IoT sensors kit for monitoring pollution of surface water bodies

AfricaConnect Meeting and Workshop on IoT-Based Acquisition of Research Data for Scientific Computing, Trieste, 21-25 October 2024

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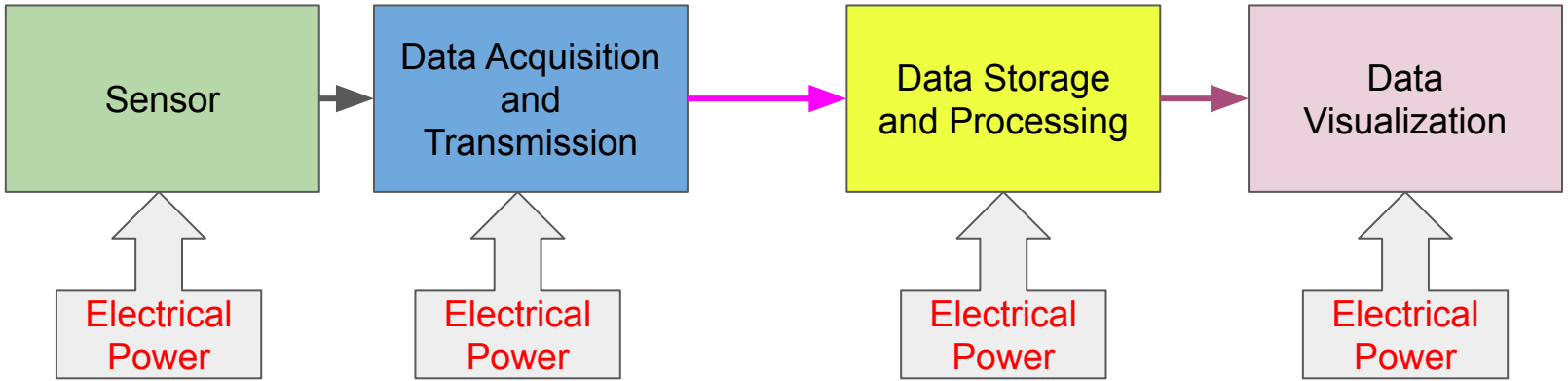
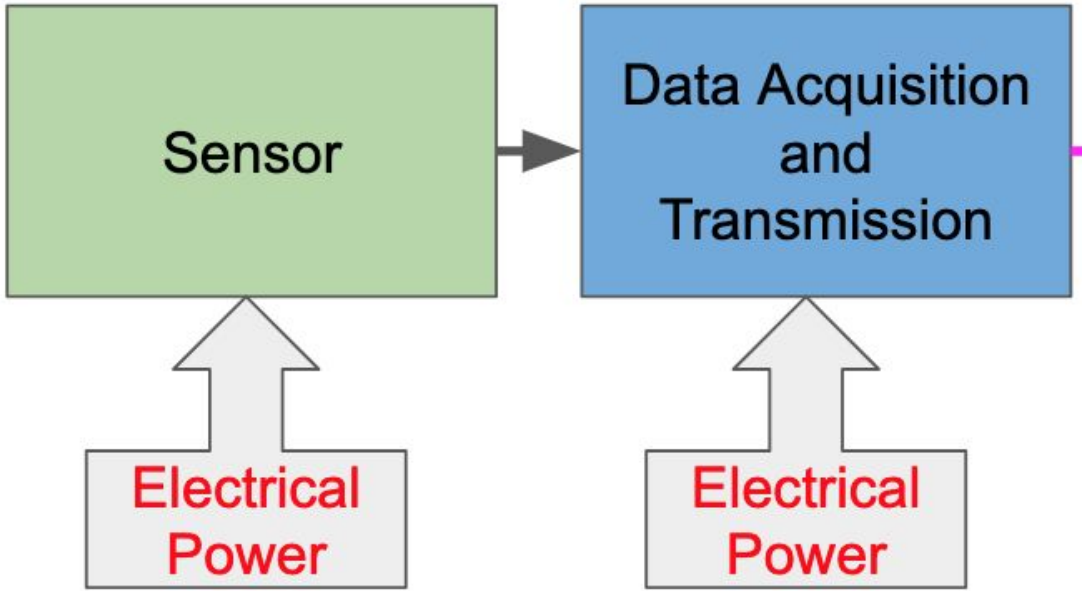
Science, Technology and Innovation unit

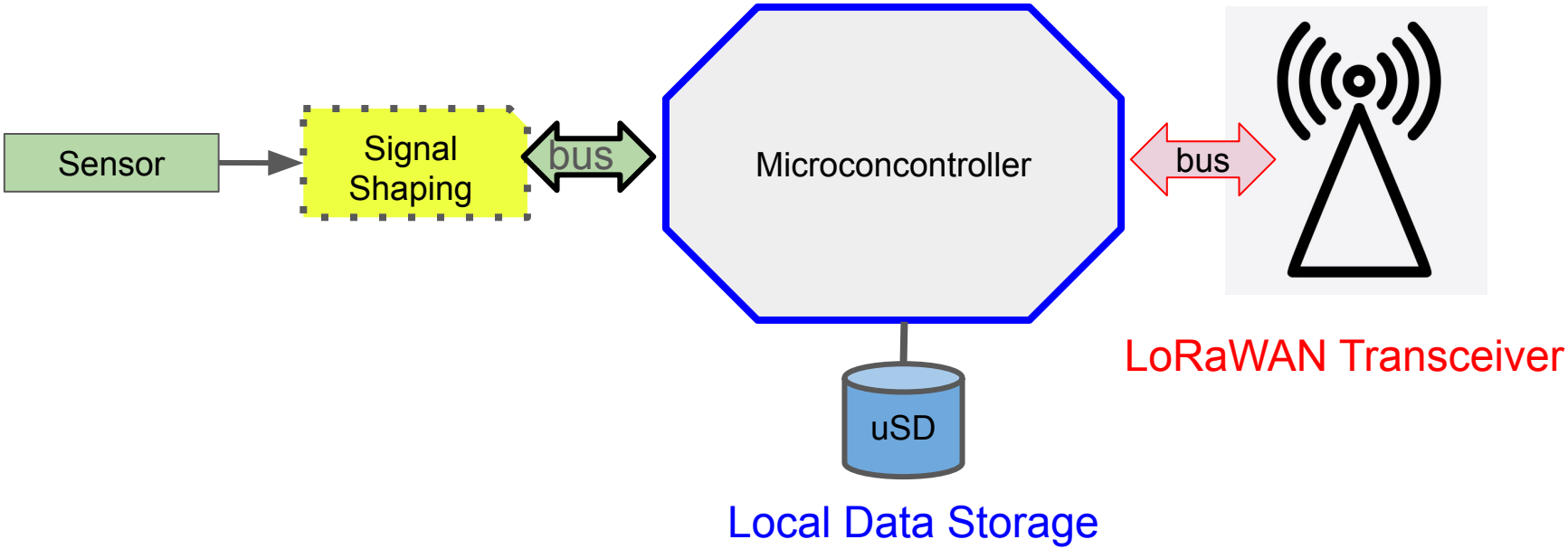
Synoptic view



Data collection and wired transmission



Data collection and wireless transmission



Sensors

Sensors convert the value of some physical variable to an electrical signal (current or voltage) change.

They are normally battery powered, but can also harvest energy from the surrounding environment.

Temperature sensors are very important because temperature affects the reading of most other sensors.

