MARITIME RESEARCH CENTER
FOUNDATION FOR UNDERWATER DOMAIN AWARENESS

<u>Research Note</u>

Real-time sensor-based water quality management system

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ABSTRACT:

Real-time sensor-based water quality management systems can emerge as a crucial tool for monitoring and maintaining the quality of water resources. With growing concerns over water pollution and the need for sustainable water management, these systems play a vital role in ensuring the safety and usability of water for various purposes, including drinking water, industrial processes, and environmental conservation.

The importance of sensor technology lies in collecting accurate and timely data on various water quality parameters such as pH, turbidity, dissolved oxygen, temperature, and contaminants like heavy metals and organic pollutants. These sensors are designed to operate continuously, providing a wealth of data that can be analyzed and acted upon promptly.

With the aid of wireless connectivity and Internet of things (IoT) technologies, the collected data can be transmitted in real-time to a centralized control center or cloud-based platform. This allows stakeholders, including water treatment operators, government agencies, and researchers, to access and monitor water quality parameters from anywhere, facilitating timely interventions and data-driven decision-making.

INTRODUCTION:

Pollution, global warming, insecurity, and risky health conditions characterize the 21st century. The contamination of water bodies is the main issue facing the world today in terms of water pollution. When toxins are released into water bodies either directly or indirectly, water contamination results. The flora and animals that inhabit these bodies of water are impacted by water pollution. Polluted water also has an effect on human health.

The constant review and revision of the guiding principles for water resources of all sizes, from the international to individual wells, is necessary due to the major global problem of water pollution. According to surveys, the primary global cause of death and diseases is water contamination. The World Health Organization estimates that 3.575 million people die from water-related diseases a year.

According to a report by Lancet Commission on Pollution and Health, more than 500,000 deaths were caused by water pollution in the year 2019. In less developed countries, contaminated or dirty water is frequently used for drinking without any prior treatment. The lack of a system to monitor the water's quality is one of the reasons for this, which presents serious health hazards to the populace, the government, and other stakeholders.

Monitoring system based on Wireless Sensor Network (WSN):

In order to keep the water resource within the parameters specified for domestic use and to be able to take the necessary actions to restore the health of the degraded water body, Wireless Sensor Networks (WSN) are used to monitor the quality of water using information sensed by sensors submerged in water. This system can measure a number of factors from water, including temperature, pH, oxygen density, turbidity, and others, using a variety of sensors.

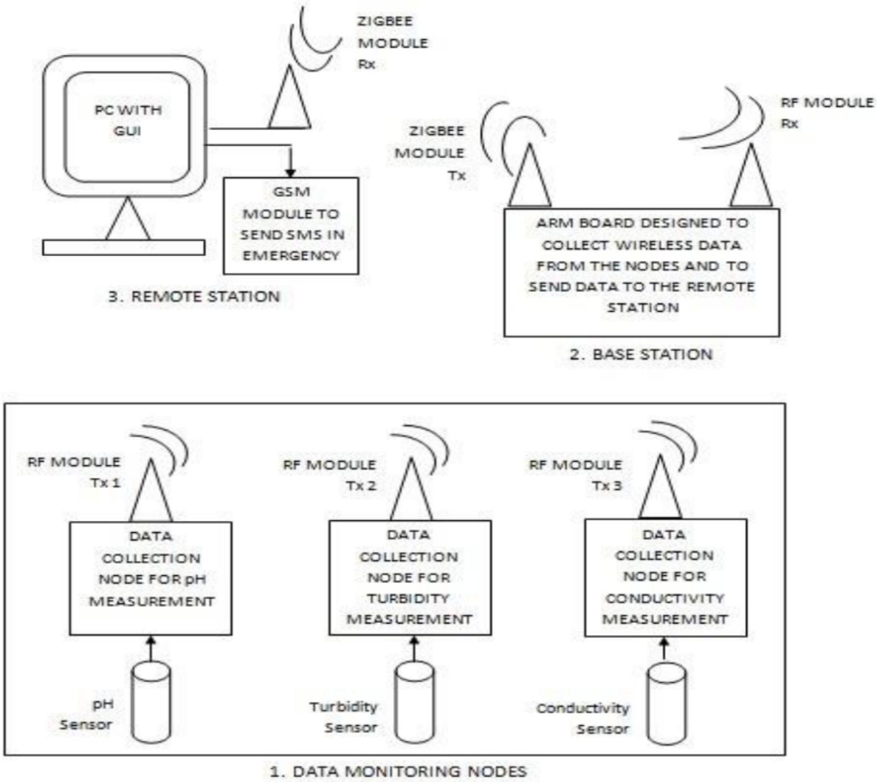
Thanks to the speedy development of wireless sensor network (WSN) technology, real-time data collection, transmission, and processing now have a novel approach. Customers get remote access to the most recent water quality data. Numerous nodes, a base station, and a distant monitoring station make up this kind of system. The nodes are dispersed over various bodies of water, and each node has a number of sensors. Data from a sensor node is sent to a base station through a WSN channel and then to a remote monitoring station. The remote monitoring station is frequently a computer equipped with a Graphic User Interface (GUI), which enables users to evaluate data on water quality. To determine future correspondence and actions, it is possible to analyze the recorded data using a variety of simulation techniques.

Real-Time Monitoring System Mechanism

A local Zigbee network that can measure a variety of water quality metrics, a WiMax network, and web-based monitoring with a controlling computer would all be included in this system. The system's goal is to gather and analyze data, then use a remote web server to make decisions in real-time. Users can remotely monitor the water quality from their location rather than collecting data on the scene since the data is sent through the Zigbee gateway from sensor nodes to the web server using a WiMax network. According to experimental findings, the system can detect water pollution in real-time.

The major goal of this project is to create a system for wireless sensor networks with high detection accuracy, low power consumption, and low cost that can continuously monitor water quality at remote locations. The characteristics that are examined to raise the water quality include pH, conductivity, turbidity level, and others. The goals for putting the notion into practise are listed below.

- To measure water parameters such as pH, dissolved oxygen, turbidity, conductivity, etc., using available sensors at a remote place.
- To collect data from various sensor nodes and send it to the base station by wireless channel.
- To simulate and analyze quality parameters for quality control (Graphical and numerical record using MATLAB).

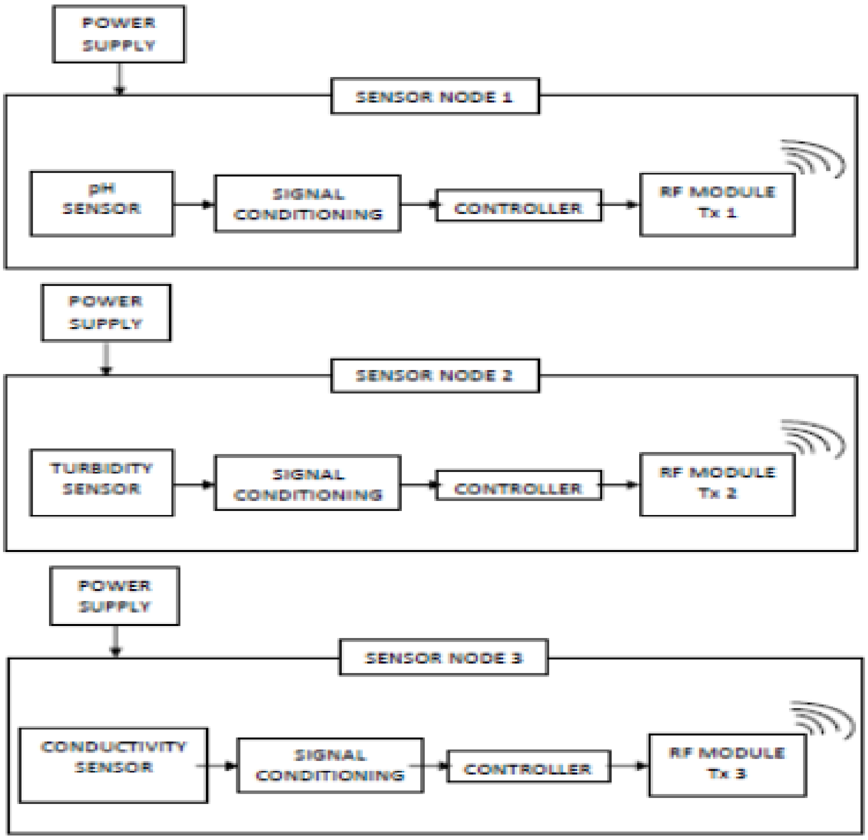


The proposed water quality monitoring system based on WSN can be divided into three parts:

