Water Quality Network: Research Proposition

Presenters: Lucas Colias & Aaron Ramirez

The Problem:

We started this research project with the intent of implementing refillable safe-water nodes around a city. We were inspired by the docu-series “Down to Earth”, where in episode two the host(Zac Efron) talks about the availability of tap water in Paris, France. We came to realize that there are no city wide infrastructures like this anywhere in the United States that we could beyond small scale projects on college campuses and at some public parks.

Our research took us to how water quality is monitored on a city-by-city basis starting with Long Beach. We found that although the water supply is routinely monitored each week, there is no real-time information about the quality of water flowing through the water mains. **To implement our idea for safe-water nodes, we felt it was important to first have a network of sensors that reported live water quality data.**

Our Solution:

Our ideal solution for this problem would be to create a network of sensors attached at different points on the water mains throughout the city. The sensors would also ideally relay a live feed of the same data that the city tests for on a weekly basis. The goal would to use this data combined with the information that we know about the water mains and create a real time map of the cities water quality.

We believe our implementation of this would have to be broken down into the following subtopics:

- Testing for contaminants
- Sensors and their measurements
- Forming a sensor network
- Mapping the cities water mains
- Mapping network to water main map

*This list is variable to change as there are definitely things we are missing. If this were to become a real life project we implement we would eventually need to build the sensors, attach them to the water mains, ect...

Test for Contaminants

Before we begin on the journey of trying to deploy a physical network onto the water supply we really need to identify what were even looking for in the first place. This begins with learning the business of a government run water department. We will first take a look at the terminology used by the Long Beach Department of Water(LBDW) for testing, and then at examples the contaminants they had found in the Long Beach water supply over the year of 2019.

Terminology can be broken down into three categories:

- Water Quality Standards
- Water Quality Goals
- Measurements

Water Quality Standards:

Terms used to describe the procedures that the city MUST follow, based on the requirements set by the city, state, and national government.

AL Regulatory Action Level: The concentration of a contaminant which, if exceeded, triggers treatment or other requirements that a water system must follow

DLR Detection Limit for Purpose of Reporting: The level at which a contaminant is detected for compliance reporting determination

HRAA Highest Running Annual Average

LRAA Locational Running Annual Average

MCL Maximum Contaminant Level: The highest level of a contaminant that is allowed in drinking water. Primary MCLs are set as close to the PHGs (or MCLGs) as is economically and technologically feasible. Secondary MCLs (SMCLs) are set to protect the odor, taste, and appearance of drinking water

MRDL Maximum Residual Disinfectant Level: The highest level of a disinfectant allowed in drinking water. There is convincing evidence that addition of a disinfectant is necessary for control of microbial contaminants

NL Notification Level: NLs are health-based advisory levels established by State Board for chemicals in drinking water that lack MCLs. When chemicals are found at concentrations greater than their notification levels, certain requirements and recommendations apply

NS No Standard

PDWS Primary Drinking Water Standard: MCLs and MRDLs for contaminant that affect health, along with their monitoring and reporting requirements and water treatment requirements

RTCR Revised Total Coliform Rule

TT Treatment Technique: A required process intended to reduce the level of a contaminant in drinking water

Water Quality Goals

The different types of goals and requirements that the state and national government set for water quality.

Test for Contaminants

- **Biological Contaminants**
  - Sewage
  - Septic systems
  - Agricultural
  - Livestock operations
- **Inorganic Contaminants**
  - Salts and metals
    - Urban stormwater runoff
    - Industrial or domestic wastewater discharges
    - Oil and Gas production
    - Mining and farming
- **Pesticides and herbicides**
  - Agricultural
  - Urban Stormwater runoff
  - Residential uses
- **Organic Chemicals**
  - Synthetic and Volatile
    - Industrial process (products)
    - Petroleum production
    - Gas station
    - Urban stormwater runoff
    - Agricultural applications
    - Septic system
- **Radioactive materials**
  - Naturally occurring
  - Oil and gas production
  - Mining activities

Ways of Testing Natural Contaminants

- IoT based system
  - Monitors and controls direct water treatment
  - Smart Water Management System (SWMS)
    - Emphasis on Chlorine in water
- Wireless sensor networks
- Hydraulic modeling tools (EPANET)
  - Application for modeling drinking water distribution systems
- Crowdsensing for Monitoring

Quarterly Testing

What if there

REGULATED PRIMARY HEALTH STANDARDS, 2019

PARAMETER (UNIT OF MEASURE)	GOALS	REGULATORY LEVELS			MWD ZONE (114)			BLENDED ZONE (325)			TYPICAL SOURCES OF CONTAMINATION
	PHG (MCLG)	MCL	2nd MCL	NL (AL)	AVE	MAX	RANGE	AVE	MAX	RANGE	
CLARITY											
Turbidity[2] (NTU)	NA	TT	5	NS	ND	0.11	ND - 0.11	ND	0.08	ND - 0.08	Soil Runoff
Turbidity[2] (Lowest monthly percent of samples meeting limit) = 100%											
MICROBIOLOGY (% POSITIVE)											
Total Coliform Bacteria[4]	(0)	5%	NS	NS	City-Wide: Highest Monthly-0.70%; Range ND-0.70%						Naturally present in the environment
INORGANIC CHEMICALS											
Aluminum (ppb)	600	1000	200	NS	54.3	100	31 - 100	5.9	31	ND - 31	Erosion of natural deposits, added during water treatment
Arsenic (ppb)	0.004	10	NS	NS	0.4	2	ND - 2	ND	1	ND - 1	Erosion of natural deposits, runoff from orchards and industrial process
					City-wide: 90th percentile = 196, 83 sites sampled;						Corrosion of plumbing

IoT based System

The availability of a variety of low cost sensors and the evolution of the Internet of Things (IoT), lead to the development of remote real-time monitoring and controlling systems. Without the need of direct human intervention - has expanded significantly in various applications domains.