Sensor issues

Accuracy: How close is the measurement to the variable being measured

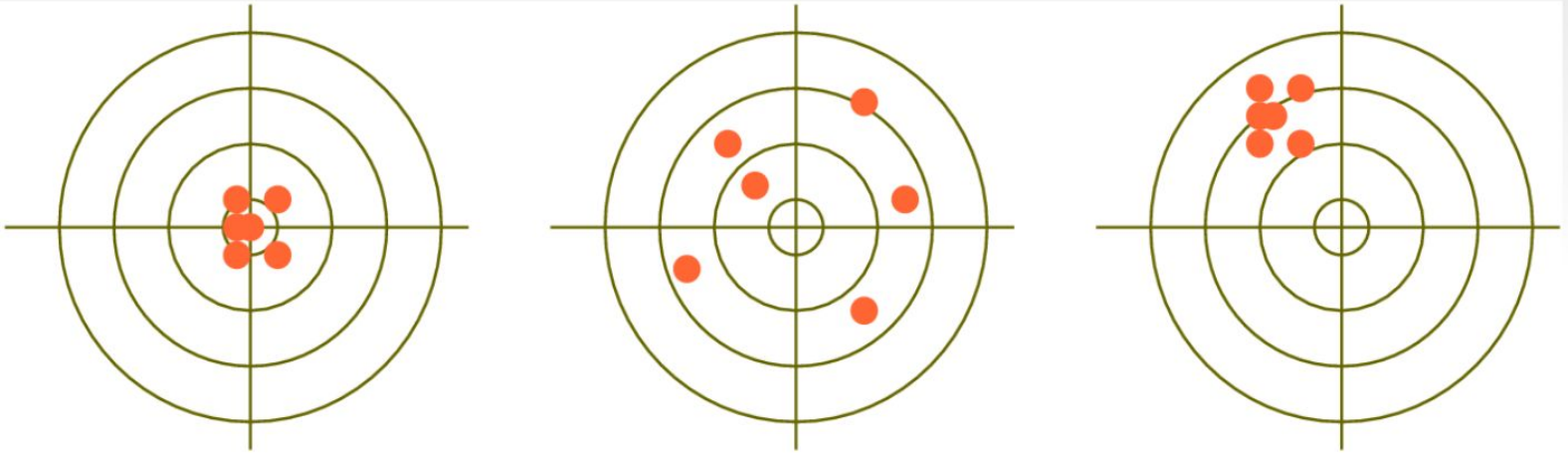
Precision: What is the uncertainty in the measurement

Range: Which value interval is measurable?

Sensitivity: Amount of the change in output for a given change in input

Resolution: Smallest amount of measurable change

Repeatability: Under the same conditions, can we get the same measurement?



Accurate,
Precise

(In)accurate,
Imprecise

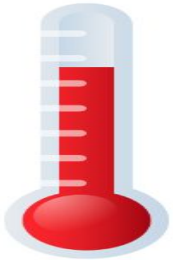
Inaccurate,
Precise

- Inaccurate but precise?
  - Metal ruler on a hot day: Same precision bad accuracy

Analog or digital sensors

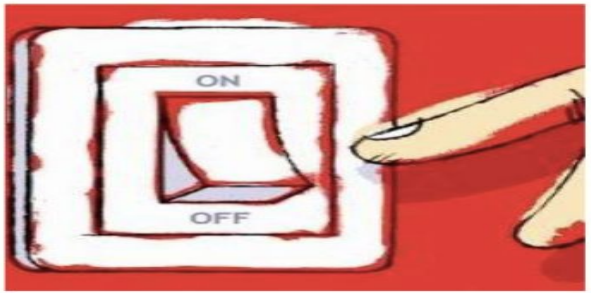
Example of analog sensor:

Temperature



Example of digital sensor:

Status of a switch



An ADC converts analog variables into digital signals, the only one that the microprocessor can handle. The ADC can be integrated in the sensor.

Interfaces

A peripheral interface is the data pathway that connects peripheral devices to the microcontroller, using two or more wires. It can be:

Asynchronous, using special start and stop signals

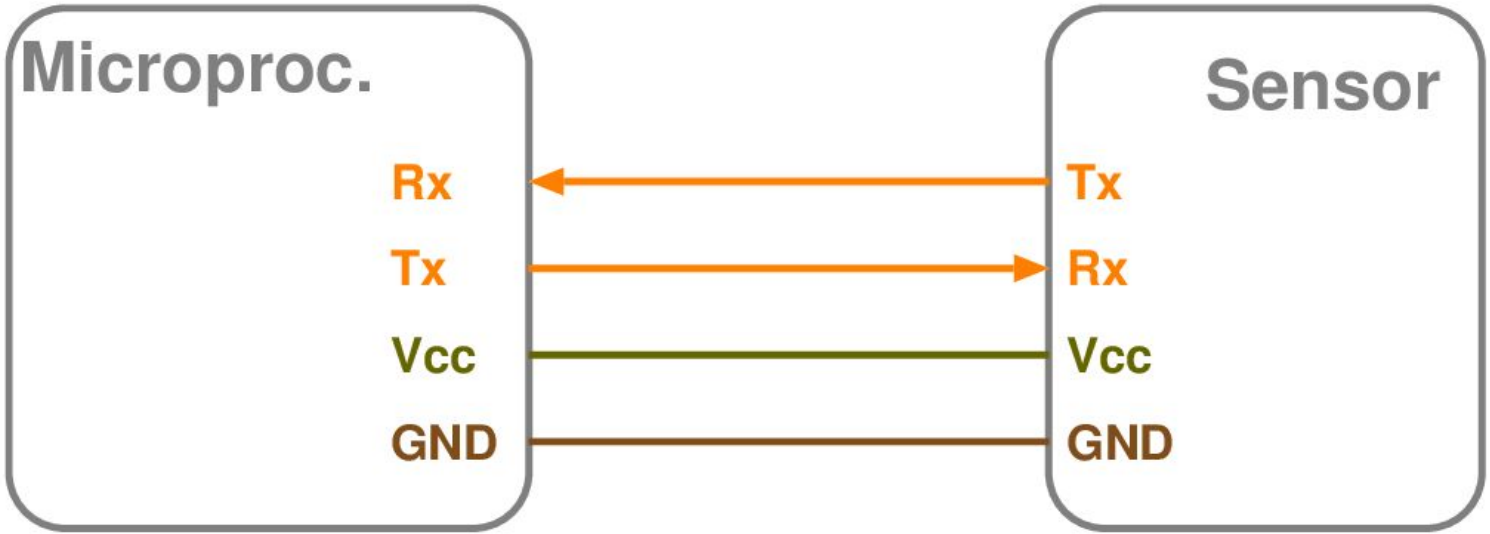
Synchronous, controlled by a common clock

Single ended, One Main, one Secondary

Multiterminal, One or more mains, multiple secondaries

UART (Universal Asynchronous Receiver Transmitter)

Point to point connection, commonly known as serial port. Two distinct wires - TX and RX - for uplink and downlink message plus a grounded reference wire GND.



I^2C (Inter-Integrated Circuit) interface

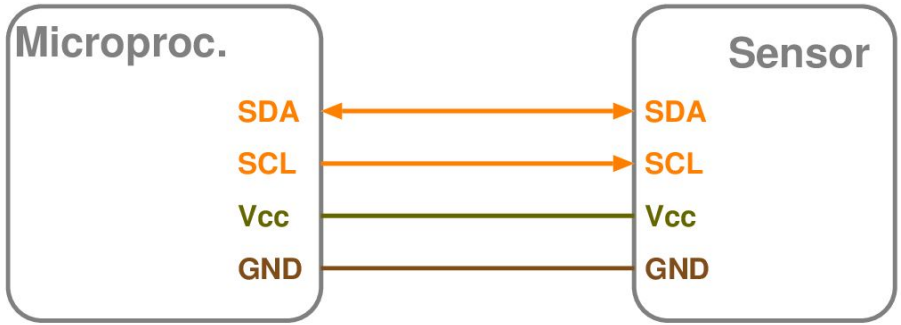
Main-Secondary (former Master-Slave). Secondary selection by address

Synchronous, two data wires plus ground, Serial Data and Serial Clock

Half duplex

Bidirectional data: SDA

Primary generated clock: SCL



SPI (Serial Peripheral Interface)

Full Duplex. Synchronous. One Main, several Secondaries.