• Data monitoring nodes
• Data base station
• Remote monitoring centre

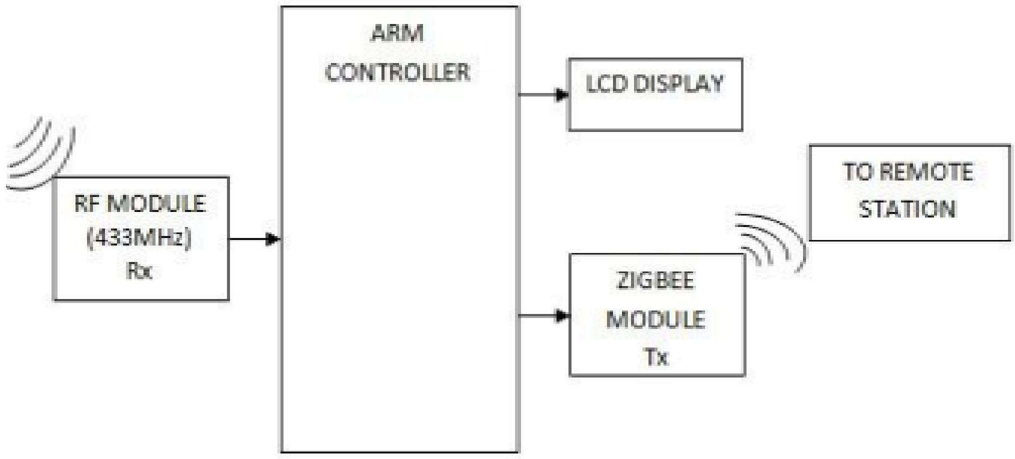
1. <u>Data Monitoring Nodes</u>:

It is made up of sensors (pH, turbidity, and conductivity), a controller, a signal conditioning circuit, and an RF module. The sensor's data will be routed through a signal conditioning circuit to modify the analog signal so that it complies with the demands of the following step for additional processing. The controller (PIC16F877A) will then receive the altered data. For further processing, the internal ADC will convert the analog signal to a digital signal. The altered detected data will be transmitted to the Data Base Station with the aid of the RF module.



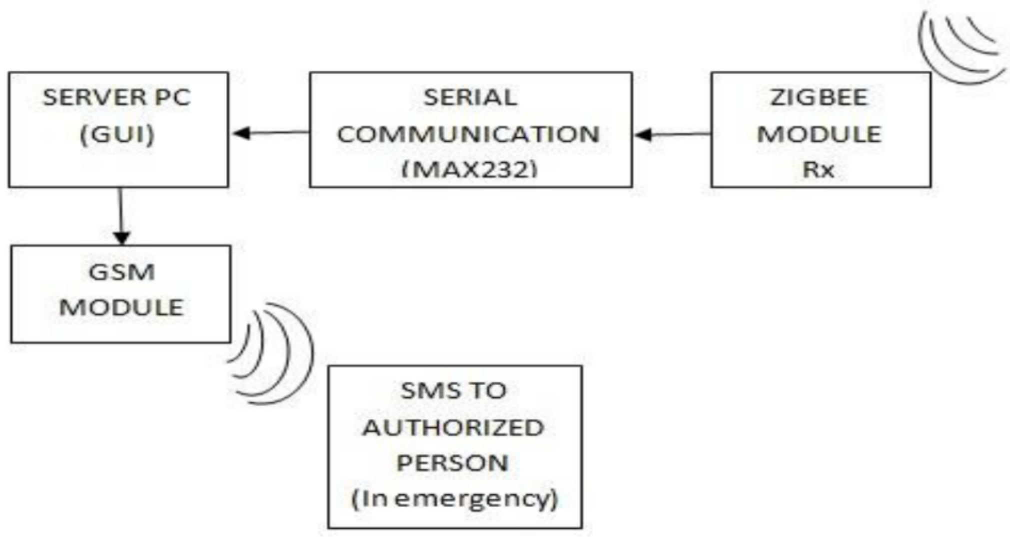
2. <u>Data Base Station:</u>

The data from all the nodes is collected at the Data Base station consisting of ARM processor (LPC2148). The data from each node is collected one after another i.e. using time multiplexing. This obtained data is displayed on an LCD display. Also, this data is forwarded to the remote monitoring station via the ZigBee module.



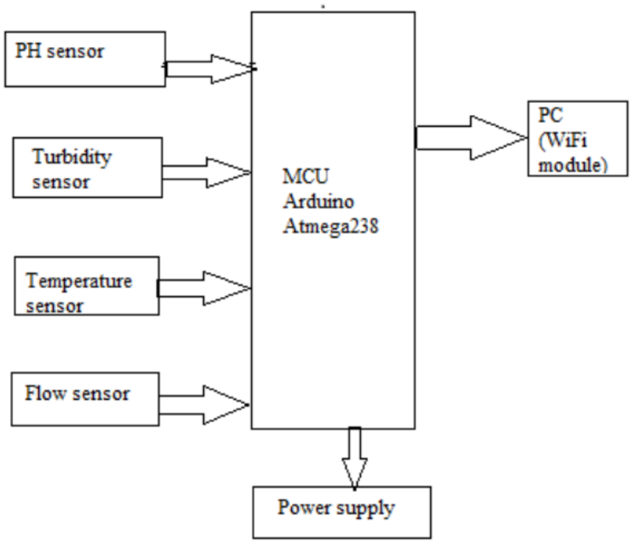
3. <u>Remote Monitoring Station:</u>

The data transmitted by the Data Base station will be received by a ZigBee module that makes up the remote monitoring station. Through serial connectivity, this data will be transmitted to a server PC with a Graphic User Interface (GUI). With the aid of MATLAB, the collected data will be represented graphically and preserved for future use. The acquired data is also contrasted with the water parameter standards. An alert signal will be sent to a designated person to take precautionary action if the obtained water parameters do not match the predefined levels.



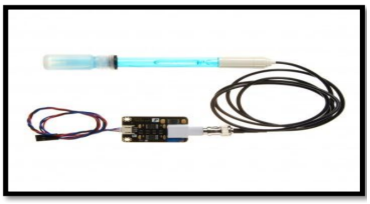
IoT based Water Sensing System:

One of the main concerns for green globalization is water contamination. The quality of the water needs to be constantly examined to ensure a secure supply. Here, we demonstrate the design and creation of a low-cost system for Internet of Things (IoT) real-time water quality monitoring. The system, which comprises of a number of sensors, is used to gauge the water's physical and chemical characteristics. It is possible to measure the water's characteristics, including its temperature, PH, turbidity, and flow sensor. The core controller is capable of processing the measured values from the sensors. A core controller can be created using the Arduino model. Finally, a WI-FI system can be used to see the sensor data online.



The core controller is coupled to a number of sensors (temperature, pH, turbidity, and flow) in this suggested block diagram. The main controller accesses the sensor readings and modifies them before sending the data over the internet. The central controller is Arduino. On the internet wi-fi system, the sensor data can be accessed.

pH Sensor: It operates on a 5V power supply and it is easy to interface with Arduino. The normal range of pH is 6 to 8.5.



Turbidity Sensor: Turbidity is a measure of the cloudiness of water. Turbidity has indicated the degree at which the water loses its transparency.

