

Wireless Water Quality Monitoring System

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Introduction

Several industries such as beverage production, pharmaceutical plants, waste water treatment plants, and so on, rely on water quality monitoring systems to measure and control important water quality indicators. Parameters defining physical, chemical, and biological characteristics of water can be used as water quality indicators. Examples include:

- ▶ Physical: temperature and turbidity
- ▶ Chemical: pH, oxidation reduction potential (ORP), conductivity, and dissolved oxygen
- ▶ Biological: algae and bacteria

The article focuses on chemical measurement parameters that have been historically indispensable and unreliable, posing an implementation burden. Electrochemistry is a branch of chemistry that characterizes the behavior of reduction-oxidation (redox) reactions by measuring the transfer of electrons from one reactant to another. Electrochemical techniques can be used directly or indirectly to detect and measure example water quality indicators previously listed. An electrochemical measurement system consists of two main blocks:

- ▶ Sensor: a device used to measure a water quality indicator and generate a corresponding electrical signal.
- ▶ Measurement and processing unit: circuitry that measures and processes the electrical signal.

Typically, individual wired sensors are deployed across the processing plants. The in-field sensors need to be cleaned and calibrated frequently and replaced often. Wireless networks could reduce some of this burden, yet they are not typically considered robust enough to deploy in the harsh environments of these applications.

In process, high reliability wireless sensing networks are now possible with new measurement and networking technologies. This article describes a demonstration platform that combines the universal sensor interface capability of the [ADuCM355](#) and the wire-like reliability of Analog Devices' [SmartMesh](#)® IP technology to form a robust and low power, wireless water quality monitoring

system focused on pH measurement as the example water quality indicator. The principle can readily be extended to other electrochemical parameters to form a suite of water quality measurements for each wireless sensing node.

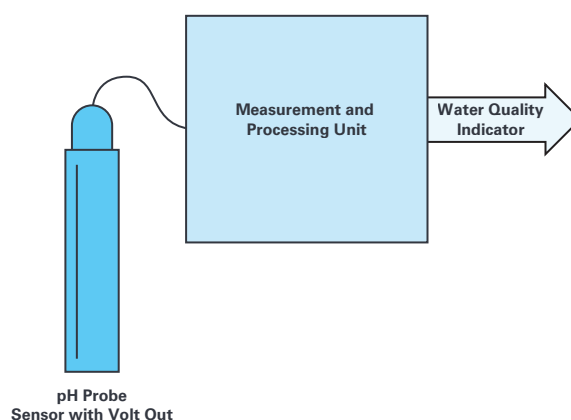


Figure 1. Typical electrochemical measurement system.

pH Measurement and pH Probe

The pH value is a measure of the relative amount of hydrogen and hydroxide ions in an aqueous solution. A neutral solution is one in which the hydrogen ion concentration exactly equals the hydroxide ion concentration. pH is another way of expressing the hydrogen ion concentration, measuring acidity or basicity of the solution, and is defined as:

$$pH = -\log_{10}(H^+) \quad (1)$$

Where H^+ is the hydrogen ion concentration in mol/liter.

The pH value of a solution ranges from 0 to 14, with a neutral solution having a pH of 7, an acidic solution having a pH less than 7, and an alkaline solution having a pH greater than 7.

The pH probe is an electrochemical sensor consisting of a glass electrode and a reference electrode.

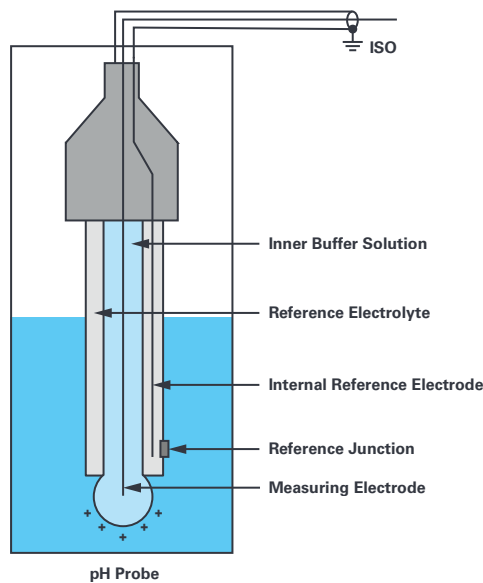


Figure 2. pH probe.