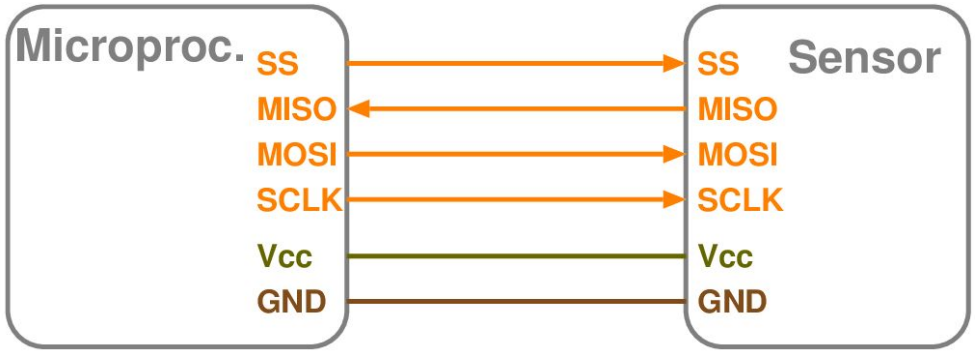
4 Unidirectional data lines:

MISO (Main Input, S. Output)

MOSI (Main Output, S. Input)

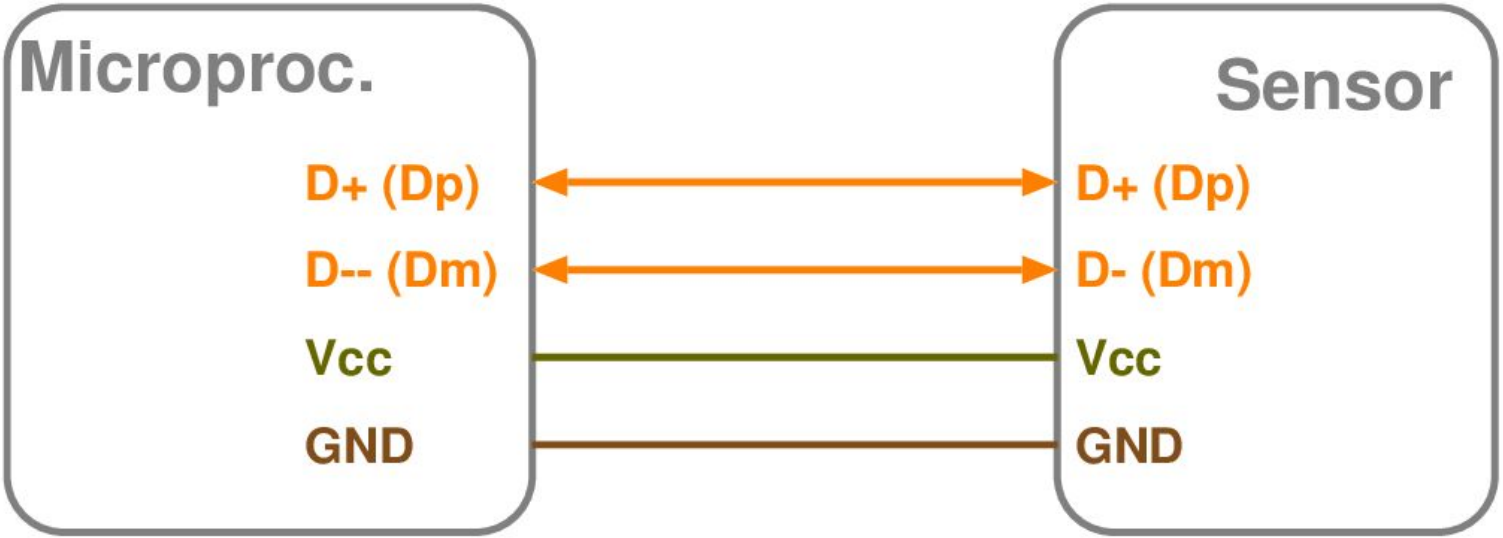
Main generated clock: SCLK

Main generated Secondary Select: SS



USB (Universal Serial Bus)

Evolution of the serial bus

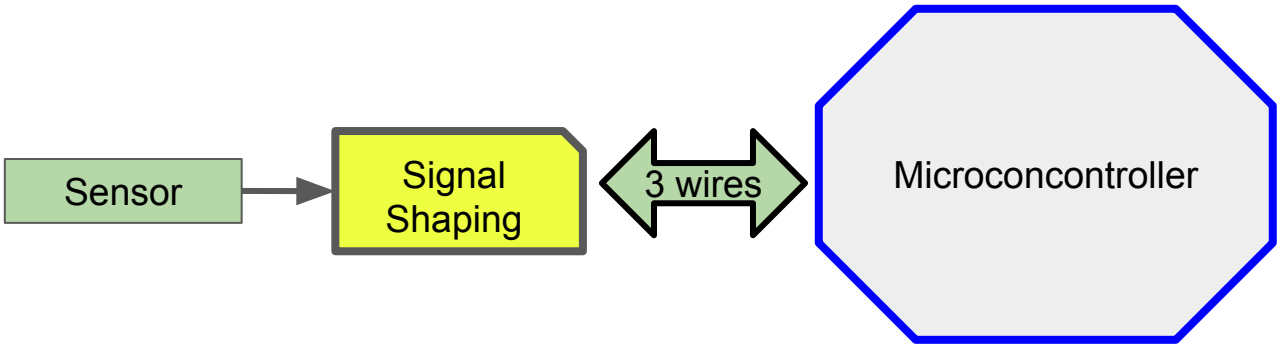


Sensors used in this project

- Temperature
- Electrical Conductivity, correlated to total dissolved solids (TDS)
- Analog TDS Sensor
- Turbidity, indication of total suspended solids (TSS)
- pH level
- Dissolved Oxygen

The choice of the sensors was made by the team at Ile-Ife University in Nigeria.

Sensor signal shaping: small board for adapting the probe output to the microprocessor requirements, including voltage translation, if needed



Digital Temperature sensor DS18B20

Temperature fluctuations can indicate environmental changes or contamination. Temperature also impacts other water quality variables such as dissolved oxygen and pH levels.

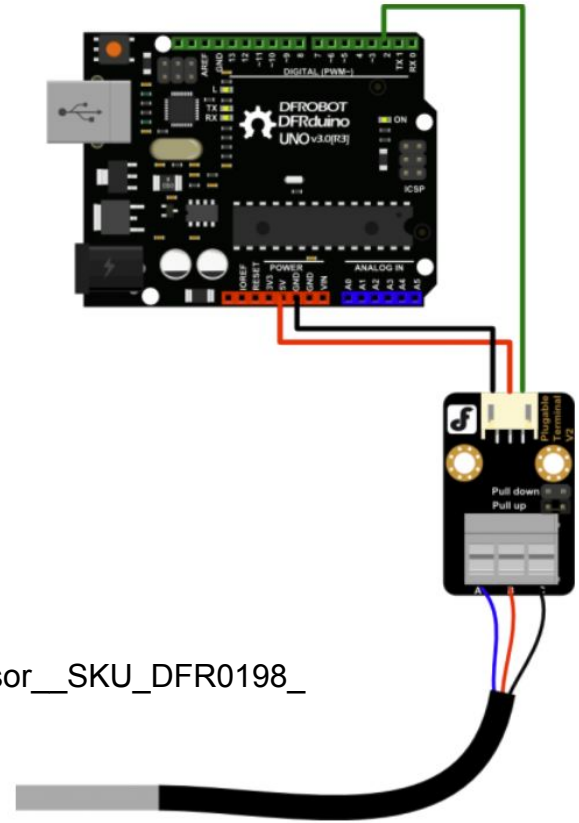
The DS18B20 uses an **integrated circuit** to convert temperature data into a digital signal, reducing susceptibility to electrical noise.

It includes a **microprocessor** and **memory**, simplifying integration with digital systems, while consuming much less power than sensors based on the linear resistance-temperature relationship.

It uses the **1-Wire protocol**, a half-duplex serial bus that provides low-speed data communication along with supply voltage over a single conductor, similar to I2C, but with **lower** data rates and **longer** range.

Digital Temperature sensor DS18B20

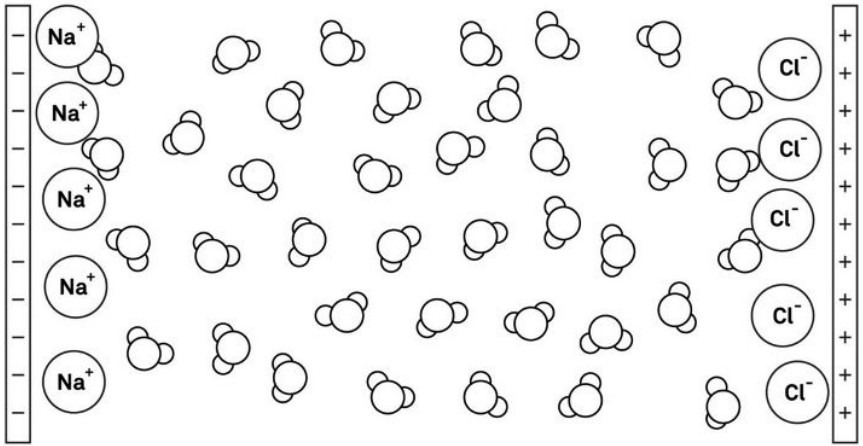
- 3.0V to 5.5V power/data
- ±0.5℃ Accuracy from -10℃ to +85℃
- Temperature range: -55 to 125℃
- 9 to 12 bit selectable resolution
- Requires only one digital pin for communication
- Unique 64 bit ID burned into chip
- Multiple sensors can share one pin
- Temperature-limit alarm system
- Query time is less than 750 ms



https://wiki.dfrobot.com/Waterproof_DS18B20_Digital_Temperature_Sensor__SKU_DFR0198_

Electrical conductivity sensors

Pure water does not conduct, the ions of dissolved substances are the transporter of electrical charge.
Conductivity provides an approximate value for TDS (Total Dissolved Solids).



https://metergroup.com/measurement-insights/soil-moisture-sensors-how-they-work-why-some-are-not-research-grade/

Electrical conductivity sensors

Conductivity is proportional to the ionic content (chloride, nitrate, sulfate, sodium, magnesium, calcium, or iron) in a body of water.