Temperature sensor: Water Temperature indicates how water is hot or cold. The range of DS18B20 temperature sensor is -55 to +125 °C. This temperature sensor is the digital type which gives accurate reading.

Flow sensor: This sensor basically consists of a plastic valve body, a rotor and a Hall Effect sensor. The pinwheel rotor rotates when water / liquid flows through the valve and its speed will be directly proportional to the flow rate. The Hall Effect sensor will provide an electrical pulse with every revolution of the pinwheel rotor.

Arduino Uno: The ATmega328P serves as the basis for the Arduino microcontroller board. It contains 6 analogue inputs, a 16 MHz quartz crystal, a USB connection, a power jack, an ICSP header, and a reset button. It also has 14 digital input/output pins, 6 of which can be used as PWM outputs. It has all the components required to support the microcontroller. The earlier revisions of Arduino have grown from the original Arduino Software (IDE). The Uno board is the first in a line of

USB Arduino boards and serves as the standard for the Arduino platform. For a comprehensive list of all the other boards, both current and old or out-of-date, visit the Arduino index of boards.

Wifi Module: A self-contained SOC with an integrated TCP/IP protocol stack, the ESP8266 WiFi Module allows any microcontroller to access your WiFi network. The ESP8266 is capable of offloading all Wi-Fi networking tasks from another application processor or hosting an application. An AT command set firmware is pre-programmed into each ESP8266 module. The ESP8266 module is a very affordable board with a sizable and expanding community.

WQI Model Structure

We can integrate a WQI method to get real-time WQI into the system.

The general structure of WQI models includes four main steps:

1) selection of the water quality parameters: one or more water quality parameters are selected for inclusion in the assessment.

2) generation of the parameter sub-indices: parameter concentrations are converted to unitless sub-indices.

3) assignment of the parameter weight values: parameters are assigned weightings depending on their significance to the assessment.

4) computation of the water quality index using an aggregation function: the individual parameter sub-indices are combined using the weightings to give a single overall index. A rating scale is usually used to categorize/classify water quality based on the overall index value.

Preferred WQI Model:

- **National Sanitation Foundation WQI** (NSF-WQI)

  The NSF WQI was developed by Brown in 1965 as a modified version of the Horton model. It has been used to evaluate surface water quality in various domains. Like the Horton model, it contains the four basic WQI components.

1. Parameter selection:

The water quality criteria were chosen using the Delphi method. The NSF index offered five groupings of the eleven water quality parameters it included: Temperature, turbidity, and total solids are physical parameters. pH and dissolved oxygen are chemical parameters. Fecal coliforms and BOD are microbiological parameters. Total phosphate and nitrates are nutrient parameters. Pesticides and other toxic compounds are toxic parameters. Most other WQI models omit toxic elements. It was recommended that the toxic parameters group be added.

2. Sub-index generation:

The parameter sub-indexing was developed based on expert panel judgement. Sub-index values ranged from 0 to 1 where the sub-index value was considered 1 when the measured value was found to be within the recommended guideline values and 0 otherwise.

3. Parameter weighting:

The model employs unequal parameter weights that add up to 1. Although a panel of experts was utilised to generate the original weight values, subsequent uses of the model have used updated weight values to assess surface water quality. The initial NSF model specified weight values for the following variables: DO (0.17), FC (0.16), pH (0.11), BOD (0.11), temperature (0.10), total phosphate (0.10), nitrates (0.10), turbidity (0.08), and total solids (0.07). In a similar vein, this approach allocated the parameter weight value while taking the environmental impact of water quality metrics into account.

WQI	WQ parameters	Modelrecommended weight values
NSF	DO	0.17
	pH	0.11
	BOD	0.11
	tem	0.1
	TP	0.1
	Nitrate	0.1
	Turbidity	0.08
	TS	0.07
	FC	0.16
	*TON	–
	*SS	–
	Total	**1**

4. Aggregation:

The original NSF model used a simple additive aggregation function. In 1973, Brown proposed an alternative aggregation function – the multiplicative function given as

$$WQI = \prod_{i=1}^{n} {s_i}^{w_i}$$

5. WQI evaluation:

The model outputs a WQI that ranges from 0 to 100. 0 indicates the worst water quality and 100 indicates excellent water quality. The model proposed five water quality classes:

1) excellent (WQI = 90–100)
2) good (WQI = 70–89)
3) medium (WQI = 50–69)
4) bad (WQI = 25–49)
5) very bad quality (WQI = 0–24)

Khadakwasla Lake Reservoir:

The Mutha River, which has its source in the Western Ghats, flows for about 21 km until merging with the Mula River in Pune. The Mutha River has been dammed twice, the first time at the Panshet Dam (on the Ambi River), which supplies irrigation and drinking water to Pune. Pune relies heavily on this water, which is dammed up again at Khadakwasla, as a supply of drinking water. Later, a second dam was constructed at Temghar on the Mutha River.

All along its journey in Pune city, it receives raw sewage and garbage and is one of the most polluted rivers. Pune takes about 1000 MLD water for drinking from Mutha River through closed pipes and discharges about 750 MLD of its sewage into Mula River.

(**Taken from a report of Hindustan Times**) According to the Namami Chandrabhaga report 2019, the water along the stretch of river between Khadakwasla dam and Mundhwa bridge (Pune Municipal Corporation/PMC area) was found to be of poor quality as the dissolved oxygen reduces by 42.6% and the BOD (biochemical oxygen demand) increases 6.1 times only to then reduce to an increase of 4.8 times.

The Central Pollution Control Board (CPCB) – which studied the river samples at multiple spots – found that the dissolved oxygen levels, which should be 5mg/litre, are 6.62mg/litre at the Khadakwasla dam source; 3.70mg/litre along the Mutha river at Sangam bridge; and 3.80mg/litre at Mundhwa bridge.

While the main cause of pollution along this stretch of river is sewage runoff, as fecal coliform increases 10 times in the western part of Pune city, other sources include industrial pollution from chemical industries such as electroplating; agricultural runoff containing fertilizers; and untreated sewage.

Some data on the Khadakwasla dam reservoir :

According to National Water Informatics Centre - *AVAILABLE PARAMETER LIST FOR MUTHA RIVER AT KHADAKVASLA DAM KHADAKVASLA HAWELI PUNE. , PUNE, MAHARASHTRA*

Parameter	Unit	Value	Year
Dissolved Oxygen	mg/L	6.5	2021
Biochemical Oxygen Demand	mg/L	7.4	2021
Fecal Streptococci	MPN/100mL	2	2021
Fecal Coliforms	MPN/100mL	8	2021
pH		7.1	2021

According to CPCB's Official website -
Values of some more parameters are as follows:

- Temperature (min-max):- 23-28 °C

- Conductivity (min-max):- 104-966 µmhos/cm
- Nitrate (min-max):- 0.3-4.7 mg/L
- Total Coliform level (min-max):- 4-70 MPN/100mL

Water quality of Khadakwasla dam reservoir A/c to Namami Chandrabha report 2019

Month	Year	pH	DO (mg/L)	BOD (mg/L)	FC MPN /100ml	TC MPN /100ml	Water Quality
January	2017	8.1	6.5	4			Non Complying
	2018	7.7	6.5	2.4	4	14	Complying
February	2017	7.8	6.1	4			Non Complying
	2018	8.2	6.8	2.6	14	45	Complying
March	2017	7.2	5.9	4.5			Non Complying
	2018	7.9	6.7	2.4	6	17	Complying
April	2017	8.1	5.9	4			Non Complying
	2018	7.9	6.4	2.6	12	350	Complying
May	2017	8	5.9	4.5	13	70	Non Complying
	2018	7.31	6.6	2.4	6	120	Complying
June	2017	7.6	6	5	20	195	Non Complying
	2018	8.5	6.1	3.4	8	200	Non Complying
July	2017	7.5	6.6	3.2	4	14	Non Complying
	2018	7.2	6.2	2.5	9	225	Complying
August	2017	8.2	7.0	3.8	2	6	Non Complying
	2018	8.1	6.8	2.2	2	20	Complying
September	2017	8.0	7.2	2.8	4	45	Complying
	2018	7.8	6.8	2.2	2	35	Complying
October	2017	7.9	6.7	3.2	140	900	Non Complying
	2018	8.0	6.2	2.4	10	200	Complying
November	2017	8.0	6.5	2.6	6	40	Complying
	2018	7.9	6.4	2.2	7	170	Complying
December	2017	8.2	6.2	2.6	4	20	Complying
	2018	7.51	6.6	2	6	250	Complying

APPLICATIONS:

1. Real-time water quality monitoring: With the measured parameters observed through these sensors, water quality index can be calculated instantaneously and with WQI it can placed in water quality class accordingly.