When the pH probe is inserted in the solution, the measuring electrode generates a voltage that depends on the hydrogen ion activity of the solution, which is then compared to the potential of the internal reference electrode. The difference between the measuring and reference electrode is the measured potential and is expressed in the Nernst equation as:

$$E = a - \frac{2.303 R(T + 273.1)}{nF} \times (pH - pH_{ISO}) \quad (2)$$

Where:

E is the voltage of the electrode with unknown activity

a = ±30 mV, zero point tolerance

T is the ambient temperature in °C

n = 1 at 25°C, valence (number of charges on ion)

F = 96485 coulombs/mol, Faraday constant

R = 8.314 volt-coulombs/°K mol, ideal gas constant

pH = the hydrogen ion concentration of an unknown solution

pH_{ISO} = hydrogen ion concentration of the reference electrolyte; consult the probe documentation; typical pH_{ISO} = 7

The equation indicates generated voltage that varies with the pH in a known manner. It also shows that the generated voltage is directly proportional to the temperature of the solution. As the solution temperature increases, the potential difference between two electrodes increases and vice-versa. An ideal pH probe produces ±59.154 mV/pH units at 25°C.

Change in temperature can also change the sensitivity of the measuring electrode, which in turn causes measurement error. This error is predictable and can be accounted for by calibrating the probe across temperature, and then correcting for temperature during subsequent measurements. Typically, a temperature sensor is integrated into the pH probe. The temperature sensor could be a negative temperature coefficient (NTC) thermistor or RTD such as PT100 or PT1000. A pH probe with a temperature sensor is shown in Figure 3.

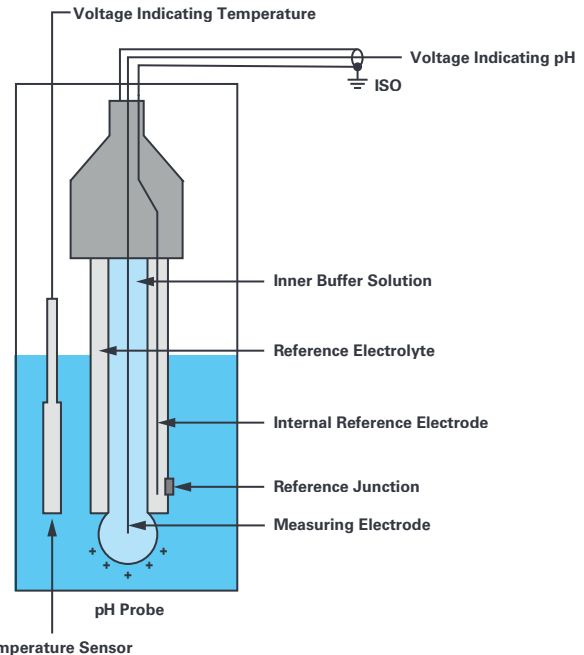


Figure 3. pH probe with temperature sensor.

If the temperature sensor measures change in temperature, the correction factor is applied to the final pH reading, and the meter then shows a corrected and more accurate reading. This mechanism works well to compensate for any error in pH that can arise due to temperature variations.

pH Measurement Unit with ADuCM355

ADuCM355 is the industry's most advanced and highly integrated chemical sensor measurement front end provides a platform solution for pH measurement with all the necessary measurement functions integrated with a low power microprocessor. The ADuCM355 enables a very low power measurement platform in a small form factor, making it small enough to be implemented inside the sensor housing while providing the capability and performance of benchtop instruments. Figure 4 shows ADuCM355's pH measurement board with BNC and RCA connectors for pH probe and temperature sensor connections. This board is from the [CN-0428](#) reference design, and more details about the board can be seen in Figure 5.

