reducing wiring complexity, minimizing noise, and ensuring that the sensors could be interfaced with the Raspberry Pi through the I^2C protocol.

This added functionality extends the sensing capabilities of the Raspberry Pi beyond the onboard sensors provided by the Sense HAT, enabling measurement of water turbidity in real time. The integration of the custom PCB lays the foundation for the hardware assembly and firmware development described in the following sections.

2.1 Sensor/Effector purchase

Component	Description	Supplier	Part Number/Link	Purpose in Project
SEN0189 Turbidity Sensor	Measures water cloudiness by detecting light transmission and scattering in liquid. Outputs an analog voltage proportional to turbidity.	DFRobot / Amazon	SEN0189	Provides real-time turbidity measurements of water samples.
ADS1015 Analog-to-Digital Converter (ADC)	12-bit precision ADC with I^2C interface. Converts analog signals from sensors into digital values readable by Raspberry Pi.	Adafruit / Digi-Key	ADS1015	Enables the Raspberry Pi to read the analog voltage output from the SEN0189 turbidity sensor.
Custom PCB (Fabricated)	Designed using KiCad to host and	Humber PCB Creation	–	Provides stable wiring, GPIO routing,

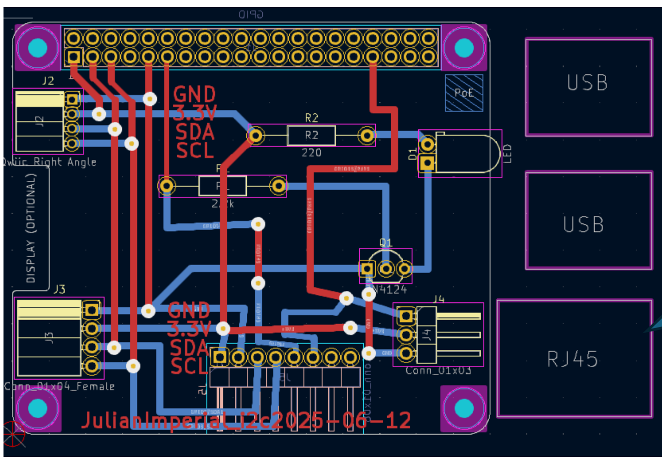
Component	Description	Supplier	Part Number/Link	Purpose in Project
	interconnect the SEN0189 and ADS1015.			and I^2C connections to the Raspberry Pi.

Component	Description	Supplier	Part Number / Link	Purpose in Project	Unit Price
Stacking Header	**Raspberry Pi stacking header for connecting PCB to Pi GPIO pins.**	**Adafruit Industries**	**1979**	**Provides mechanical and electrical connection to Pi GPIO.**	**$4.29**
4-Pin STEMMA / Grove Cable	**Cable for connecting I^2C devices to PCB.**	**Adafruit Industries**	**4528**	**Connects ADC or other I^2C devices to custom PCB with minimal wiring.**	**$2.83**
Flexible Qwiic Cable	**Flexible I^2C cable for routing signals on PCB.**	**SparkFun Electronics**	**CAB-22726**	**Enables flexible sensor connections between PCB and Pi.**	**$2.32**
Phillips Screws M2.5 x 4	**Screws for mounting PCB and components.**	**Essentra Components**	**50M025045I016**	**Secure custom PCB and sensors in enclosure.**	**$0.23**
STEMMA QT/Qwiic Cable 400mm	**Long cable for connecting distant sensors.**	**Adafruit Industries**	**5385**	**Connects PCB to Raspberry Pi or sensors at a distance.**	**$2.18**