Water Pump Station (WPS)

Water Pump station are buildings that contains all mechanical machines needed for water pumping from wells.

- Chlorine Sensors
  - Pump takes liquid chlorine material from ground tank with direct connection to a pipe
  - Manually configured on same pipe after each dosing pump
  - Connected to analog analyzer which reads chlorine concentration
    - Milligram of chlorine for each one liter of water (mg/L)
    - Chlorine is used in drinking water to disinfect it and kill all germs

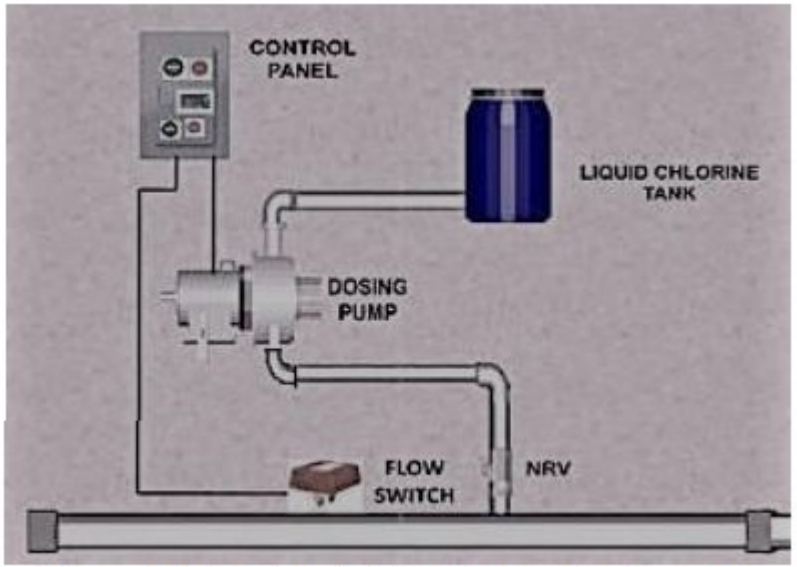


Figure 1: Architecture for Water Chlorination Treatment

Water Chlorination Process

- Process of water chlorination begins with:
  - Manual configuration (controlling)
    - Chlorine concentration for each one liter of water
      - 0.5 mg/L
    - Chlorine Concentration should be between a range of a minimum concentration
      - 0.2 mg/L
- Concentration becomes
  - **Under 0.2 mg/L**
    - the water will be risky for people to be able to drink
  - **Over 0.8 mg/L**
    - It will cause severe danger on human lives.
- Case: Chlorine liquid material tank is empty
  - Dosing pump will continue working without dosing the needed chlorine leading to a concentration less than 0.2 mg/L

Smart Water Management System (SWMS)

The data that is collected from the controllers such as:

- Temperature
- Conductivity
- Chlorine concentration

Aim to analyze and study the effectiveness of:

- Controlling decisions
- Proposing recommendation for better control
- Minimizing chemical usage
- Problem prediction

The monitoring parameters are:

- Conductivity
- turbidity
- Level of water
- pH (measure of hydrogen ion concentration)
    - pH = -log[H+]

Wireless Sensor Network (WSN) to automate the monitoring of water quality

- Solution of three main blocks
    - WSN sensor nodes
    - WSN gateway nodes
    - Application software