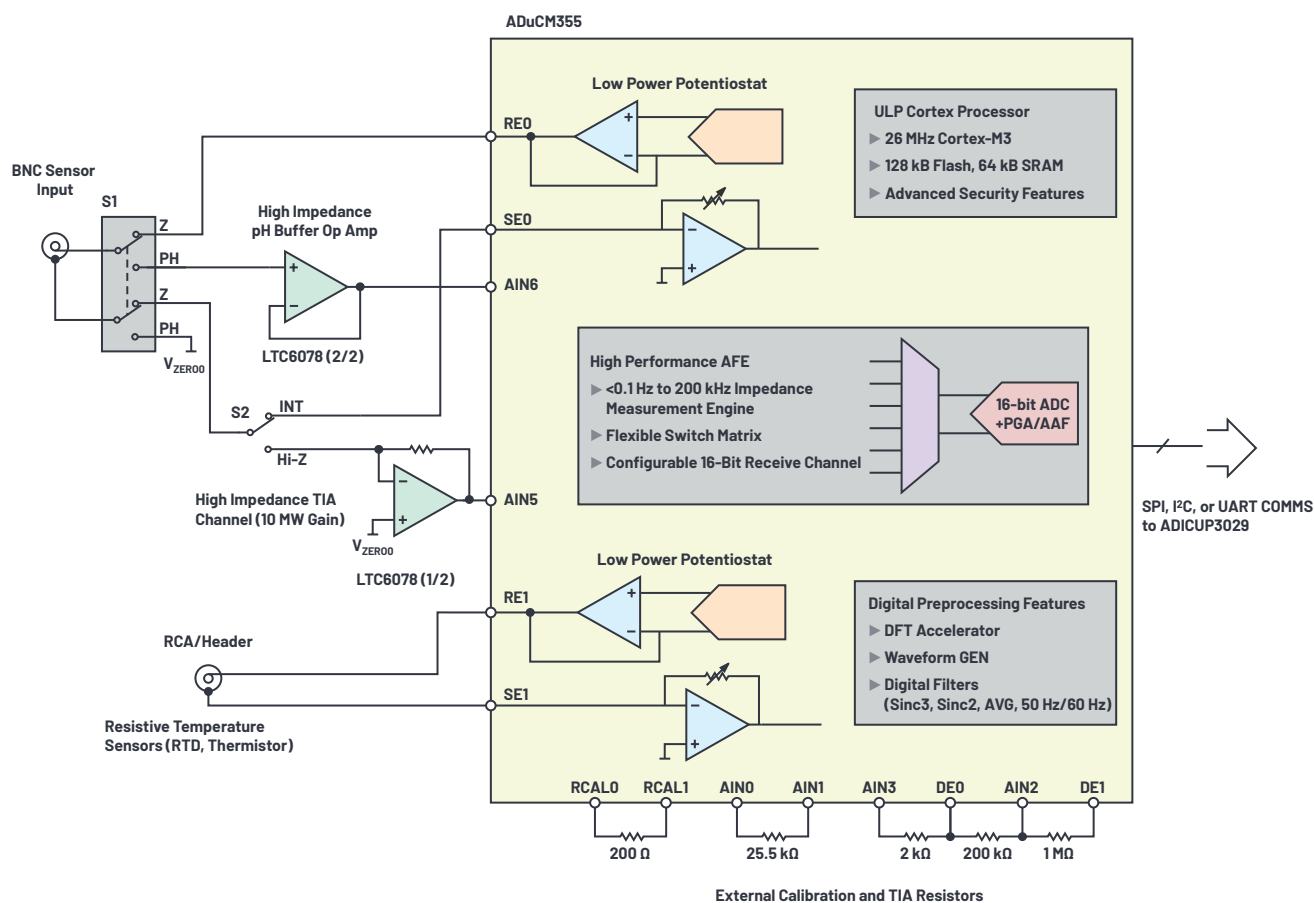


Figure 4. pH probe with integrated temperature sensor connected to ADuCM355.

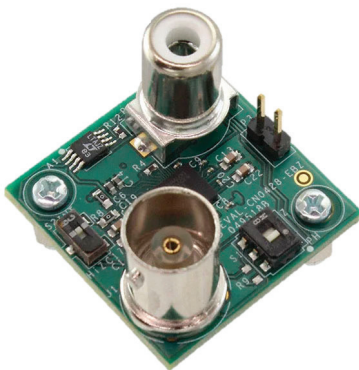


Figure 5. ADuCM355 pH measurement PCB with BNC and RCA connectors.