It is measured by placing a probe in the water and measuring the flow of electricity between its electrodes.

As temperature influences conductivity measurements, conductivity is reported at 25 degrees Celsius (25 °C).

In rivers and lakes, conductivity is usually between 100 – 1000 µS/cm (microsiemens/centimetre).

https://waterrangers.com/testkits/tests/conductivity/?v=0d149b90e739

Typical water conductivity values

Distilled water	0.5 – 3 µS
Melted snow	2 – 42 µS
Can effect fish reproduction	over 500 µS
Tap water	50 – 800 µS
Potable water	30 – 1500 µS
Freshwater streams	100 – 1,000 µS
Industrial wastewater	10,000 µS
Sea water	55,000 µS

https://waterrangers.com/testkits/tests/conductivity/?v=0d149b90e739

Type of water	Resistivity [Ω·cm]	Conductivity [µS/cm]
Pure water	20000000	0,05
Distilled water	500000	2
Rain water	20000	50
Tap water	1000-5000	200-1000
River water (typical)	2500	400
River water (brackish)	200	5000
Sea-water (coastal)	30	33000
Sea-water (open sea)	20-25	40000-50000

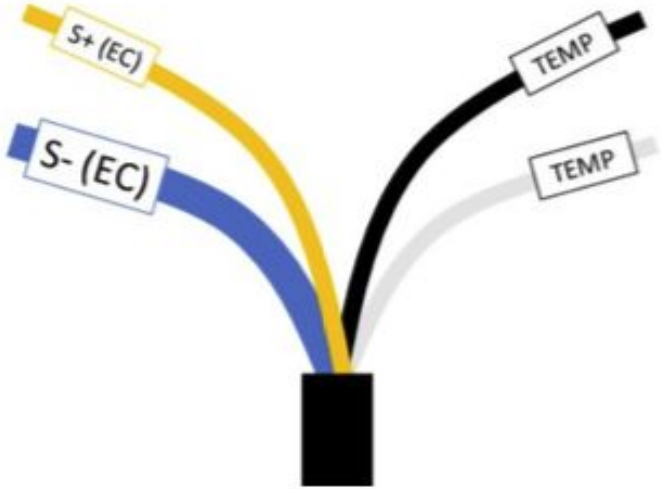
Water resistivity and conductivity at 25 °C [3, 4]

https://www.researchgate.net/figure/Water-resistivity-and-conductivity-at-25-C-3-4_tbl1_267975875

Analog Electrical conductivity Sensor PRO

Conductivity is strongly affected by the temperature, therefore this sensor has 2 wires to measure the conductivity and other 2 for measuring the temperature of the probe.

The PT1000 sensor operates on the principle of RTD (resistance temperature detection), where the resistance of a **platinum element** changes linearly with temperature. It offers better sensitivity but consumes more current, and requires an analog-to-digital converter.

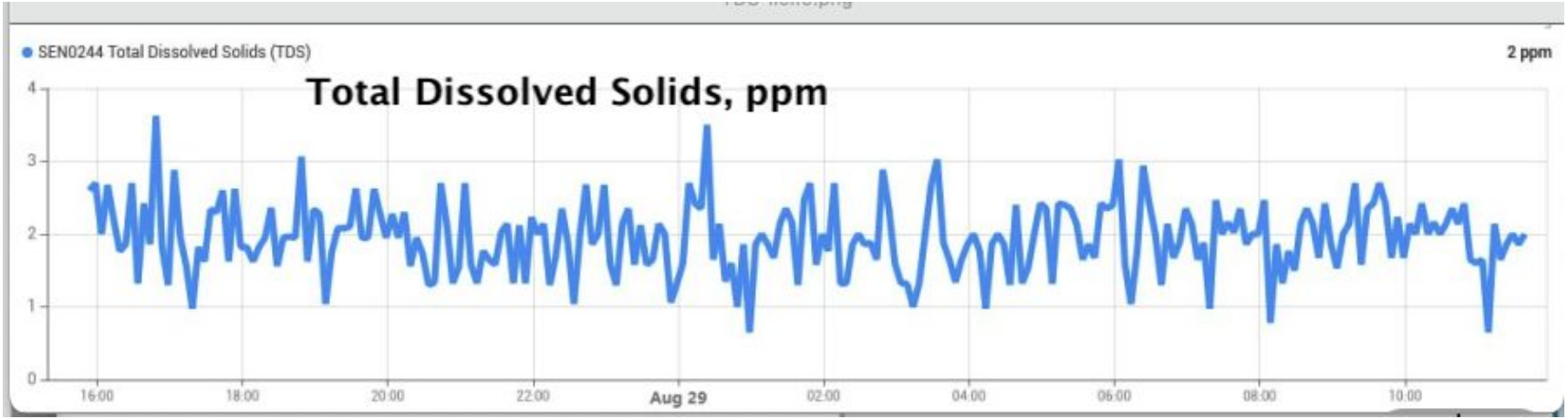


https://www.dfrobot.com/product-2565.html

Analog TDS (Total Dissolved Solids) Sensor

Measures the concentration in ppm (parts per million) of dissolved substances, such as salts, minerals, and organic matter.

◦ High TDS levels can indicate contamination or poor water quality, impacting both human consumption and aquatic ecosystems.



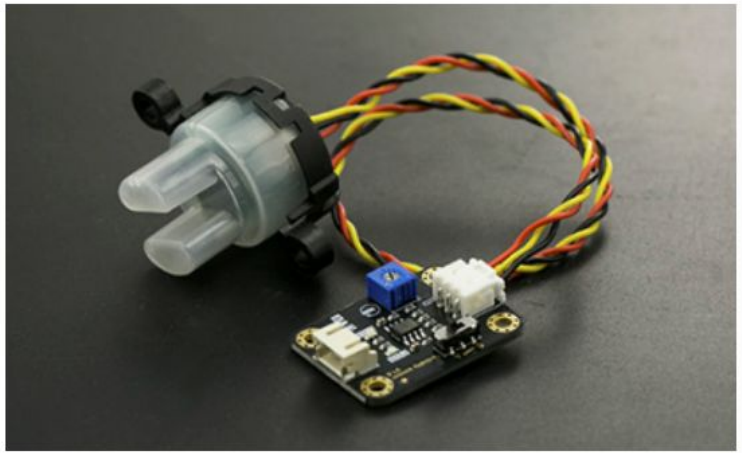
Analog Turbidity Sensor

Detects the amount of **suspended particles** in water by measuring the light transmittance and scattering rate, which changes with the amount of total suspended solids (TSS) in water.

High turbidity levels can indicate water contamination from soil runoff, pollutants, or algae blooms.