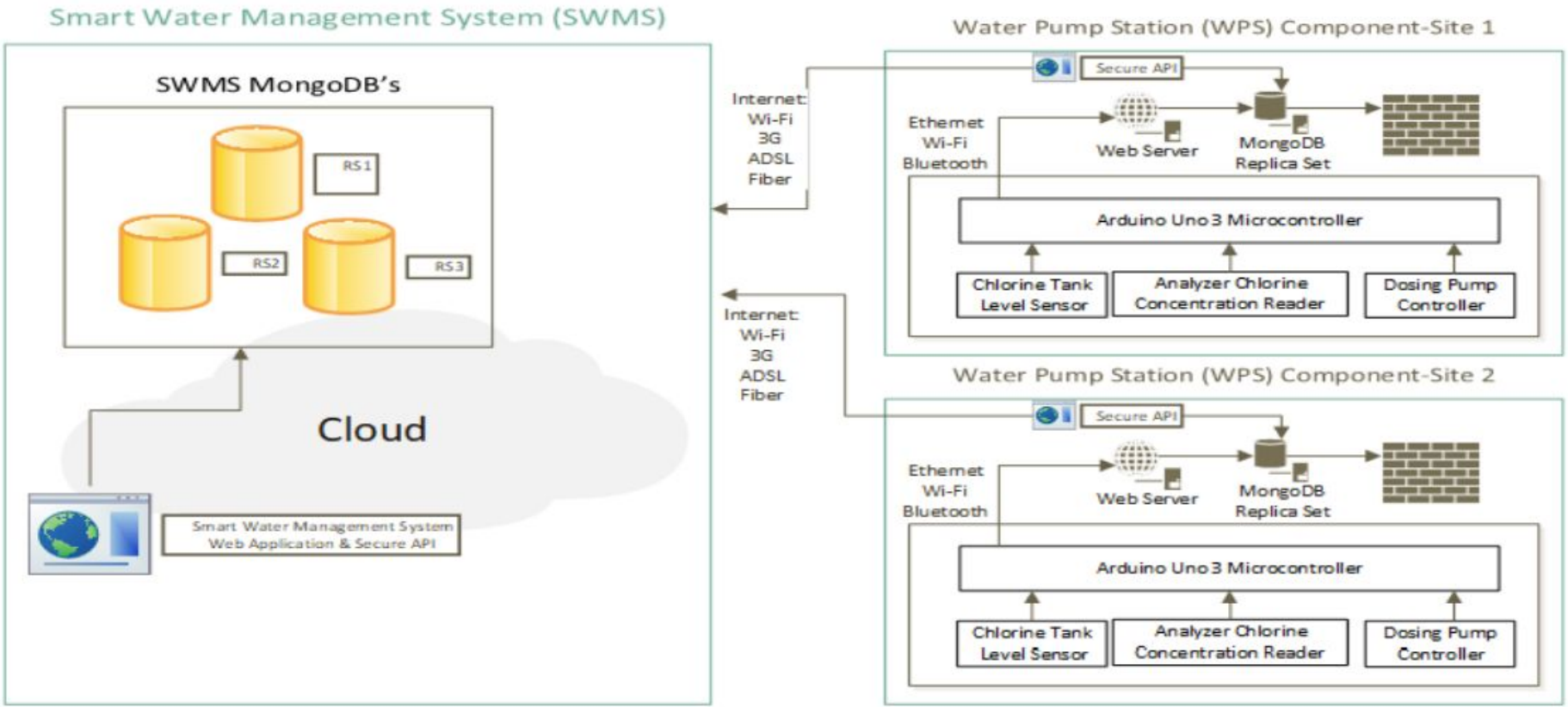


Figure 2: Proposed System Architecture with Various Components

Sensors needed

- Ultrasonic Sensor (HC-SR04)
  - Provides 2cm to 400cm of non-contact measurement functionality, the ranging accuracy can reach up to 3mm.
  - price : $2.99
- Arduino Uno 3
  - Microcontroller board
  - price : $23.00

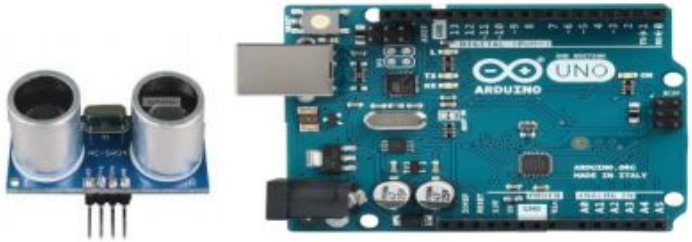


Figure 3: Ultrasonic Sensor (HC-SR04) and Arduino Uno 3

The produced output form the ultrasound reflects the distance of how far away the liquid is from the ultrasound sensor

- Determine the level of chlorine in tank

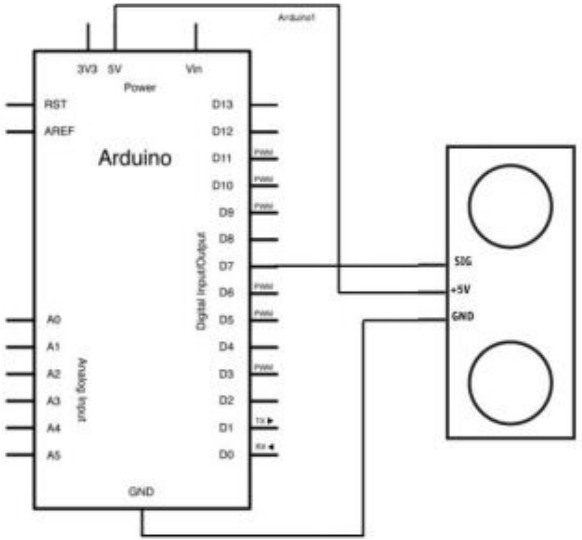


Figure 4: Arduino and Ultrasonic Circuit

Continuation

WPS are connected to an Analyzer that reads chlorine concentration in milligram for each liter of water mg\L

- “Liquisys M CCM223/253”
  - A transmitter for determining the amount of free chlorine, chlorine dioxide or total chlorine dissolved in water
  - price : $338.00 (Amazon)

The data that is produced by the equipment are mapping values for current, Arduino Analog value, and chlorine concentration