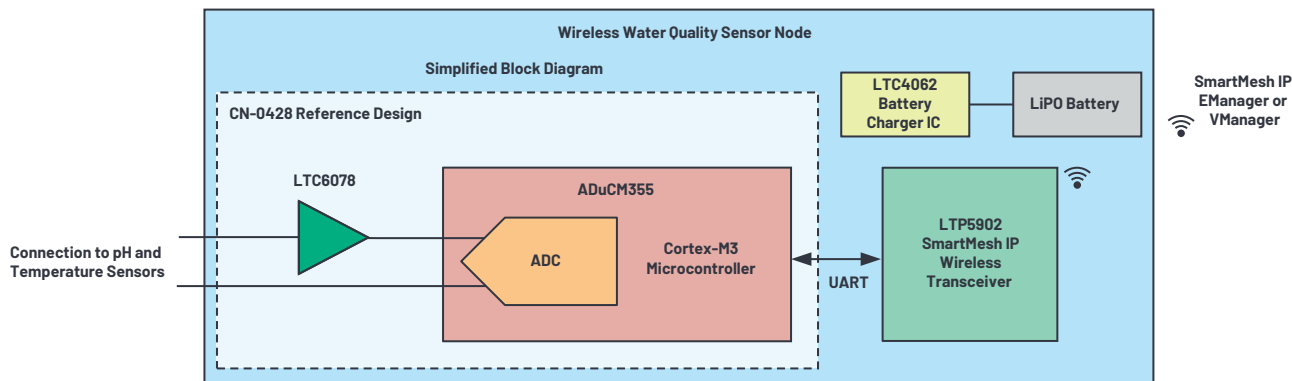


Figure 6. pH sensor connected to the ADuCM355 and the SmartMesh wireless sensor node.

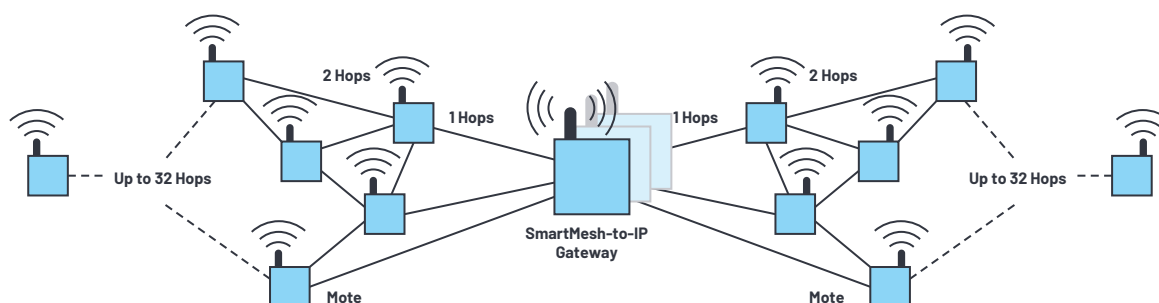


Figure 7. SmartMesh network with sensor nodes and network IP manager within the gateway.

Connecting pH Measurement Sensor Node to SmartMesh

By combining the ADuCM355 with an Analog Devices SmartMesh transceiver, we created a small, low power pH measurement sensor node. The ADuCM355 provides measured pH data as a digital output. This digital data is then connected via UART to Analog Devices' LTP5902 SmartMesh IP wireless transceiver. The LTP5902 transmits digital data over SmartMesh network to the SmartMesh IP manager.

SmartMesh is Analog Devices' proprietary 2.4 GHz multihop wireless mesh networking solution based on IEEE 802.15.4e standards. It includes AES 128 encryption and authentication, providing robust end-to-end security. It is ultra low power and energy efficient, enabling each sensor node to run on batteries.

SmartMesh networks communicate using a time slotted channel hopping (TSCH) link layer, which provides triple-play redundancy. The SmartMesh network manager (part of the gateway) coordinates the schedule, manages security, performs over-the-air programming (OTAP), and automatically optimizes connectivity 24 hours a day, 7 days a week. The network manager also provides detailed network health reports via an API. For small networks, one embedded manager can support up to 100 sensor nodes (also called motes). Truly enormous installations of up to 50,000 nodes are supported with VManager.