2. Hotspot detection: Problematic areas of the water body can be identified and alerted to the user quickly. It can be measured when any parameter value goes beyond ideal standards.

3. Health of Aquaculture: With the observed values of DO, BOD of the lake water, we can estimate the health of its marine life.

4. Important tool for organizations: By detection of various parameters, it can help various organizations (that are responsible for maintaining water quality) to kickstart their approach towards solution methods.

5. Remote Surveillance: An HD camera can be attached with the model that can give real-time pictures of its surroundings. It can help in detection of any suspicious activity.

FUTURE SCOPE:

- Integration of many other sensors as it is important to calculate WQI and helps in a thorough study of water quality.
- GPS tracking: Integration of GPS tracking is must as it will help in monitoring water quality of a particular location with the help of remote control.
- Advantages of WSN based system over existing methods.
- Integration of Disruption Networking Technology (DTN): It will help in prevention of data loss during intermittent or limited network connectivity.

CONCLUSION:

Utilising an existing GSM network and WSN network as well as a water detection sensor with a unique advantage, monitoring of turbidity, PH, and temperature of the water is possible. The device can automatically check the quality of the water, is inexpensive, and does not need anyone to be on duty. Testing the water quality should therefore be more affordable, practical, and quick. The method is very adaptable. By putting various sensors into action, we may obtain the values of numerous parameters simultaneously. The process is easy and can be manageable.

It is possible to expand the system to track hydrologic conditions, air pollution, industrial and agricultural output, and other variables. It has a wide range of uses and extension values. By retaining embedded devices in the environment for monitoring, the ecosystem can protect itself (creating a smart environment). To put this into practice, a mobile sensor-based system must be set up in the surroundings for data collection and analysis. It's controllable from a distance. We can make the environment more realistic by placing sensor devices there, allowing the environment to communicate with other things across a network. The final user will then have access to the gathered data and analysis results via the various methods described in the paper.

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Remotely Controlled model :

A remotely controlled boat which can monitor the real-time water characteristics of a water body is the need of the hour. The output characteristics obtained can be used to plot a geo-map of the respective water bodies and help find possible zones of concentrated contamination. The water monitoring boat is designed with a square frame structure utilizing Poly Vinyl Chloride (PVC) pipes which will limit the resistivity of water stream and this shape likewise keeps up the stability of the boat in the water.

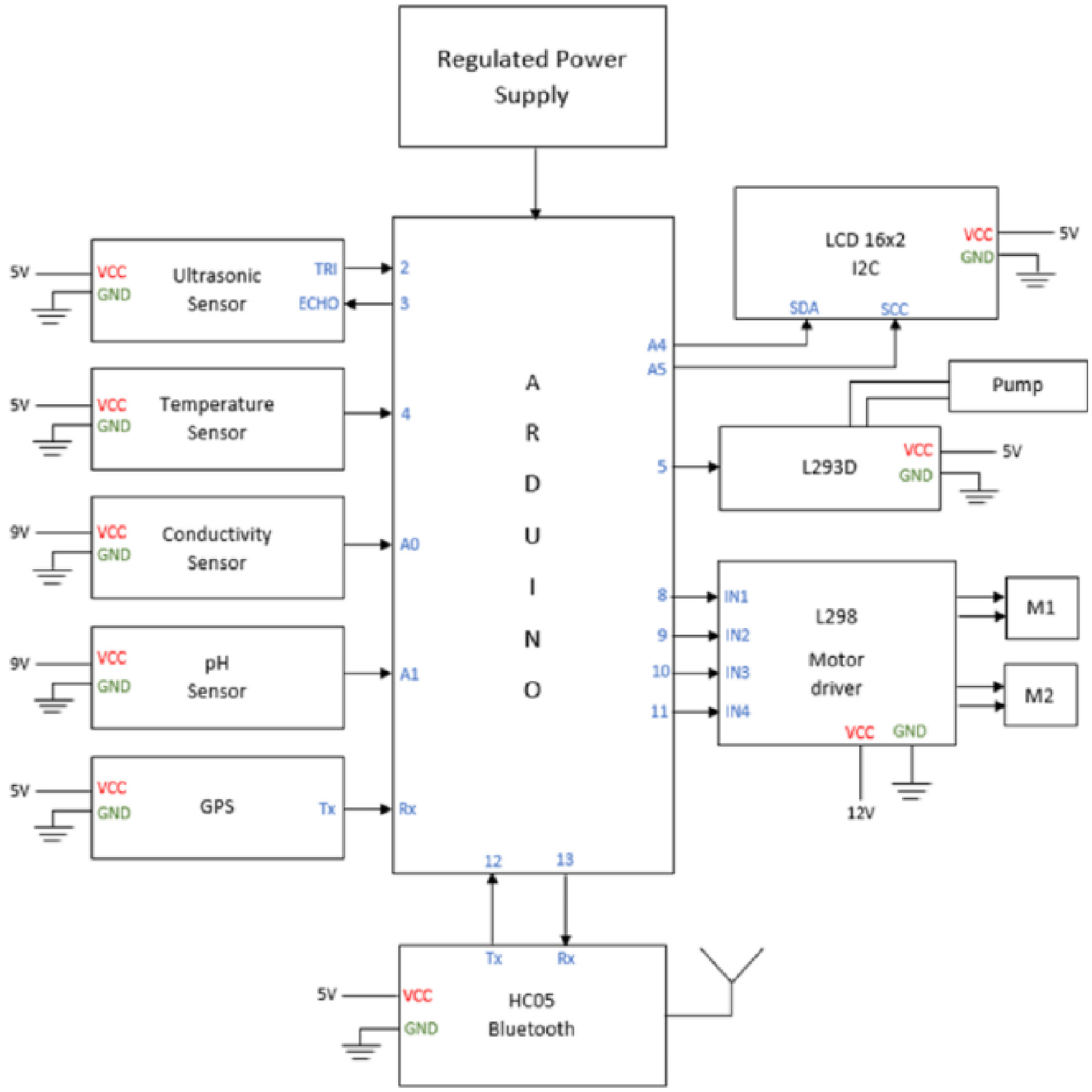


Fig. 3. Electronic circuitry for boat.