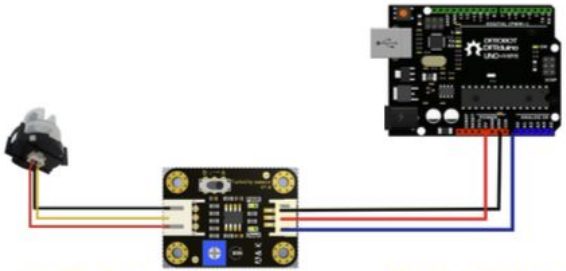
Operating Voltage: 5 V DC

https://www.dfrobot.com/product-1394.html



Connection Diagram

Meant For lab use.



https://wiki.dfrobot.com/Turbidity_sensor_SKU__SEN0189

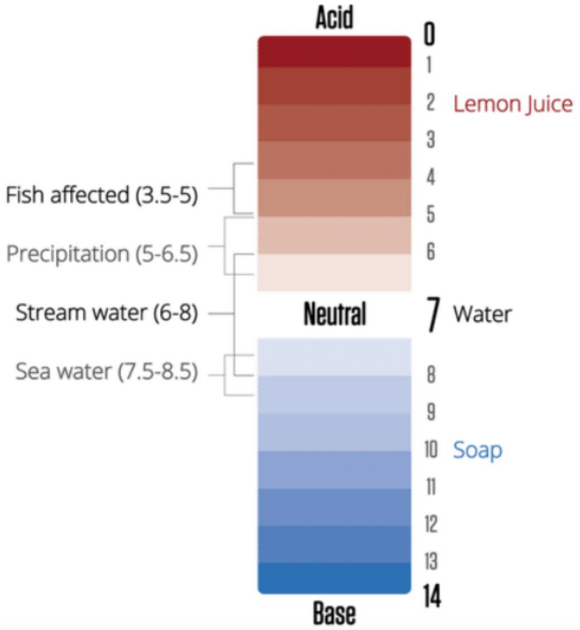
pH Sensor

pH is the negative logarithm of the concentration of hydrogen ions in an aqueous solution. pH levels indicate the chemical balance of the water, essential for aquatic life and drinking water safety.

Unbalanced pH can signal the presence of harmful substances in the water.

Rivers and lakes generally range between 5 (acidic) and 9 (basic) on the pH scale.

Low pH can reduce the quantity of fish eggs hatching and can make life difficult for fish and macroinvertebrates (the backbone of our water ecosystems).



Analog Industrial-Grade pH Sensor Pro Kit

Detection Range: 0~14

Temperature Range: 0~60°C

Supply Voltage: 3.3~5.5 V

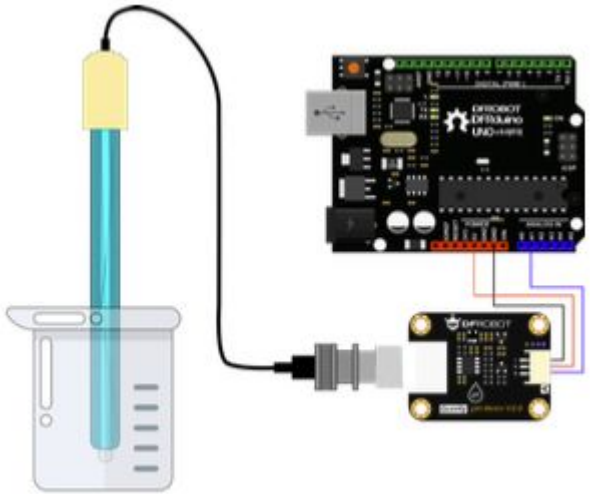
Output Voltage: 0~3.0 V

Probe Connector: BNC

Measurement Accuracy: ±0.1@25℃

Probe Life: 7*24hours > 0.5 years

https://www.dfrobot.com/product-2069.html



Dissolved oxygen

Dissolved oxygen is the amount of gaseous oxygen (O_2) present in water, measured in mg/L. It is essential for aquatic life—low levels can indicate pollution or poor water quality.

Oxygen dissolves into the water in various ways:

It is created by aquatic plants and algae during photosynthesis.

Oxygen from the air also dissolves into the surface of the water.

Winds and wave activity in lakes and fast-flowing rivers promote the mixing of air and water, increasing the amount of oxygen that dissolves.

Dissolved oxygen typical values

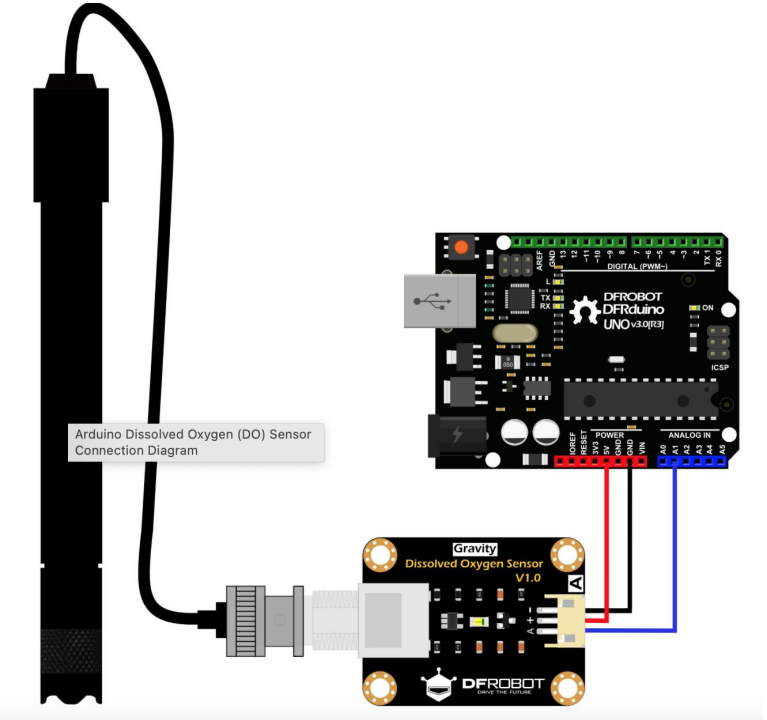
Not enough oxygen to support life	0 – 2 mg/L
Only a few fish and aquatic insects can survive	2 – 4 mg/L
A good range for many aquatic animals, but too low for most cold-water fish	4 – 7 mg/L
Very good for most stream fish and freshwater aquatic life	7 – 11 mg/L

https://waterrangers.com/testkits/tests/dissolved-oxygen/?v=0d149b90e739

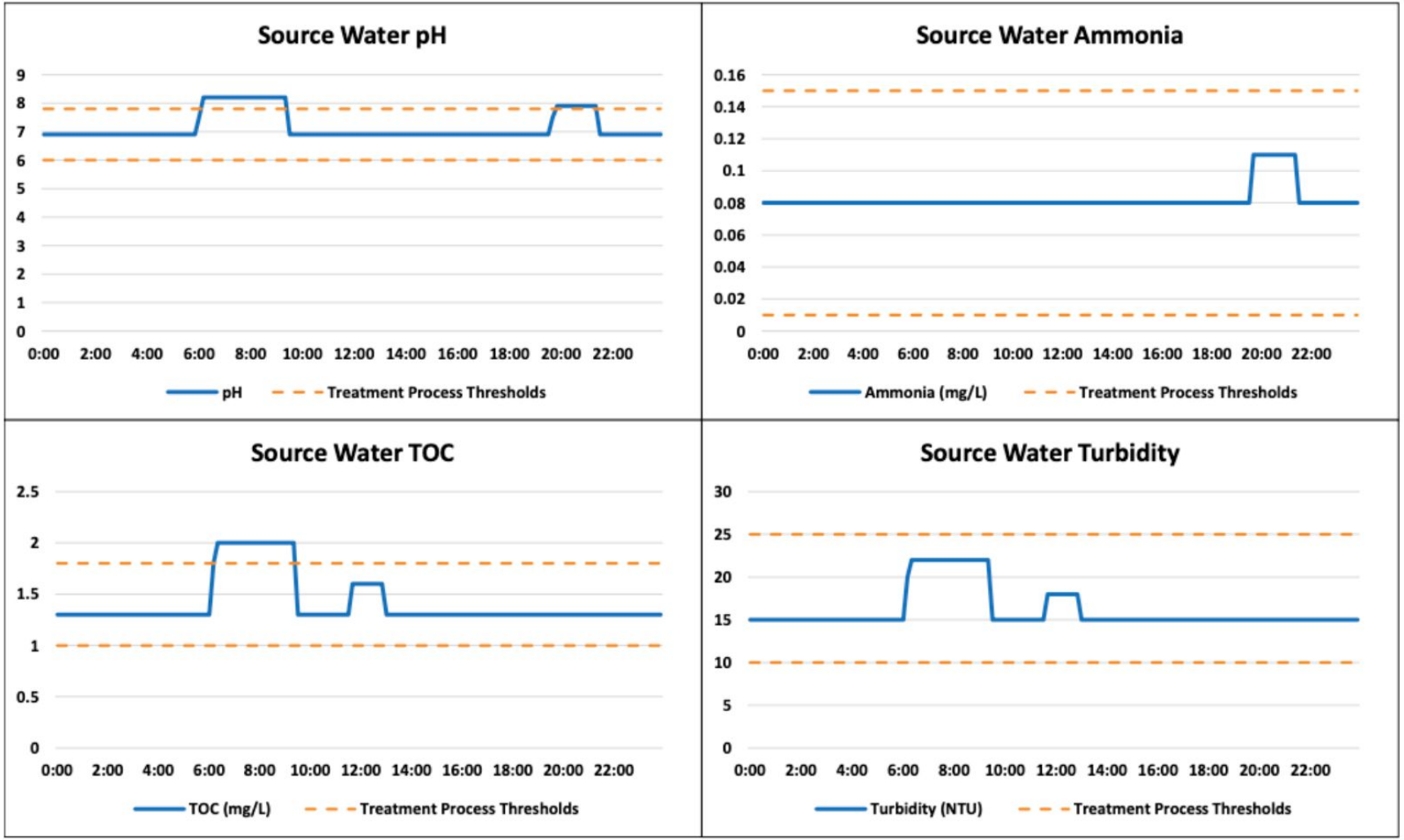
Dissolved oxygen

Type: Galvanic Probe
Detection Range: 0~20 mg/L
Electrode Service Life: 1 year (normal use)
Maintenance Period: Membrane Cap
Probe Connector: BNC
Signal Converter Board