Rigorous network stress testing ensures >99.999% data reliability, making SmartMesh the perfect solution for industrial wireless sensor networks that must maintain high network availability and not lose packets.

Wireless Water Quality Monitoring System:

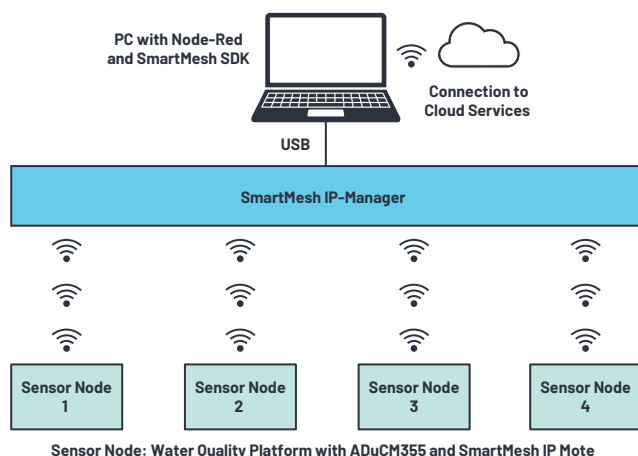


Figure 8. Wireless water quality monitoring system using ADuCM355 and SmartMesh.

The wireless water quality network demonstration as shown in Figure 8 consists of:

- Four sensor nodes:
 - Each sensor node consists of an off-the-shelf glass electrode pH probe with an integrated temperature sensor connected to ADuCM355 and SmartMesh IP mote as shown in Figure 6.
 - The pH probe senses the pH, ADuCM355 performs the measurement and calculations, and provides measured pH in digital output, which is then transferred over the wireless SmartMesh network to the SmartMesh IP manager.
 - SmartMesh IP manager connected via USB to the PC.
- A gateway in this system is performed by a PC. This PC has Node-Red and SmartMesh SDK installed. The SmartMesh SDK is used to create a JavaScript object notation (JSON) server for the data, which is connected to Node-RED. Node-RED is used to display measured pH data from each sensor node and allows connection to cloud services like IBM Watson, Amazon AWS, etc.

Hardware Setup



Figure 9. Wireless water quality network.

For demonstration purpose, we are using a staggered three chamber fish tank with water flowing from the top to subsequent chambers. A pH sensor probe is immersed in each chamber. We have a fourth sensor placed in a reference solution at a distance (not shown in Figure 9) to illustrate SmartMesh wireless communication over distance. As we change the pH of the solution in the top chamber, the data on Node-RED is updated, indicating a new pH. As this new pH

solution flows from the top to subsequent chambers, the other two pH sensors update their measurements and the data is displayed on the screen. Since the fourth sensor is immersed in a reference solution with no pH change, the readings from this sensor are constant. More information on Node-RED and measured data is provided in following sections. You can also view the demo recording [here](#).

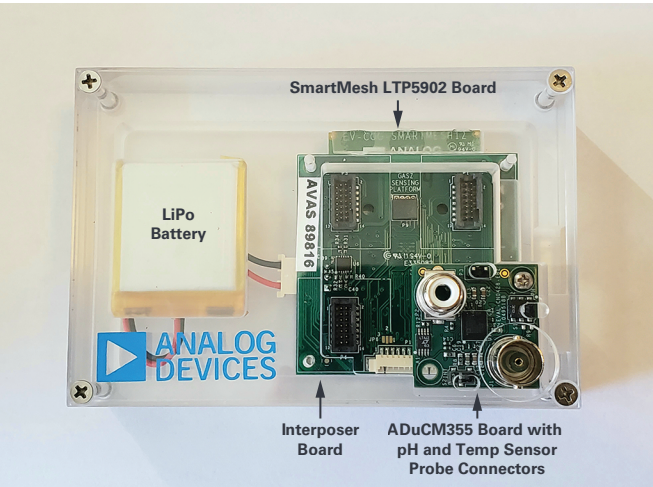


Figure 10. Sensor node.