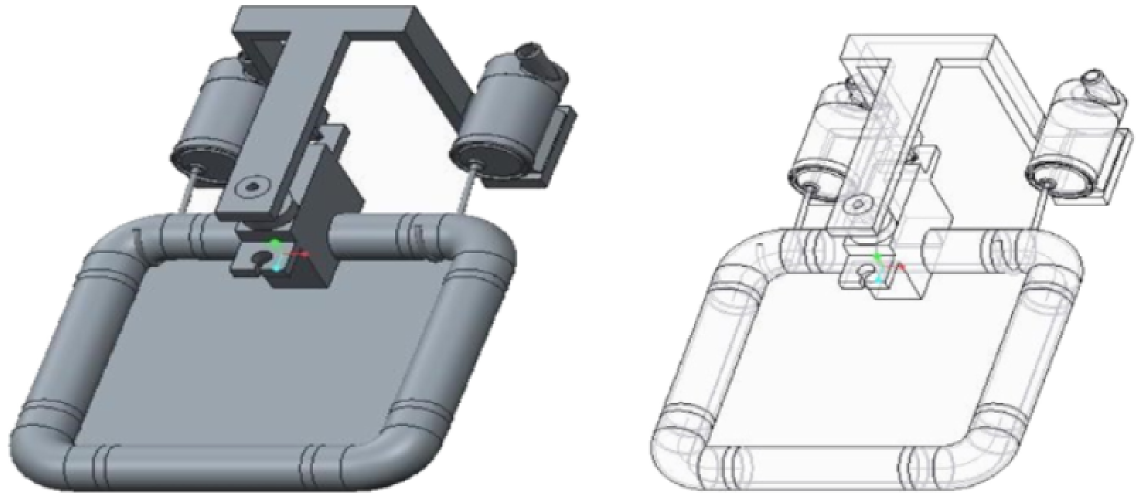


Fig: Body Frame of boat.

Methodology:

The remotely controlled boat is mainly used for water monitoring and sampling. The propulsion unit consists of two DC geared motors of 100 rpm. The boat is controlled using the smartphone application interface which is interconnected via Bluetooth. The boat is made to move on the surface of the water body and the water characteristics at different locations are monitored and sampled. The boat travels to different areas of the water body and collects data and samples. The locations at which the water is monitored and sampled are marked using a GPS Module. The readings are received on the smart phone.

To ensure that the boat would float and accommodate the necessary sensors and components it is imperative that the buoyant force generated by PVC pipes is sufficiently greater than the total weight of the remaining components. To achieve this the buoyant force generated by the pipes have to be twice that of the weight of the components. The buoyancy force calculated as 3:9312lb=ft, and the diameter of the pipe used for the float is 0.3ft. The total length of the pipe used is 5.6568ft therefore the pipes that are used in the boat can accommodate load up to 10.0850 kg.
The Arduino control boards, GPS module, motor driver and other electrical components are connected to the square frame of the pipes. The sampling of water is done with the help of a 5 V submersible pump.

Electronic Circuitry of the boat:

A 16x2 LCD is connected to Arduino pin A4 and A5 using the I2C module. A 5 V water pump is controlled by Arduino through an L293D motor driver which is connected to Arduino pin number 5. Movement of the boat is done by a combination of two DC geared motors which are controlled by L298 motor driver which is connected to Arduino pin number 8, 9, 10 and 11. To calculate the distance of the object which is in front of the boat, there is an ultrasonic sensor (HCSR-04) connected to the Arduino pin number 2 and 3. To check the temperature of the water, there is a waterproof temperature sensor which connects to the Arduino pin number 4. To check the conductivity level and pH value of the water, there is a conductivity sensor and pH sensor connected to the Arduino pin number A0 and A1 respectively.

To track down the latitude and longitude values, we have connected a GPS module to the RX of Arduino. To communicate with the boat, we have used an HC-05 Bluetooth module which is connected to pin number 12 and 1. There is a Wi-Fi camera which is placed at the top of the boat which is controlled via Wi-Fi. Various components here require 5 V supply and some require 12 V supply which is given using a Regulated Power Supply Board. There are some components which require 9 V supply and this requirement is fulfilled using an LM2596 DC-DC converter.

Working Principle:

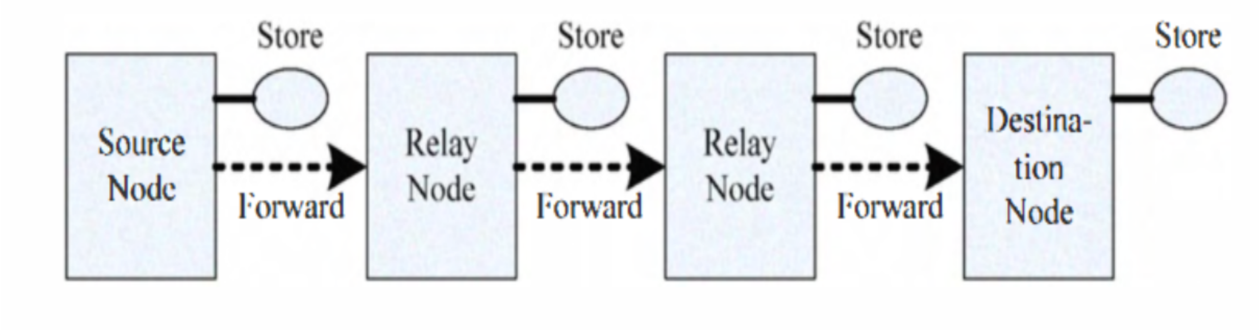
The boat can be released in any water body (Lake, river, etc.) and can provide real-time water quality parameters. These parameters are detected with the help of the different sensors. The boat is controlled with the help of the Bluetooth controller app (V380) that is loaded on an android smartphone. The results of various sensor readings can be obtained from the boat. The sensors used on the boat are temperature, conductivity, pH, GPS, and ultrasonic sensors.
The results of these tests are displayed on the Liquid Crystal Display (LCD) 16X2. The ultrasonic sensors are used to detect any obstacle ahead of the boat and displays the same message when it encounters any obstacle. The result from the ultrasonic sensor is displayed on the LCD screen. Also, the LCD screen displays the values of the other tests conducted on the boat.

Here instead of a Bluetooth module, a WiFi module can also be used for wireless communication of data for water quality monitoring. Long-range wireless communication cannot be achieved in many existing water quality monitoring systems using Bluetooth. ESP32(WiFi module) is used in low power IoT sensor applications. The LoRa sender module in the water quality sensing node performs wireless transmission of sensor data to LoRa receiver which is several kilometers away from the water quality node. LoRa receiver connected to ESP32 gateway via SPI communication. The server used here is ThingSpeak IoT platform.

Disruption Tolerant Networking:

Disruption Tolerant Networking (DTN) is a technology that will provide network services for environments so extreme that no end-to-end path exists through a network. DTN hopes to tackle the problem of communicating in areas where, due to various factors, normal means of communication have limited success and are unreliable. It is important due to the importance of managing network congestion.

Currently, end-to-end congestion control is handled by the TCP protocol that prevents the network from collapsing, but network degradation does occur when the network becomes congested. TCP/IP works well when there is no disruption to end-to-end communication. Disruption Tolerant Networking addresses weaknesses in TCP, such as implementing congestion control mechanisms where each router can make decisions based on local information, such as accepting a bundle of data from another router. It limits the data loss within a network by inducing flow control which is automatically triggered when there is a difference in the arrival rate and transmission rate of data within the network.



DTN uses a "store-carry-forward" to resolve the issue of information exchange. All data or data-chip from one node's storage to another node's storage, and carried by the node and forwarded to the next node until the final destination. Using "store-carry-forward," intermediate nodes will always cache data regardless of whether the link is connected before data sending to the destination.

Regions where it is difficult to deploy DTN:

1. Remote Islands and Polar Regions: Remote islands and polar regions often have limited infrastructure and face challenges in establishing reliable communication networks. Harsh weather conditions, extreme temperatures, and logistical difficulties can make it challenging to deploy and maintain DTN in these areas.
2. Deep Ocean and Underground Environments: Deep ocean environments and underground structures pose unique challenges for communication due to the absence or limited availability of traditional network infrastructure. Deploying DTN in these environments may require specialized technologies and equipment for communication and data transmission.

It's important to note that despite the challenges, DTN can still provide benefits in these regions by enabling communication and data transfer in situations where traditional infrastructure is unreliable or unavailable. In some cases, alternative technologies such as satellite communication, mobile ad hoc networks, or localized infrastructure may be used to support DTN deployment in these challenging environments.