Operating Voltage: 3.3~5.5 V
Output Signal: 0~3.0 V
Meant for Lab use



https://www.dfrobot.com/product-1628.html

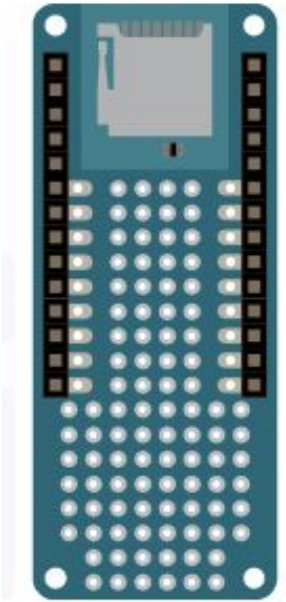


Note that this figure displays idealized data, without noise, to clearly demonstrate the concept of threshold analysis.

Other peripherals used in this project

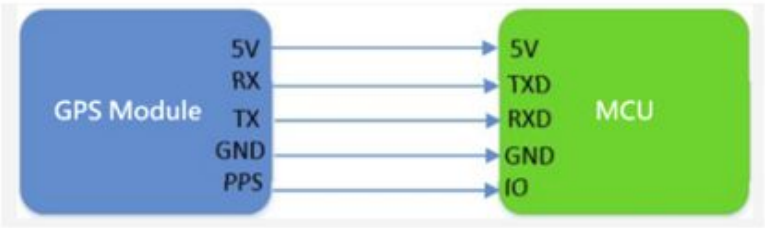
microSD and its MKPR SD Proto Shield for local data storage

https://docs.arduino.cc/hardware/mkr-sd-proto-shield/

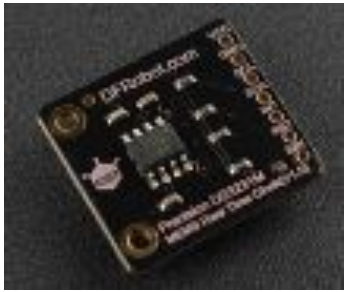


Real-Time Clock

GPS



DS3231M MEMS Real-Time Clock



Provides accurate timekeeping for data logging and timestamping sensor readings, even in power-off conditions.

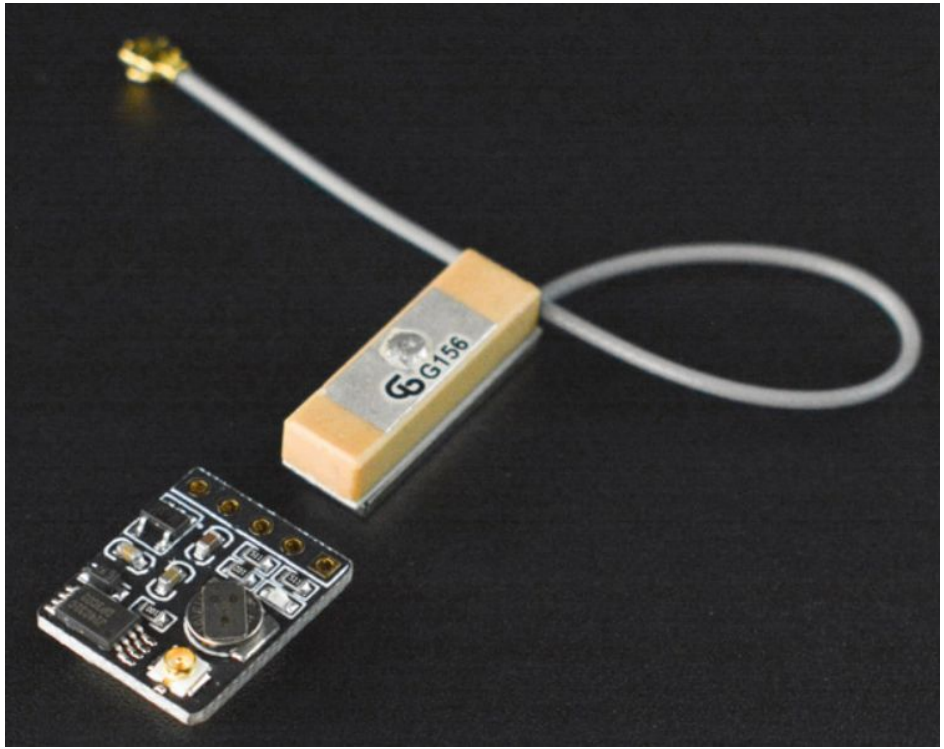
- Key Features:
  - Temperature-compensated: Maintains accuracy regardless of environmental temperature changes.
  - Battery Backup: Retains time information during power loss using a small backup battery.
  - Interface: Communicates with the MKR1310 via the I²C bus (SDA, SCL pins).

https://www.dfrobot.com/product-1991.html

GPS + BDS BeiDou Dual Module

Provides geographical location data (latitude, longitude, altitude) and precise time (derived from atomic clocks) information using both GPS and BeiDou satellite systems through a UART interface.

Allows for the correlation of water quality data with specific geographic points, crucial for environmental monitoring.



https://www.dfrobot.com/product-2080.html

Sensor wired connectivity

Some sensors connect directly to the microcontroller.

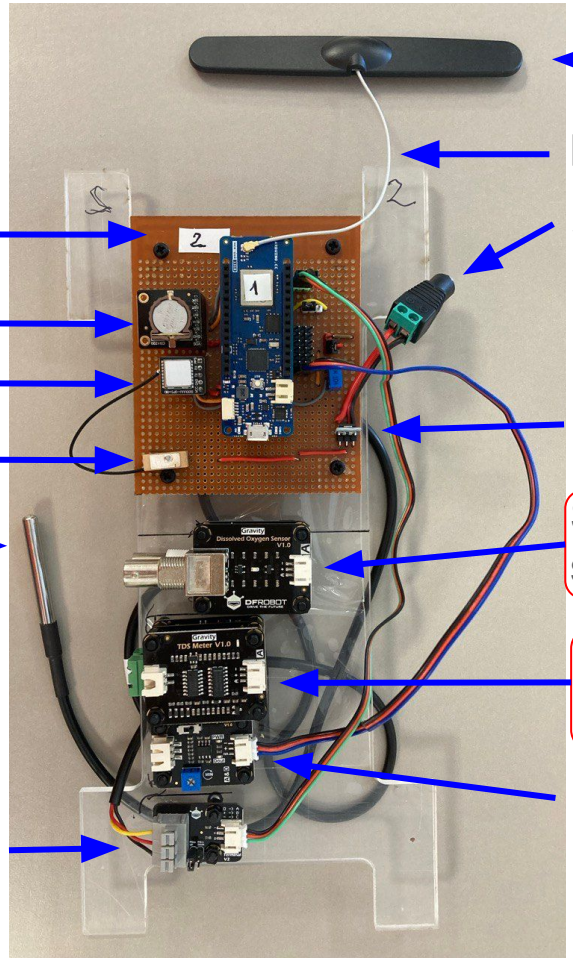
Others need an intermediate circuit board interface to shape the signal conveyed to the microcontroller.

The sensor might have its own battery, but most often the electrical power is provided from the microcontroller.

The simplest connection is an asynchronous one made with 3 wires, one for the positive voltage, one for data and a common ground for data and power.