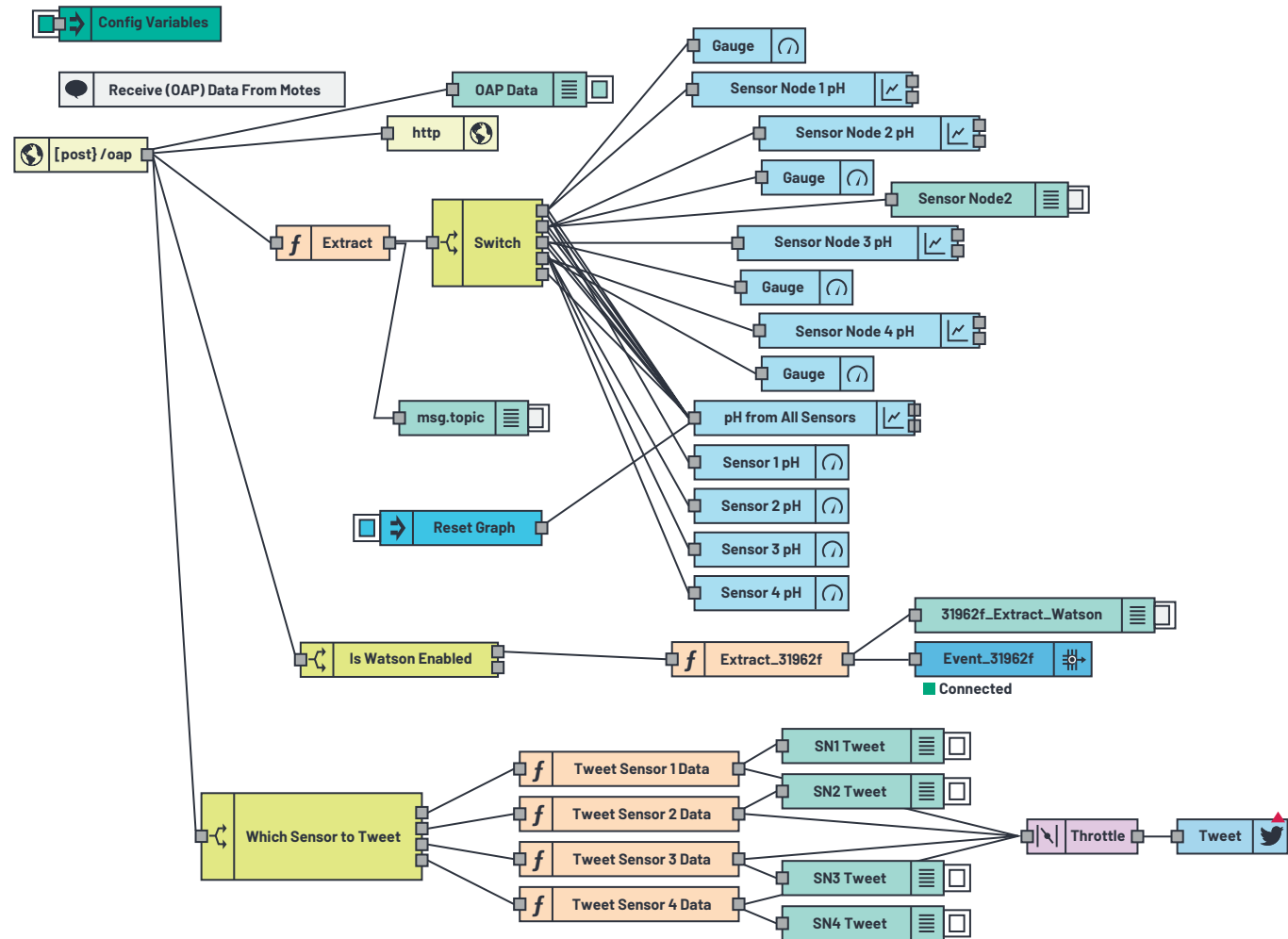


Figure 11. JSON flow.

Measurement Data:

pH measurement from 4 sensor nodes is displayed on the PC using Node-RED.