Acoustic Beamforming Architecture for Real-Time Marine Sensing:

Hydrophones are a special type of microphone designed for use underwater to record or listen in the marine acoustic environment. In the past, they have been used to locate submerged vehicles and marine vocal animals and even to study global warming through ocean temperature evolution.
This architecture consists of vertical linear arrays of two or four RHSA10 hydrophones models attached to a buoy or a vessel for sound detection; a frequency domain beamformer (FDB) technique implemented in a Xilinx

Spartan-7 field programmable gate array (FPGA) for sound source localization; a LoRa wireless sensor network mote to provide convenient access from a base center.

Materials and Methods:

Each of the floating buoys is equipped with a global positioning system receiver (GPS), a beamformer fully embedded in a field programmable gate array (FPGA), which processes several operations to detect the signal incoming source, a battery pack, and a wireless sensor mote to relay the input signal location result to a control center and an array of RHSA-10 model hydrophones. **The system aims to track vessels emitting sound waves with frequencies up to 20 kHz in a specific area.**

The FPGA is linked to the system via Serial Peripheral Interface (SPI), a synchronous serial communication protocol that provides full duplex communication at very high speeds. It provides low-cost support for as many devices as the number of available chips, with speeds up to about 100 MHz. Each floating buoy in the system is equipped with a linear array of 2 RHSA-10 model hydrophones, fixed on an alloy rod at a 3 m distance from each other. The 4 m long alloy rod is itself fixed under the buoy, which has hydrophones at 0.5 m from each edge. A deflector and a weight are fixed at the down edge of the rod to reduce drifting flow and procure more stability.

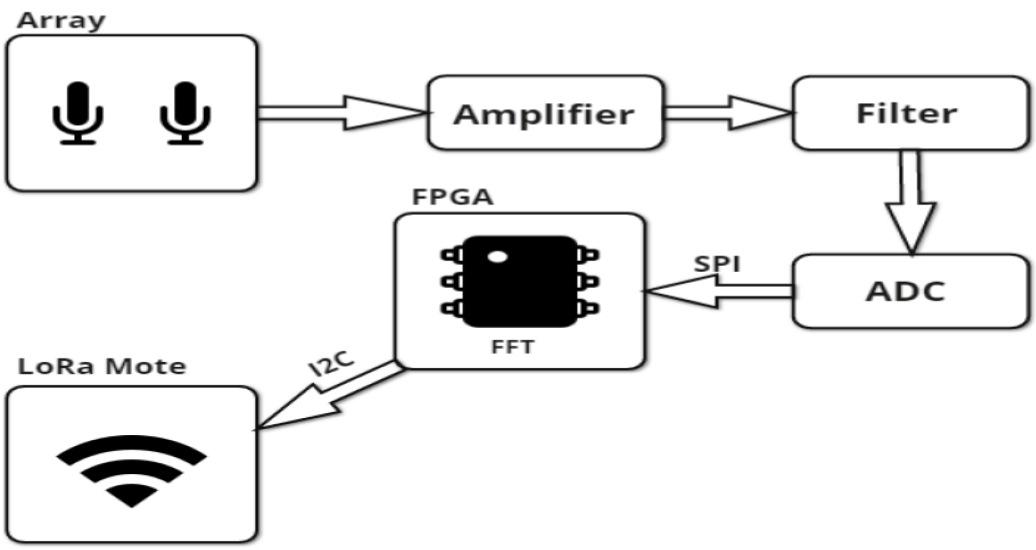


Fig: Hardware Block Configuration

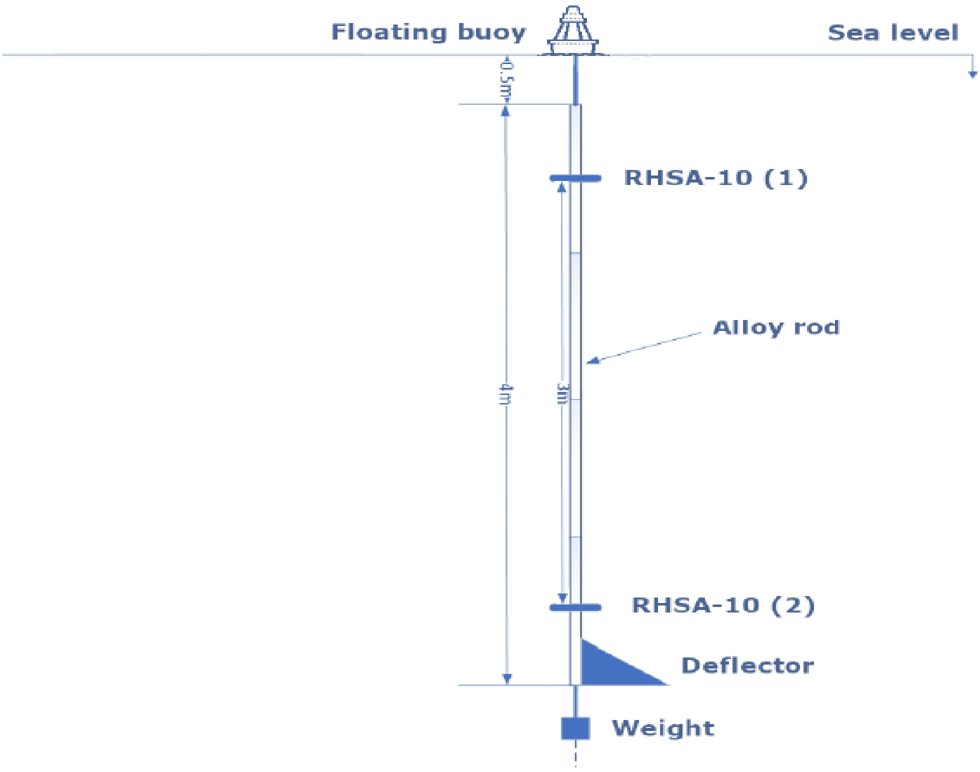


Fig: Buoy configuration.

Array Design: Linear Array

From a technical perspective, a linear arrangement of hydrophones is the best configuration to fix on a floating buoy from a cost and energy perspective, as this arrangement requires the lowest number of elements per array, which is of great importance when designing a low-cost, long-lasting real-time architecture.

A linear array is a row of hydrophones equally spaced in a line. This can be described as an x-axis array. A good example of this is towed arrays, which are usually fixed behind a submarine or, in this case, on a floating buoy. The most prominent **advantage** of a ship's towed line array is its ability to be towed so that it can be away from its ship, away from the only noise source in the area, which is the vessel it is attached to.

However, its **disadvantage** comes from its linear formation: whenever it does have a contact, it can detect one of two directions of the incoming sound wave. This means that if a sound wave comes from a position at the right to the array, each of the hydrophones detects the wave and not the direction it is coming from. Later, the system can compare the hydrophones' Time Difference of Arrival (TDoA) to find the sound wave direction.

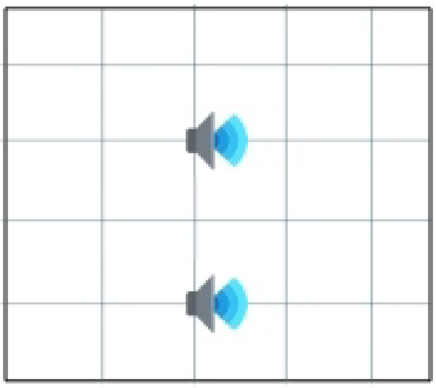


Fig: Linear array

Xilinx Spartan-7 FPGA:

A field-programmable gate array (FPGA) is an integrated circuit that contains an array of configurable logic blocks (CLBs), wired together via programmable interconnects that are designed to be configured by a customer after manufacturing. The Spartan-7 is built on the 28 nm (28 HPL) process from TSM, featuring a MicroBlaze soft processor running over 200 DMIPs with 800 Mb/s DDR3 support. This process enables an excellent balance between performance and power consumption.
It is suited for applications such as acoustic beamforming, sensor interfacing, communication bridging, etc.