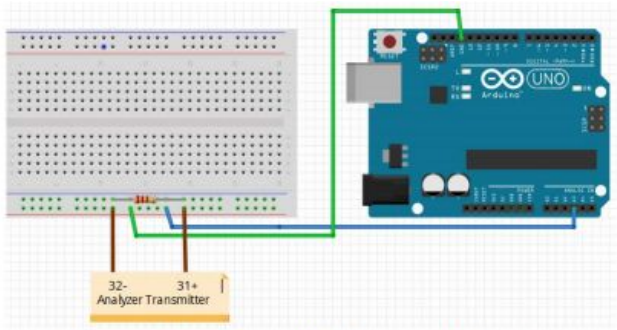


Figure 5: Arduino Controller Connected to Analyzer Transmitter

- Current (mA)
- Arduino Analog Value (0-1023)
- Chlorine Concentration (mg\L)

Table 1: Mapping Values for Current, Arduino Analog Value, and Chlorine concentration

Current (mA)	Arduino Analog Value (0-1023)	Chlorine Concentration (mg\L)
0	0	0
4	80	0.2
8	160	0.4
16	320	0.8
20	400	1

Mapping the Cities Water Main:

Mapping water mains to a map of the city itself will probably be the trickiest part. We only found one city that has this as public information and that's Seattle. After some digging around, we reached out to a few cities for more information, but from all the cities we had emailed. The city of Long Beach’s department of water for a Utility Map Request. With this information we will create an overlay of the cities water mains onto an actual map of the city.

Contaminant & Disinfected sensors, and the data collected from them

Sensors, transmitters, compact devices and assemblies
Experts in Liquid Analysis

Measuring Parameter Overview

pH/ORP

- pH value monitoring guarantees optimized production output in all areas of industry.

Conductivity

- Monitoring electrolytic conductivity is important for monitoring wastewater treatment and controlling cleaning process (CIP) in the food and pharmaceutical industry.

Turbidity

- In drinking water, the turbidity value is an important measure of quality. Turbidity is measured to control wastewater treatment processes for primary sludge, sludge dewatering and in the aeration basin and outlet.

Dissolved oxygen

- Dissolved oxygen is a key water quality indicator when monitoring surface water or in water treatment systems.
- Dissolved oxygen is usually reported in milligrams per liter (mg/L) or as a percent of air saturation.

Disinfection

- The measurement of chlorine and chlorine dioxide is needed in all areas of disinfection to ensure safe and effective water treatment.

pH/ORP sensors

pH electrodes using the potentiometric method

Data that the sensor produces:

- Display high selectivity (low cross-sensitivity to ions other than H+) over a wide temperature range.
- Linear measurement of a material component over a concentration range of (pH 0-14)
- Combined pH/ORP sensors, the values together can be used to calculate the rH value which measures for the oxidizing or reducing effect of a medium

ORP electrodes using the potentiometric method

Data that the sensor produces:

- Indicator of the oxidizing or reducing properties a process medium and is measured in mV.
- Range: -1 500 mV and +1 500 mV.
- Can be used for chromate detoxification, cyanide detoxification or to measure the metering of oxidants for disinfection purposes.

1 Memosens CPS16D combined pH/ORP sensor
Standard sensor for long-term monitoring in water treatment or the chemical industry; dirt-repellent Teflon ring diaphragm; poison-resistant ion trap

2 Memosens CPS76D combined pH/ORP sensor
Hygienic sensor for food, pharmaceutical industries; CIP-, SIP- and autoclavable; certified biocompatibility; pressurized reference for fermenters

3 Memosens CPS96D combined pH/ORP sensor
Robust sensor for chemical processes, pulp and paper industry; open aperture diaphragm for very contaminated media and suspended solids; fast response time

4 Standard sensor Orbisint CPS12D/12
Long-term monitoring in water treatment, detoxification, or the chemical industry; platinum cap or gold pin; measuring range: -1500 to +1500 mV; dirt-repellent Teflon ring diaphragm

5 High-performance sensor Ceraliquid CPS42D/42
Chemical industry, detoxification, water treatment, power stations; for media that tend to form buildup, and fast-changing medium compositions; platinum cap

6 Hygienic sensor Ceragel CPS72D/72
Food industry, fermenter, biotechnology with rapidly changing oxidation reduction potential; platinum cap; acrylamide-free, ion trap, excellent resistance to temperature and pressure changes

7 Sensor for suspensions Orbipore CPS92D/92
Paper and pulp industry; open aperture diaphragm for contaminated media such as emulsions, precipitation reactions, dispersions; platinum cap for rapid response

Conductivity sensors

Conductivity sensors using the conductive method

Data that the sensor produces:

- The electrical conductivity of liquids is determined using a measuring arrangement incorporating two electrodes located opposite from one another
- $\kappa = k \ G = k / R$
- Measuring range:
  - The lower the conductivity, the smaller the cell constant selected
- Size of cell constant affects the optimum arrangement of the electrodes.

Four-electrode method

Method is suited for applications which cover a wide measuring range.