Node-RED is a programming tool with a web-based browser that allows connection of hardware devices, APIs, and other online services together. The JSON flow for the demo is displayed in Figure 11.

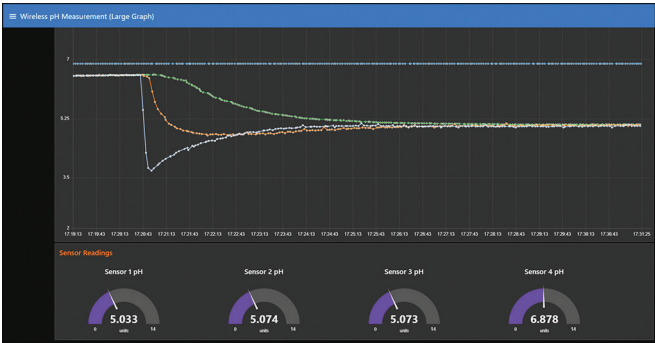


Figure 12. Wireless water quality demo dashboard.

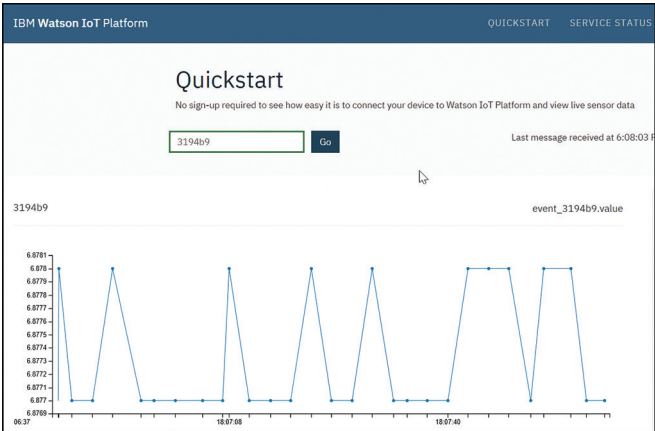


Figure 13. pH measurement data as displayed on IBM Watson.

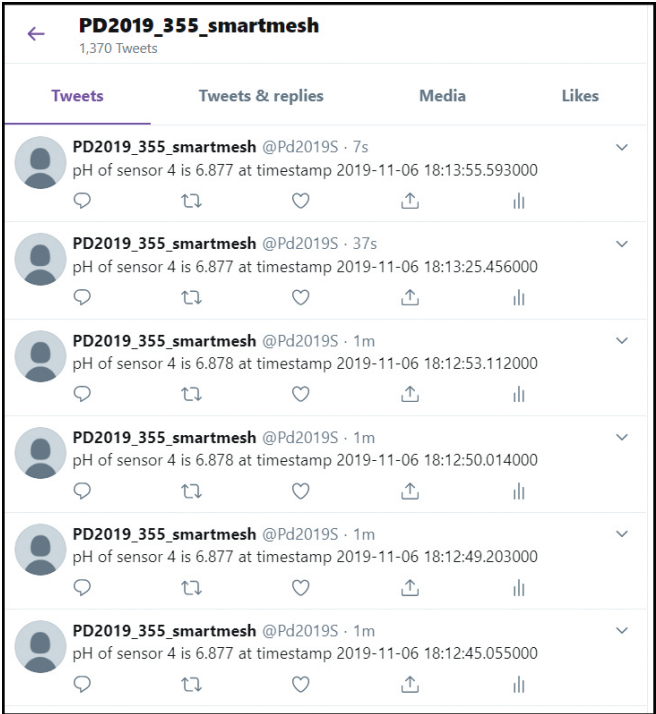


Figure 14. pH measurement data as a tweet.

Conclusion

This article describes the wireless water quality monitoring system using Analog Devices' ADuCM355 and SmartMesh IP technology. The small form factor and low power features of these products allow the sensor node to be powered by a battery. Robust SmartMesh technology reliably transfers data, even in harsh external environments. The demonstration illustrates a highly reliable wireless monitoring system and connectivity to cloud. This has tremendous potential depending on the end application, as this technology allows for monitoring of water quality at a location that is hard to reach, enables users to create alarms and warnings for different water quality thresholds, and leverages data to get more robust and better information about the continuous water quality.

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