Hydrophone: RHSA-10 Model:

Hydrophones are waterproof sound listening elements; the quality of a hydrophone depends on the sensitivity of its piezoelectric material. The RHSA-10 model is a uniform omnidirectional hydrophone, offering a flat receiving response in a wide frequency range, operating at depths of up to 500 m underwater with excellent durability. The RHSA-10 provides a wide-band frequency response, ranging from 1 Hz to 150 kHz, at temperatures from 0 to 40 degrees Celsius. A 15 m long BNC shielded cable, together with a hydrophone, weighs around 1kg and can be stored at a temperature ranging from -40 to 80 degrees Celsius.

When the piezoelectric material is under pressure, an immediate increase or decrease in voltage is observed across its entire plate. The variation is proportional to the pressure being applied to it, and so the intensity and frequency from which the source is being generated can be identified from that variation.

Frequency Domain Beamformer:

Rather than using time delay for beamforming, the frequency domain beamformer uses an alternative approach that measures the phase difference between each sinusoid to recover the original time signal. **Fast Fourier Transform** is used to compute the hydrophone data into the frequency domain. The equation used here is as follows:

$$Y_k = \sum_{n=0}^{N-1} y[n] e^{-\frac{j2\pi kn}{N}}$$

It represents the sampled signal from hydrophones at specific frequency of N points block, where Yk is the Fast Fourier Transform coefficient in kth frequency bin, y[n] the discrete representation of the sampled input signal, and k = 0, 1, 2, . . . , N - 1.

LoRa Mote:

LoRa stands for Long Range. This is a wireless technology allowing a battery-powered sender to transmit small data packages to a receiver over a long distance. A gateway can handle several devices at the same time; in our case,

this means that we can easily set up a network with more than hundreds of buoys. The end node is composed of a radio module with an antenna and a microprocessor to process the data.
LoRawan network architecture is deployed in a star topology. Communication between the end nodes and gateway is bidirectional, which means that both end nodes and gateways can receive and send data.

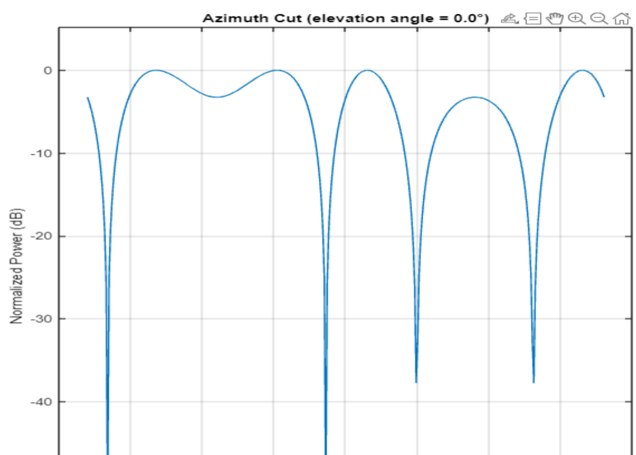
Simulation Results:

Here, we have performed a simulation on Matlab using phased array system toolbox to check the accuracy of a linear array of hydrophones used for the purpose of sensing marine acoustic signals. The idea here is to know which would be the more effective way to arrange by maintaining space between array elements. The examples we have taken here is of 2-element and 4-element system.

For the purpose of simulation, we assumed a case of a small ship which is having a sound of **100-500 Hz** flowing over a water body. Since, taking the depth of this water body to be not deep, we consider the acoustic signal is interacting with the hydrophone-based array system, which is deployed vertically inside the water body, at an angle of **15 degrees**. The speed of sound taken here is **1530 m/s** underwater which is derived from earlier research. The sampling frequency is **250 Hz** which is close to the average shipping traffic noise range.

The element spacing in hydrophone configurations is an essential factor in the design of the array sensor. The simulation is done for the inter-element spacing of $\lambda/4$, $\lambda/2$, and λ. For 2λ, the spacing will be too large to handle in the desired case. Now, the performed simulation is being shown here:

Fig: N = 2, d = λ



Array Characteristics

	@ 250 Hz
Array Directivity	3.01 dBi at 15 Az; 0 El
Array Span	x=0 m y=6.12 m z=0 m
Number of Elements	2
HPBW	30.05° Az / 360.00° El
FNBW	63.29° Az / -° El
SLL	0.00 dB Az / - dB El
Element Polarization	None

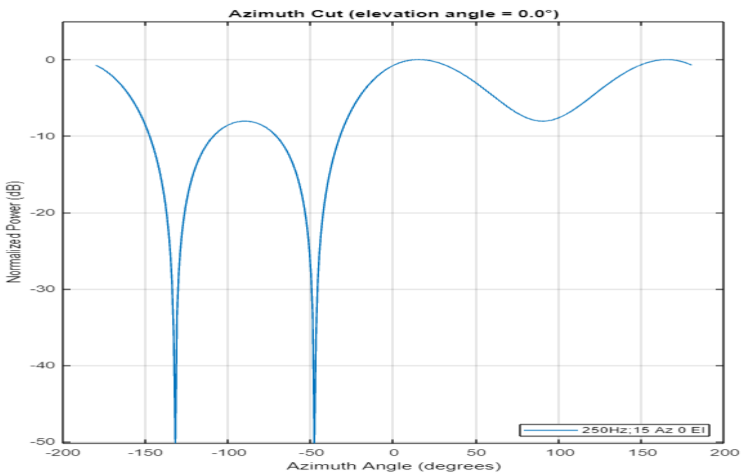


Fig: N = 2, d = $\lambda/2$

Array Characteristics

	@ 250 Hz
Array Directivity	3.01 dBi at 15 Az; 0 El
Array Span	x=0 m y=3.06 m z=0 m
Number of Elements	2
HPBW	63.22° Az / 360.00° El
FNBW	138.00° Az / -° El
SLL	0.00 dB Az / - dB El
Element Polarization	None

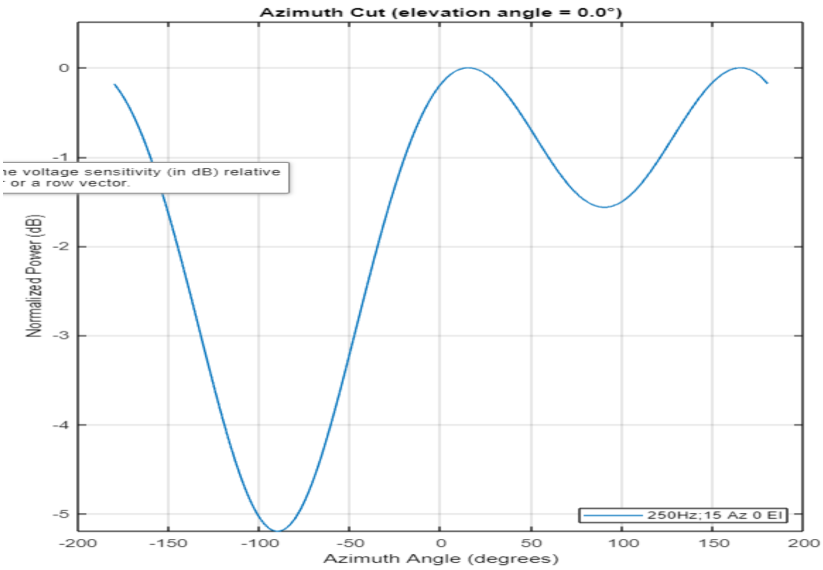


Fig: N = 2, d = $\lambda/4$

Array Characteristics

	@ 250 Hz
Array Directivity	1.01 dBi at 15 Az; 0 El
Array Span	x=0 m y=1.53 m z=0 m
Number of Elements	2
HPBW	275.42° Az / 360.00° El
FNBW	-° Az / -° El
SLL	- dB Az / - dB El
Element Polarization	None