A clock signal must be shared in synchronous systems.

Up to eight wires are sometime used.


LoRa 868 MHz antenna
pigtail cable with U.FL connector
5 V DC input
MKR 1310 microcontroller
5 V to 3.3 V converter
Stacked dissolved oxygen and pH sensor circuit board interfaces
Stacked TDS, conductivity and temperature circuit interfaces
Turbidity Sensor
Protoboard
RTC
GPS
GPS antenna
Temperature probe
DS18B20 temperature sensor

Microcontroller

It is a small computer that controls the interfaces for connecting to the sensors and to the radio, according with the configuration instructions supplied.

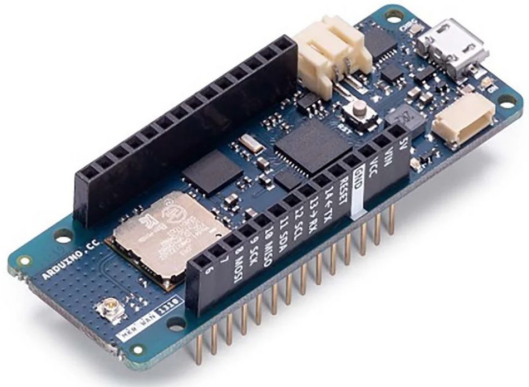
The configuration is performed from a full fledge computer by means of an environment specific program.

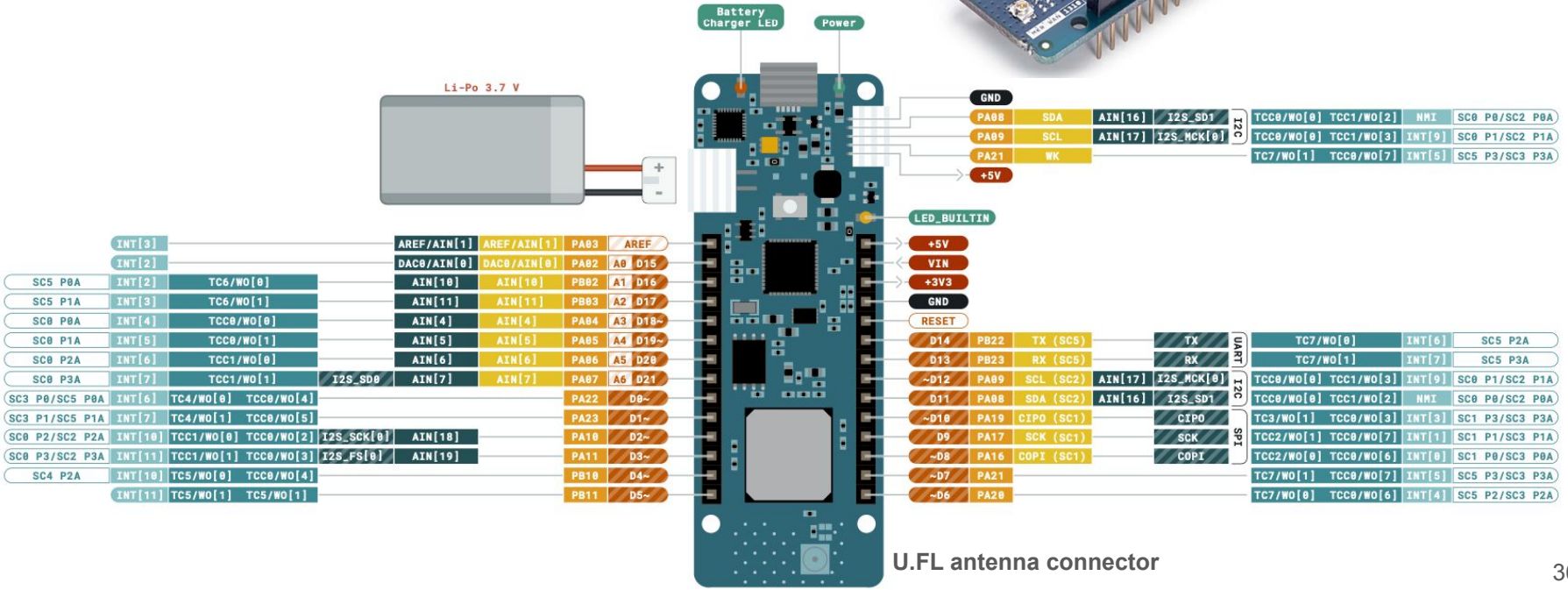
There are a variety of microcontrollers. We chose one manufactured by Arduino, the **MKR 1310**, which has an on-board LoRa radio and many I/O options.

Arduino uses the IDE (Integrated Development Environment) to upload programs and communicate with the sensors via different interfaces.

It is also used for the configuration of the radio communication parameters.

Arduino MKR 1310





Arduino MKR1310

- Processor: SAMD21 Cortex-M0+ 32-bit low-power ARM microcontroller
- Memory: 256 KB Flash, 32 KB SRAM
- LoRaWAN: Integrated LoRa module for long-range communication
- I²C, SPI, UART: Multiple communication interfaces for sensor integration
- Power Supply: Via USB, Li-Po battery (Integrated Charging Circuit) or external 5 V source
- Operating Voltage: 3.3 V logic level (requires voltage adaptation for 5 V sensors)
- Digital I/O Pins: 8, including PWM outputs
- Analog Inputs: 7 channels with 12-bit ADC
- Low Power Mode: Designed for low energy consumption, ideal for battery-operated projects

Voltage levels adaptation

The MKR1310 operates at 3.3 V, while some sensors and modules (e.g., Turbidity Sensor) require or output 5 V signals.

- The MKR1310's analog input pins (A0 to A6) can read voltages from 0V to 3.3 V.
- 12-bit ADC: Converts analog signals into a digital value between 0 and 4095, allowing precise sensor readings.
- Use level shifters or voltage dividers to protect 3.3 V digital pins from 5 V devices.
- Level Shifters are dedicated ICs designed to safely translate 5 V logic to 3.3 V and vice versa.

MKR1310 physical connections

- Power Supply:
  - USB: Powers the board and allows programming.
  - Li-Po Battery: Connect to the onboard JST connector for battery-powered operation.
  - External 5 V: Can be supplied through the VIN pin.
- Sensor Connections:
  - I²C: Use SDA (Pin 11) and SCL (Pin 12) for sensors like the Real Time Clock (DS3231M).
  - Analog Sensors: Use the analog pins (A0 to A6) for sensors like the pH and turbidity sensor.
  - Digital Sensors: Use digital I/O pins (D0 to D7) for sensors like the DS18B20.

MKR1310 other connections

- U.FL (I-PEX) connector :
    - To connect a LoRa antenna for long-range wireless communication.
- MKR SD Proto Shield board:
    - To connect the board to the microSD Card for data logging.
- Voltage Adaptation:
    - Ensure proper voltage levels when connecting 5V sensors to the MKR1310, which operates at 3.3V.

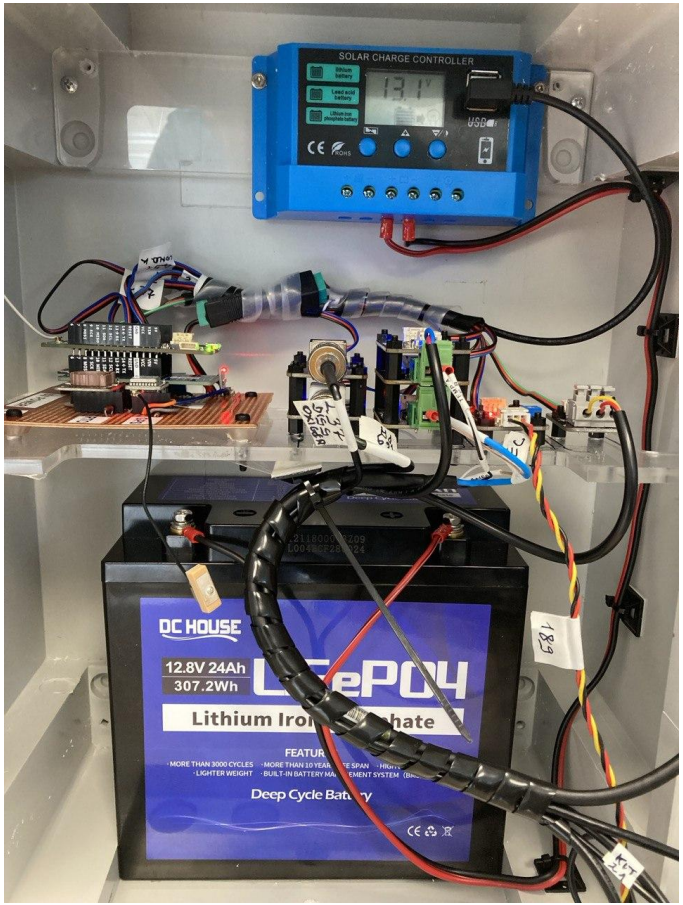
Sensor box content

Solar Charge Controller: for charging the 12 V battery and providing regulated 5 V USB output.