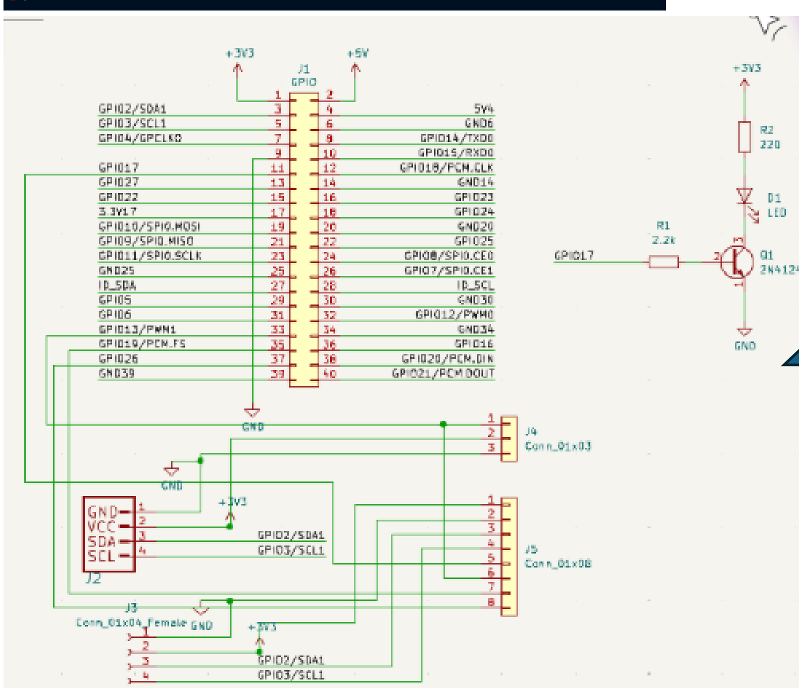
2.2 PCB design and soldering

Assembly was performed using hand soldering. Key components soldered included two resistors (2.2 kΩ and 220 Ω), a bipolar junction transistor (BJT), and the Qwiic connector to allow the ADS1015 to interface with the custom PCB. A **GPIO-style header** was soldered onto the PCB to provide pins corresponding to the Raspberry Pi's GPIO, enabling straightforward connections to the BJT, ADC, and other components. All vias were also carefully soldered to ensure reliable electrical connections between layers.

After soldering, the PCB was inspected to verify proper solder joints and continuity, confirming that power, ground, and I^2C signals were correctly routed. This ensured reliable communication between the Raspberry Pi and the sensors during testing.



