

pH Sensor

The pH sensor provides water quality measurement critical for environmental monitoring and anomaly detection.

Hardware Specifications

Parameter	Value
Model	DFRobot SEN0161 (Analog pH meter)
Interface	Analog ADC
Reference Voltage	3.3V or 5.0V (configurable)
Output Range	0-5V analog
Measurement Range	0-14 pH units
Accuracy	±0.1 pH @ 25°C
Sample Rate	Configurable (40 samples for averaging)

Calibration Model

The sensor uses linear voltage-to-pH conversion:

$$\text{pH} = (\text{Voltage} / \text{Reference_Voltage}) \times \text{Slope} + \text{Offset}$$

Default Parameters for SEN0161 @ 25°C:

- **Slope:** 3.5
- **Offset:** Variable (user calibration)

Data Structure

```
typedef struct {  
    // Raw ADC Reading  
    uint16_t raw_value;           // Raw ADC value
```

```

// Calculated Values
float voltage;           // Converted voltage (0-5V)
float ph_value;         // Calculated pH (0-14)
float reference_voltage; // ADC reference (typically 3.3V or 5.0V)

// Calibration Parameters
ph_calibration_t calibration; // { offset: float, slope: float }

// Averaging Buffer (Noise Filtering)
uint16_t sample_buffer[40]; // Last 40 samples
uint8_t sample_index;       // Current position in buffer
uint8_t samples_collected; // Total samples collected (0-40)
} ph_sensor_t;

```

Initialization & Usage

Initialize pH Sensor

```

ph_sensor_t ph_sensor;
ph_sensor_init(&ph_sensor, 3.3f); // 3.3V reference voltage

```

Poll pH Sensor

```

result_t ph_result = poll_ph_sensor(&ph_sensor);

if (ph_result == RESULT_OK) {
    float ph_value = ph_sensor.ph_value;
    float voltage = ph_sensor.voltage;
}

```

Manual Sample Addition

```

// For manual sampling at regular intervals
uint16_t adc_reading = 2048; // Example ADC value
ph_sensor_add_sample(&ph_sensor, adc_reading);

```

Validation

```
result_t validate_ph_value(float ph_value);  
// Returns RESULT_OK if 0 <= ph_value <= 14  
// Returns RESULT_ERR_INVALID_DATA otherwise
```

Sample Averaging Strategy

Parameter	Value
Sample Buffer Size	40 samples
Method	Circular buffer moving average
Purpose	Noise filtering and stable readings
Typical Update Latency	40ms-800ms

Averaging Algorithm

1. ADC sample added to circular buffer
2. All 40 samples averaged together
3. Averaged value converted to voltage
4. Voltage converted to pH via calibration

Two-Point Calibration Procedure

Step 1: Neutral Point (pH 7.0)

1. Immerse electrode in pH 7.0 buffer solution
2. Wait for stable reading (~2 minutes)
3. Record voltage: V_{neutral}
4. Calculate offset adjustment

Step 2: Slope Calibration (pH 4.0 or 10.0)

1. Immerse electrode in second known pH solution
2. Wait for stable reading
3. Record voltage: $V_{\text{reference}}$
4. Calculate slope from two points:
$$\text{slope} = (\text{pH}_{\text{reference}} - 7.0) / (V_{\text{reference}} - V_{\text{neutral}})$$

Protobuf Message Format

```
message SensorBoardPHInfo {  
    float ph_value;  
    float voltage;  
    SensorState state;  
    PHErrorCode error_code;  
}  
  
enum PHErrorCode {  
    PH_NO_ERROR = 0;  
    PH_COMMUNICATION_FAILURE = 1;  
    PH_INVALID_DATA = 2;  
}
```

Error Handling

```
if (ph_result == RESULT_ERR_UNIMPLEMENTED) {  
    // Hardware not connected  
    diagnostics.ph_sensor.state = SensorState_SENSOR_IDLE;  
    diagnostics.ph_sensor.error_code = PHErrorCode_PH_COMMUNICATION_FAILURE;  
} else if (ph_result == RESULT_OK) {  
    if (validate_ph_value(ph_sensor.ph_value) == RESULT_OK) {  
        diagnostics.ph_sensor.state = SensorState_SENSOR_OPERATING;  
        diagnostics.ph_sensor.error_code = PHErrorCode_PH_NO_ERROR;  
    } else {  
        // Invalid data from sensor (out of 0-14 range)  
        diagnostics.ph_sensor.state = SensorState_SENSOR_ERROR;  
        diagnostics.ph_sensor.error_code = PHErrorCode_PH_INVALID_DATA;  
    }  
}
```

Integration Notes

- Single sensor instance in main application
- Updates transmitted to network at main loop interval (5 seconds default)
- Temperature compensation not currently implemented (assumes $\sim 25^{\circ}\text{C}$)
- Sample averaging reduces noise but introduces $\sim 40\text{ms}$ latency per update
- Electrode response time: $\sim 100\text{-}300\text{ms}$ depending on pH change magnitude

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