Data that the sensor produces:

- Sensor has two additional electrodes to compensate for polarization effects that occur with two-electrode sensors at higher conductivities.
- Two additional electrodes measure the voltage drop in the medium which depends on the medium's conductivity.
- Transmitter calculates the conductance from the measured voltage and the given current

1 High-temperature sensor Condumax CLS12/13
Industrial and power plant applications (boiler feedwater); measurement of low conductivity values at high pressures (up to 40 bar) and high temperatures; Ex approval

2 Pure and ultrapure water sensor Condumax CLS15D/CLS15
Monitoring of ion exchangers, reverse osmosis, distillation and chip cleaning; electropolished electrode surfaces; Ex approval

3 Hygienic sensor Condumax CLS16D/16
Pharmaceutical industry, WFI (Water for Injection); monitoring of ion exchangers, reverse osmosis, distillation, FDA, EHEDG and 3A certificates; Ex approval

4 Drinking water and wastewater sensor Condumax CLS21D/21
Medium separation; potable water treatment, wastewater treatment; measuring range up to 20 mS/cm; Ex approval

5 4-electrode sensor Memosens CLS82D
Life sciences; monitoring of phase separation, fermentation or chromatography; FDA-listed, EHEDG, 3-A certificates, complies with USP Class VI; suitable for CIP, SIP, autoclaving; wide measuring range 1 µS/cm - 500 mS/cm

Turbidity sensors

Scattered light methods

Data that the sensor produces:

- 90 degrees scattered light measures the turbidity values under standardized, comparable conditions mainly in the low turbidity range.
- The 135-degree scattered light method is optimized for the measurement of high turbidites.
- Solid particles causes the incident light to scatter
    - Is measured using scattered light receivers
- The turbidity of the medium is calculated from the amount of scattered light
- Nephelometric Turbidity Units (NTU)

4-beam alternating light method
Based on two lights and four detectors

Data that the sensor produces:

- These light emitting diodes are pulsed at a frequency of several kHz so as to eliminate any effects of extraneous light.
- Two measuring signals are detected at the four detectors.
- The 4-beam alternating light method allows users to compensate for any fouling and aging of optical components.

Attenuation measurement

Data that the sensor produces

- A light source radiates a light beam through the medium.
- This measuring method is suitable for medium to high turbidites.

1 Online turbidimeter Turbimax CUE21
Drinking water and treated process water; with infrared light measurement according to EN ISO 7027 / DIN 27027 or white light measurement in accordance with US EPA 180.1; measuring range: 0-1000 NTU/FNU; ultrasonic cleaning, simple calibration.

2 Potable and process water sensor Turbimax CUS52D
Fine turbidity range with a resolution of 0.0015 FNU; scattered light measurement according to ISO 7027; easy calibration and verification with solid state reference; hygienic version for direct inline mounting

3 Wastewater sensor Turbimax CUS51D
All wastewater applications; 4-beam alternating light methods; excellent long-term stability; cleaning only - no maintenance; automatic air cleaning, if required

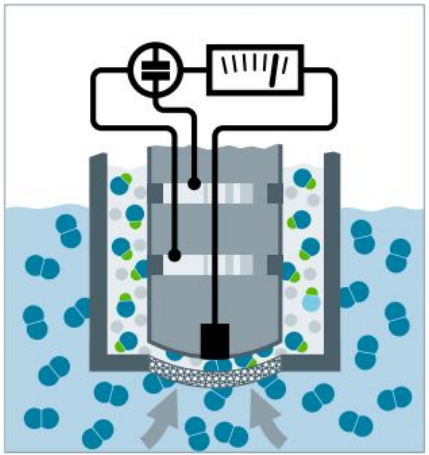
4 Absorption sensor Turbimax CUS50D
For industrial wastewater and process applications; light attenuation according to ISO 7027; high level of measurement accuracy and repeatability; robust materials for application in aggressive media or seawater; optional automatic air cleaning

Dissolved oxygen sensors

Oxygen sensors using the amperometric principle

Data that the sensor produces:

- sensor comprises a working electrode and a counter-electrode in the simplest version of the two-electrode system.
- A membrane provides the link to the medium or process
  - oxygen permeates from the medium into the electrolyte through the membrane
  - converted to a current at the working electrode
- Resulting current response is in direct proportion to the oxygen partial pressure
- The current is converted in the downstream transmitter and displayed to the user in the familiar units of oxygen saturation, concentration (in mg/l or ppm) and oxygen partial pressure.



Oxygen permeates into the electrolyte through the membrane and is converted to a current

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2

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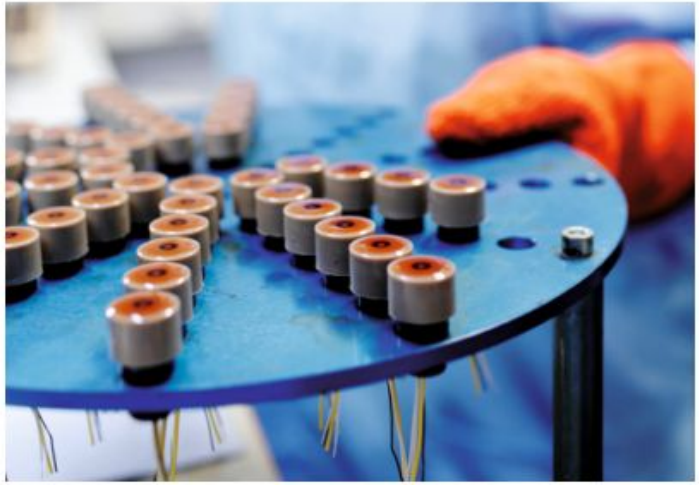


1 Hygienic sensor Oxymax COS22D
Digital sensor for food, pharmaceuticals, energy, chemicals, inertization; very wide measuring range: 0.001-10mg/l trace sensor; 0.01-60mg/l standard; 12mm stainless steel design, CIP and SIP compatible; approvals for hazardous area applications approvals