Motherboard and daughter boards for signal shaping and voltage shifting.

12 V LiFePO4 24 Ah deep cycle battery.

Marco Rainone has prepared a thorough document (available in the workshop's repository), describing the connection of the sensors and their programming.



Wireless transmission

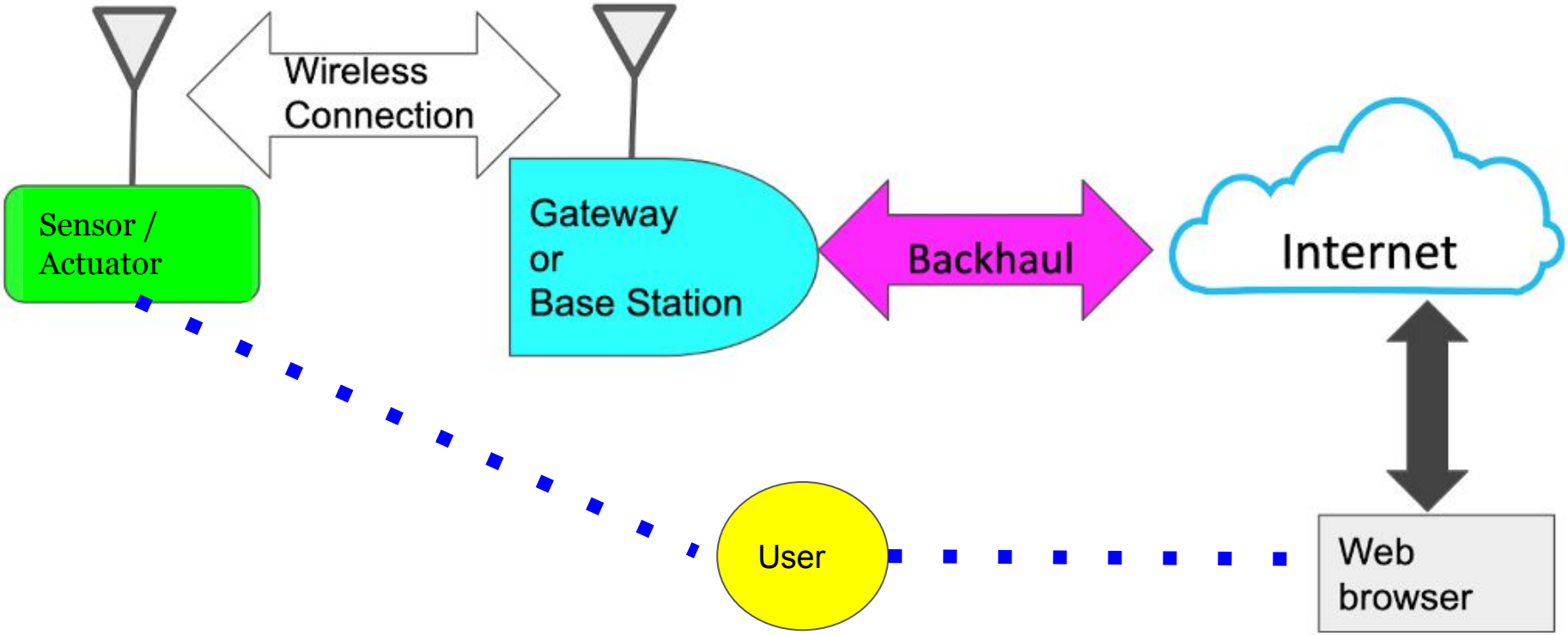
Several transmission technologies can be used for sensor networks.

The choice depends on, among other factors:

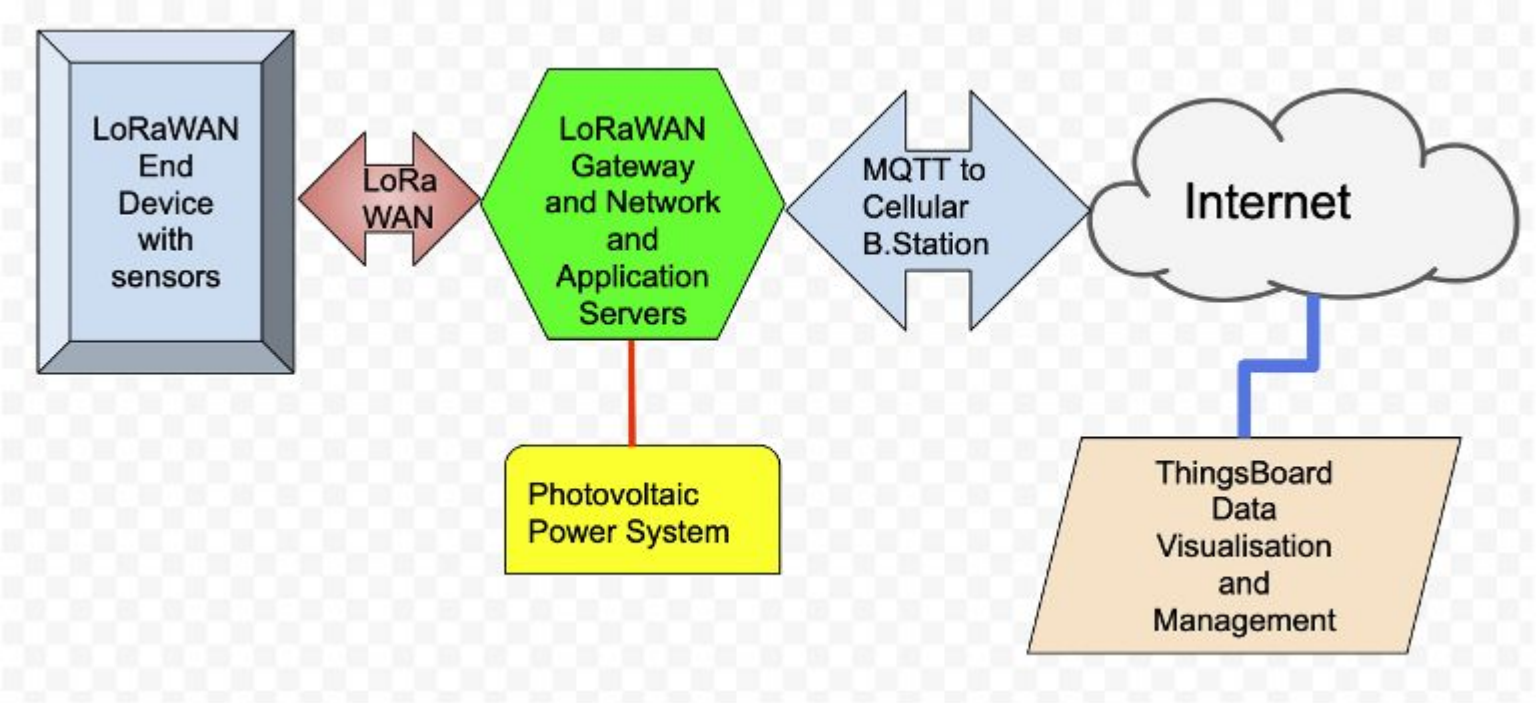
- availability of commercial service providers in the region of interest
- transmission speed required
- periodicity of transmission
- power consumption
- coverage range
- data privacy requirements
- cost (both that of initial installation and later recurring cost)

.

Generic IoT Connection



LoRaWAN connectivity implementation



Conclusions

A system to perform six types of measurements for water quality and make them available in a web page using LoRaWAN is described.

While the LoRaWAN gateway must be within Internet coverage, the sensor unit can be outside the reach of Cellular service, which makes this system very useful for remote or underserved areas.

Data are also stored locally in a micro SD card.

The water quality variables monitored are temperature, total dissolved solids (TDS), turbidity, electrical conductivity (EC), acidity level (PH) and amount of dissolved oxygen.