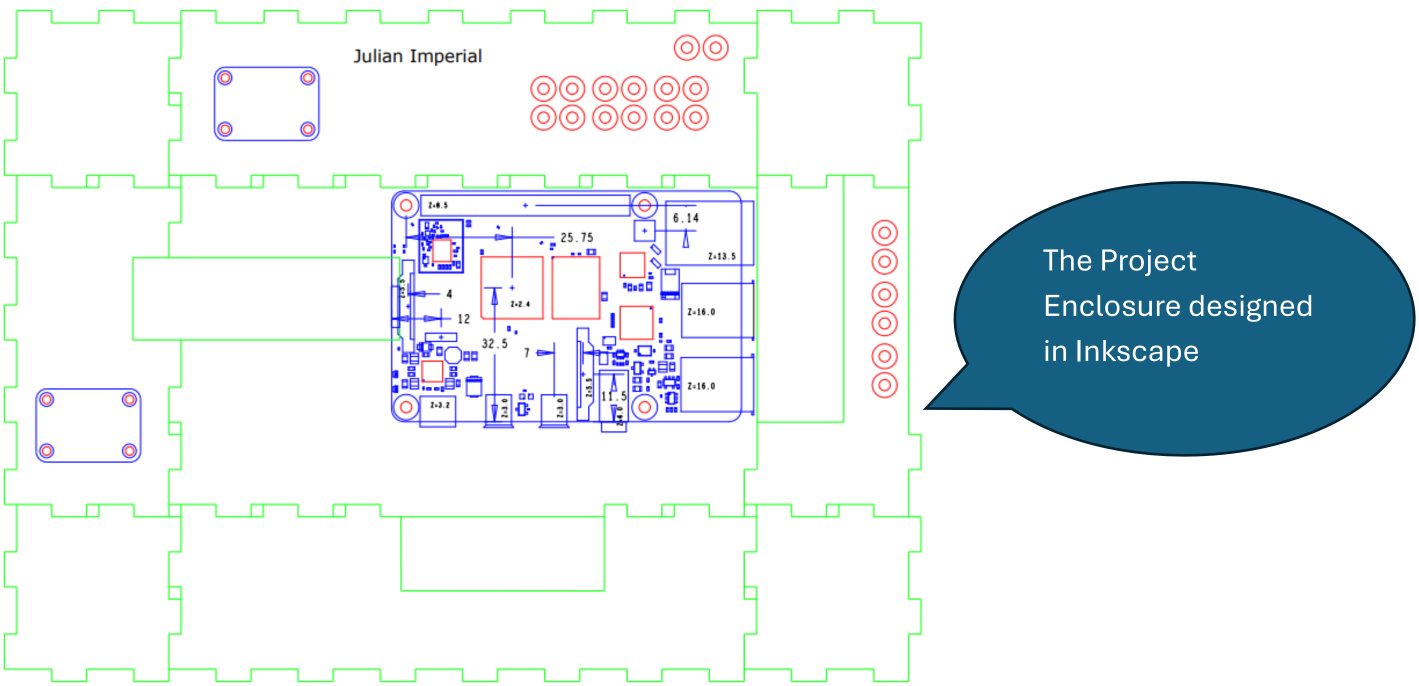
PCB Wiring and Design Schematic



The GPIO PCB Configuration Schematic

2.3 Case design and assembly

The enclosure was cut from 3 mm clear acrylic to house the custom PCB, ADC, and sensor connections. Eight donut-style spacers were used to support and align the PCB within the enclosure. The parts of the case were assembled using clear tape, ensuring that the PCB and components were held securely in place while maintaining access to the GPIO-style header and sensor connectors. Care was taken to align all openings to allow easy connection to the Raspberry Pi and external sensors.



2.4 Firmware development and use

Firmware for the Raspberry Pi was developed in Python to interface with the ADS1015 ADC, the SEN0189 turbidity sensor, and the Sense HAT for visual feedback. The program initializes I^2C communication with the ADC and continuously reads the analog voltage output from the turbidity sensor. These readings are then used to determine water quality, with a user-defined threshold indicating high turbidity.

The firmware employs multithreading to handle multiple tasks simultaneously:

- **Sensor reading thread:** Continuously reads voltage from the ADS1015 and prints timestamped turbidity measurements to the console.

- **Sense HAT visualization thread:** Provides real-time visual feedback, displaying red for poor water quality and green for clear water.
- **LED status thread:** Blinks a status LED connected via a GPIO-controlled BJT to indicate that the system is running.

GPIO pins are managed according to the custom PCB design, ensuring proper operation of the transistor controlling the LED. Error handling and cleanup routines ensure safe termination of the program, resetting the Sense HAT display, turning off the LED, and cleaning up GPIO resources. The firmware runs manually via a Python script, enabling easy testing and data collection during experiments.

3.0 Testing and Results

To verify proper operation of the system, several tests were conducted.

1. **I^2C Communication Test:** The Raspberry Pi's I^2C bus was scanned using the i2cdetect -y 1 command, confirming that the ADS1015 ADC was correctly connected and detected at its expected address 0x48.
2. **Firmware Functionality Test:** The Python firmware was executed, and sensor readings were monitored in real time. The turbidity sensor's output was tested with both clear and murky water samples. Measurements corresponded appropriately to water clarity, demonstrating that the system could differentiate between low and high turbidity.
3. **Sensor Sensitivity Adjustment:** The SEN0189 turbidity sensor includes a potentiometer for sensitivity adjustment. The potentiometer was tuned to achieve optimal voltage response for the water samples being tested, ensuring that high turbidity was reliably detected while clear water produced a stable low reading.
4. **Visual and LED Feedback:** The Sense HAT correctly displayed red for murky water and green for clear water. The GPIO-controlled status LED blinked as expected, confirming proper integration of the PCB and transistor circuit.

Overall, the system functioned as designed, with accurate turbidity detection, responsive visual feedback, and reliable I^2C communication between the Raspberry Pi and ADS1015.

4.0 References

Footnotes

1. Technology Report Guidelines. OACETT, Revised September 2022. Available at: https://www.oacett.org/getmedia/5ad707d7-f472-4b24-a7fe-f34e270b0c41/2022_TR_Guidelines_-_Updated_Version_-_Sept_2022.pdf ↩
2. DFRobot. (2017). *Turbidity sensor SKU: SEN0189*. Retrieved from https://media.digikey.com/pdf/data%20sheets/dfrobot%20pdfs/sen0189_web.pdf
3. Adafruit Industries. (n.d.). *ADS1015 12-Bit ADC - 4 Channel with Programmable Gain Amplifier*. Retrieved August 20, 2025, from https://cdn-shop.adafruit.com/datasheets/ads1015.pdf