2 Water sensor Oxymax COS41
Analog sensor for water treatment; tried-and-tested 40mm design; two-electrode system; measuring range: 0.0-20mg/l

3 All-round sensor Oxymax COS51D
Digital sensor for water and wastewater; very wide measuring range: 0.05-100mg/l; 40mm design, 3-electrode system; long-term stability

Disinfection Sensors

Sensors for disinfection using the amperometric principle

Data that the sensor produces:

- Chlorine concentration are converted to electric currents in sensor, which are then processed in the transmitter to provide the required reading
- The medium (mostly water) is supplied to the sensor via a flow assembly.
- Discharged medium is either returned under pressure or directed into the drain
- The measuring points are often fully mounted on a panel; once the water supply and operating voltage have been connected, measurement can begin without delay.

Chlorine dioxide, this process works in a wide pH and temperature range.

Data that the sensor produces:

- Hypochlorous acid diffuses through the membrane and produces a reaction
- Hypochlorous acid in the medium depends on the pH value
- This dependency is compensated by means of pH measurement in the flow assembly and balancing in the transmitter.

1 Sensors for free available chlorine Memosens CCS51D and CCS51
Drinking water, pool water, industrial and process water; measuring ranges: 0 to 200 mg/l at a flow over 5 l/h (CCA151 without pH compensation); convex, dirt-repellent membrane and ultrasonic welding for long-term stable measurement; fast response time for precise dosing

2 Sensors for chlorine dioxide Memosens CCS50D and CCS50
Drinking water, industrial and process water; measuring ranges: 0 to 200 mg/l at a flow over 5 l/h (CCA151); convex, dirt-repellent membrane and ultrasonic welding for long-term stable measurement; fast response time for precise dosing

3 Sensors for total chlorine Memosens CCS120D and CCS120
Drinking water, pool water, industrial water and wastewater; measuring range: 0.1 to 10 mg/l including chloramines; wide pH range 5.5 to 9.5; for flow and immersion operation

Monitoring panels for disinfection

The monitoring panels for disinfection are fully mounted, tested and delivered complete, including medium conducting components and connections.

- Connect them to the media pipe

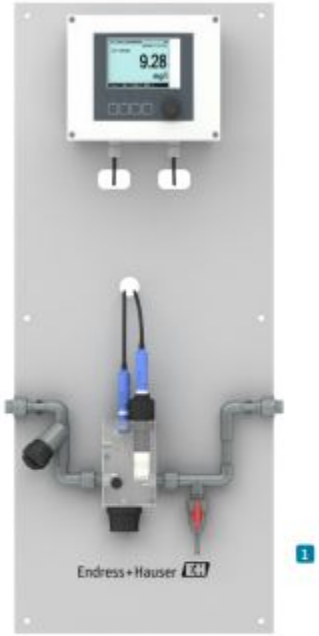
Panels for free chlorine are the standard solution for:

- Drinking water: to monitor, control and optimize disinfection process
- Swimming pools: to monitor the water quality
- Utilities of all industries

Chlorine dioxide panels are particularly suited for monitoring of:

- Cooling water systems to prevent formation of pathogens and biofilms
- Wash water for packaged vegetable and salad to ensure a high food quality
- Drinking water to ensure sufficient disinfection
- Beverage plants to secure the absence of chlorine dioxide

Measuring points - chlorine concentration are converted to electric currents in the sensor, which are then processed in the transmitter to provide the required reading.
The MP are often fully mounted on a panel; once the water supply and operating voltage have been connected.



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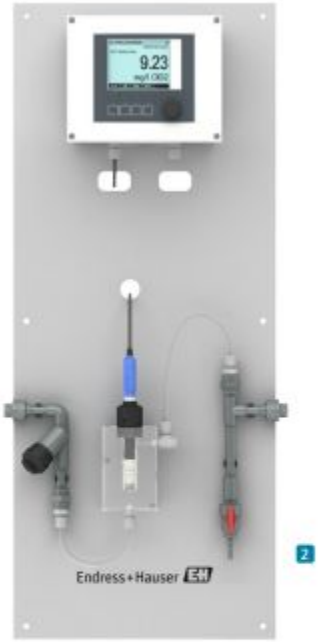

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1 Monitoring panel for free chlorine
Drinking water, industrial water, swimming pools; chlorine dosage for water treatment; based on Liquiline CM44 transmitter, Memosens CCS51D for free available chlorine, pH and temperature measurement and CCA250 flow assembly

2 Monitoring panel for chlorine dioxide
Cooling water, washwater, beverage plants; chlorine dioxide measurement to avoid pathogen and biofilm formation as well as overdosing; based on Liquiline CM44, Memosens CCS50D sensor and CCA151 flow assembly

Work cite (slides 21-35)

https://www.us.endress.com/en/field-instruments-overview/liquid-analysis-product-overview

Contaminants

- **pH**
- **Free chlorine**
- Oxidation Reduction potential (ORP)
- **Dissolved Oxygen**
- **Specific Conductance**
- **Turbidity**
- Total Organic Carbon (TOC)
- **Chloride**
- Ammonia
- Nitrate

Most information on these sensors were obtained, but some still need more research to be done.

Began research upon the other contaminations

https://www.researchgate.net/publication/228623564_On-Line_water_quality_parameters_as_indicators_of_distribution_system_contamination

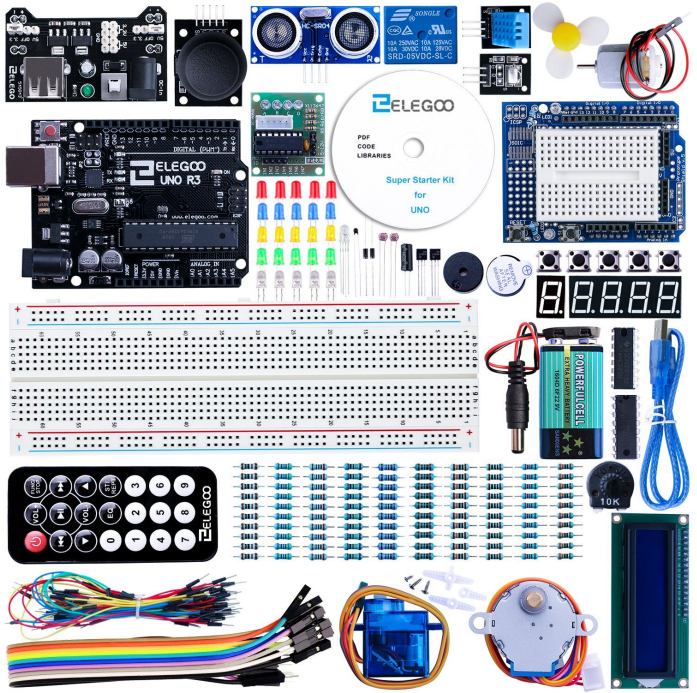
The necessary IoT sensors

Arduino Genuino 101

(ELEGOO UNO Project Super Starter Kit)

Arduino Genuino 101 collects the measurements data periodically

- Obtains the GPS coordinates, and uploads the data bundle into a database using GPRS data link.
- Compatibility with Official Arduino IDE
- **Price: $38.99**



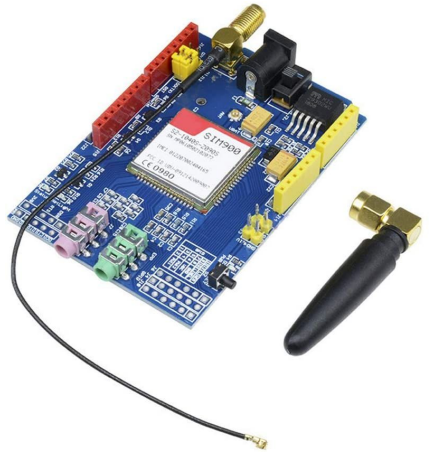
A7 GPRS and GPS module

GPRS and GPS

Price: $10.00 (Sold Out)

SIM 900A Module GSM GPRS

Price: $21.99



The SIM900A is a complete Dual-band GSM/GPRS solution in a SMT module which can be embedded in the customer applications

Featuring an industry-standard interface, the SIM900A delivers GSM/GPRS 900/1800MHz performance for voice, SMS, Data, and Fax in a small form factor and with low power consumption.

Water Quality Sensor Probes

pH sensor probe

GAOHOU PH0-14 Value Detect Sensor Module + PH Electrode Probe BNC For Arduino

Price: $39.99

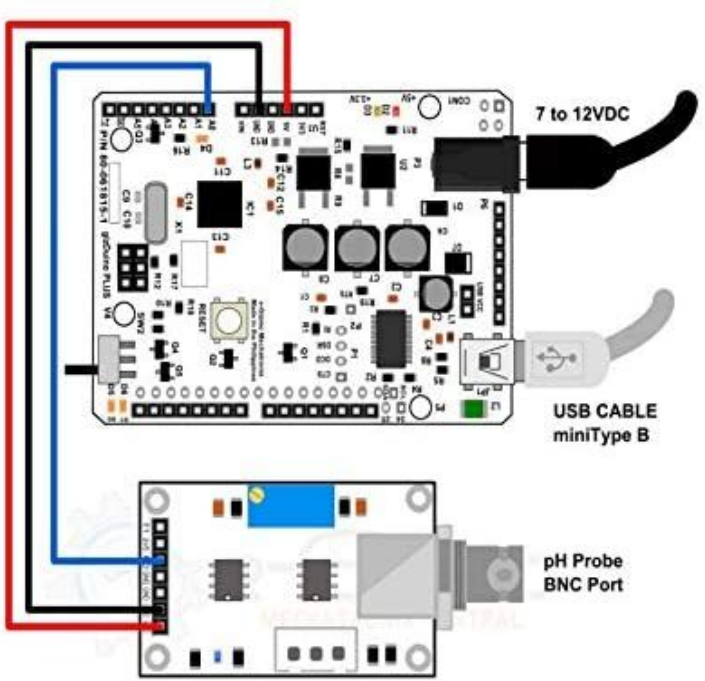


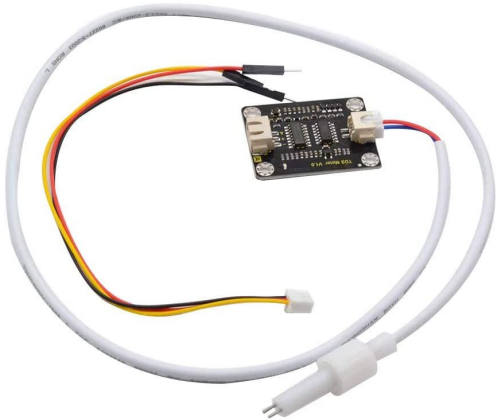
Figure 4: Sample connections.

Turbidity sensor probe

NINEFOX Analog TDS Sensor Module Waterproof Probe DIY Water Conductivity sy Use Home Metal Quality Monito Meter Tester Liquid Detection Online for ARDuino

Price: $29.30

Conductivity sensor probe



NINEFOX Analog TDS Sensor Module Waterproof Probe DIY Water Conductivity sy Use Home Metal Quality Monito Meter Tester Liquid Detection Online for ARDuino

Price: $19.06

Gravity: Analog Electrical Conductivity Sensor /Meter V2 (K=1)

Price: $69.90

Free Chlorine sensor probe

Myron L RPT4, Replacement Free Chlorine Sensor for PT4

Price: $139.00

ORP Sensor probe

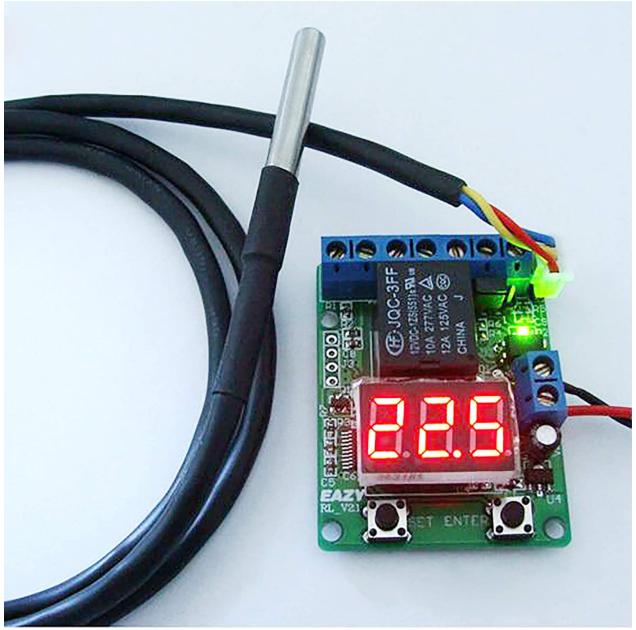
Gravity: Analog ORP Sensor Meter For Arduino

Price: $89.00

Temperature Sensor probe

Gikfun DS18B20 Temperature Sensor Waterproof Digital Thermal Probe Sensor for Arduino (Pack of 5pcs) EK1083

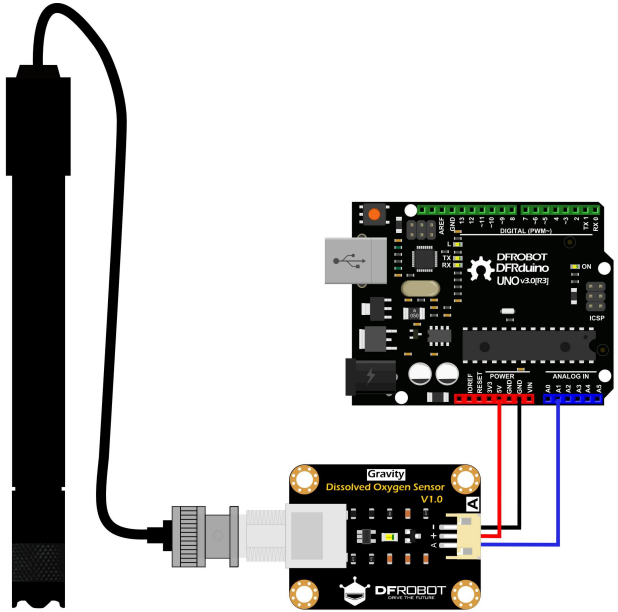
Price: $12.68



Dissolved oxygen sensor probe

Gravity: Analog Dissolved Oxygen Sensor / Meter Kit For Arduino

Price: $169.00



Waterproof Enclosure

Price: $41.50

An enclosur to protect the project sensors from potential water when being tested

- Height: 1 11/64 in
- Width: 2 11/64 in
- Depth: 4 3/4 in

Measurement	Value Range	Impact of high value	Impact of low value
PH	6.5 - 8.5	irritation to the eyes, skin, and mucous membranes. Eye irritation and exacerbation of skin disorders have been associated with pH values greater than 11. https://www.who.int/water_sanitation_health/dwq/chemicals/ph.pdf	Water with a low pH can be acidic, naturally soft and corrosive
Turbidity	1.0 NTU - 5.0 NTU		Low turbidity values indicate high water clarity
Conductivity	409 - 995 (µS/cm)		
Chlorine	0 - 4 (mg/L)	Hi level of Chlorine may cause fluid build up in the lungs, a condition know as pulmonary edema	
ORP	General: 200 mV - 400 mV Highest: 500 mV - 600 mV		
Temperature	50°F - 72°F		
Dissolved Oxygen	257-614		