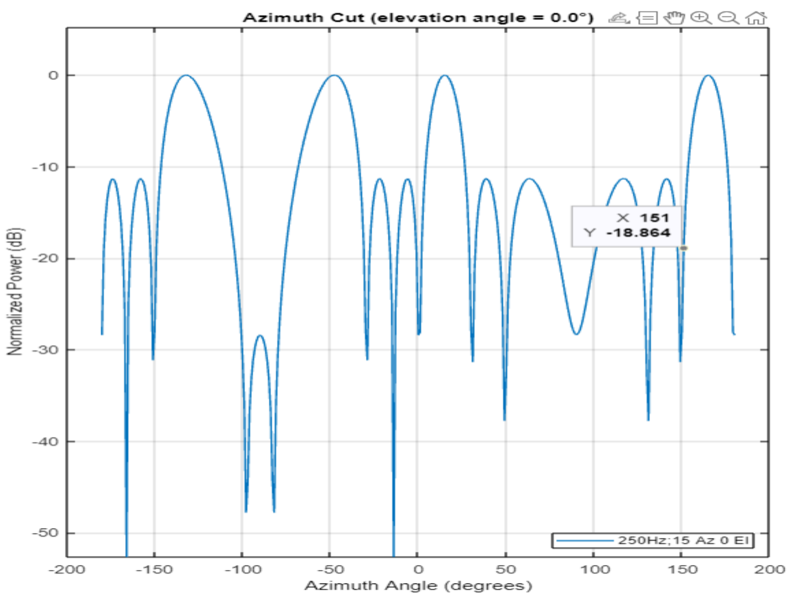


Fig: N = 4, d = λ

Array Characteristics

	@ 250 Hz
Array Directivity	6.02 dBi at 15 Az; 0 El
Array Span	x=0 m y=18.36 m z=0 m
Number of Elements	4
HPBW	13.53° Az / 360.00° El
FNBW	30.07° Az / -° El
SLL	0.00 dB Az / - dB El
Element Polarization	None

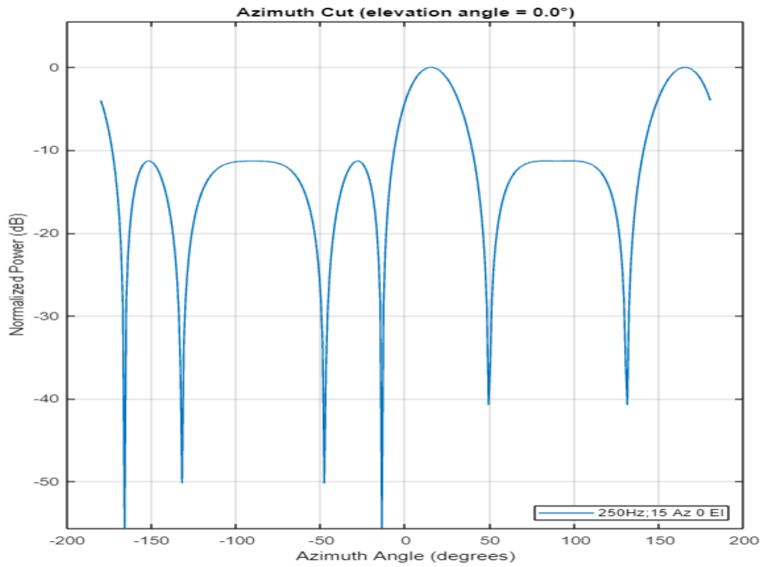


Fig: N = 4, d = $\lambda/2$

Array Characteristics

	@ 250 Hz
Array Directivity	6.02 dBi at 15 Az; 0 El
Array Span	x=0 m y=9.18 m z=0 m
Number of Elements	4
HPBW	27.29° Az / 360.00° El
FNBW	63.28° Az / -° El
SLL	0.00 dB Az / - dB El
Element Polarization	None

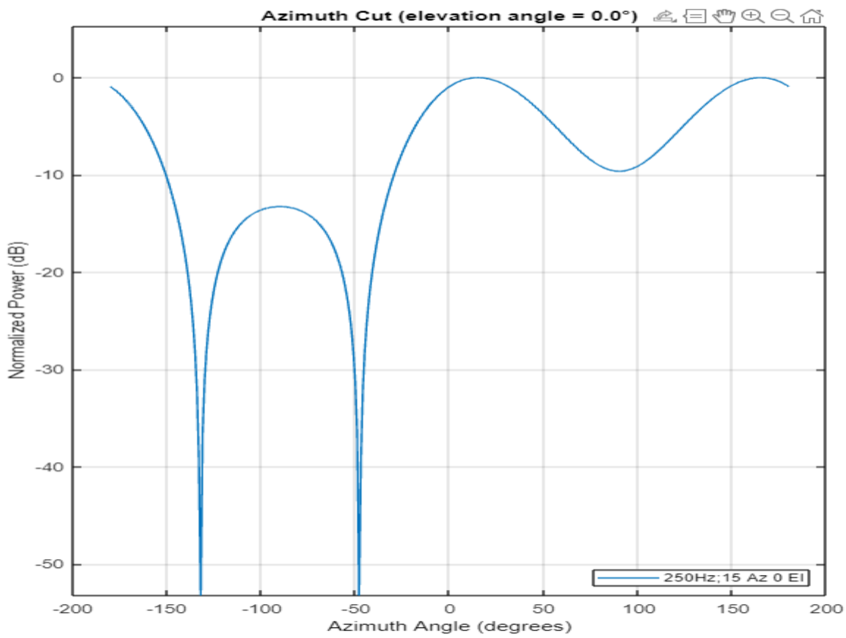


Fig: N = 4, d = $\lambda/4$

Array Characteristics

	@ 250 Hz
Array Directivity	3.37 dBi at 15 Az; 0 El
Array Span	x=0 m y=4.59 m z=0 m
Number of Elements	4
HPBW	56.83° Az / 360.00° El
FNBW	138.07° Az / -° El
SLL	0.00 dB Az / - dB El
Element Polarization	None

These figures demonstrate the resolution of hydrophones configuration when applied to the Fast Fourier Transform Algorithm. The resolution is an illustration of both the main and side lobe levels; thus, the aim is to separate the main signal from side lobe ones. The main lobe width, as well as the maximum side lobe level, are the elements that need to be taken into consideration when attempting to accurately determine the source of a signal. Distinguishing the main signal from the side lobe is a key factor; the difference between the two levels is what enables the algorithm to successfully track the wave's direction of propagation. The complexity comes from the fact that, when using only arrays of two elements, the power difference between lobes is only 5 dB, compared to a notable 10 dB when using the four-element array.

Data Acquisition:

Here, we can use three floating platforms. Each floating platform is self-powered and equipped with a distributed acquisition station to communicate with the main computer using **4G data transmission**. The longitude and latitude coordinates can be measured by GPS positioning of three floating platforms. Each acquisition station is equipped with a NI cRio-9040 compact embedded monitoring controller, with GPS synchronization, an NI 9467 module providing accurate time synchronization, a NI-9223 module for signal sampling, and a linear array of 2 RHSA-10 uniform omnidirectional hydrophones fixed 3 m from each other on a 4 m alloy rod. The alloy rod itself is also vertically fixed on the floating platform.

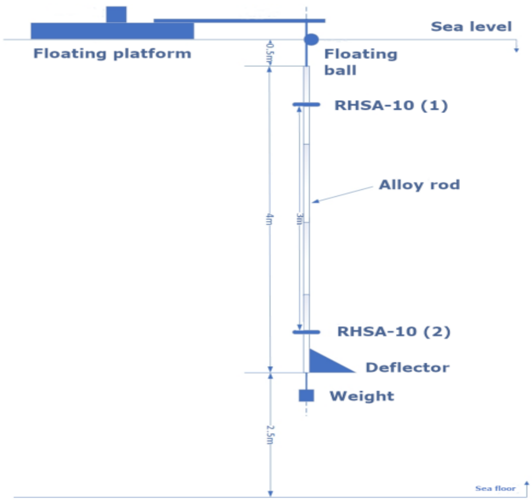
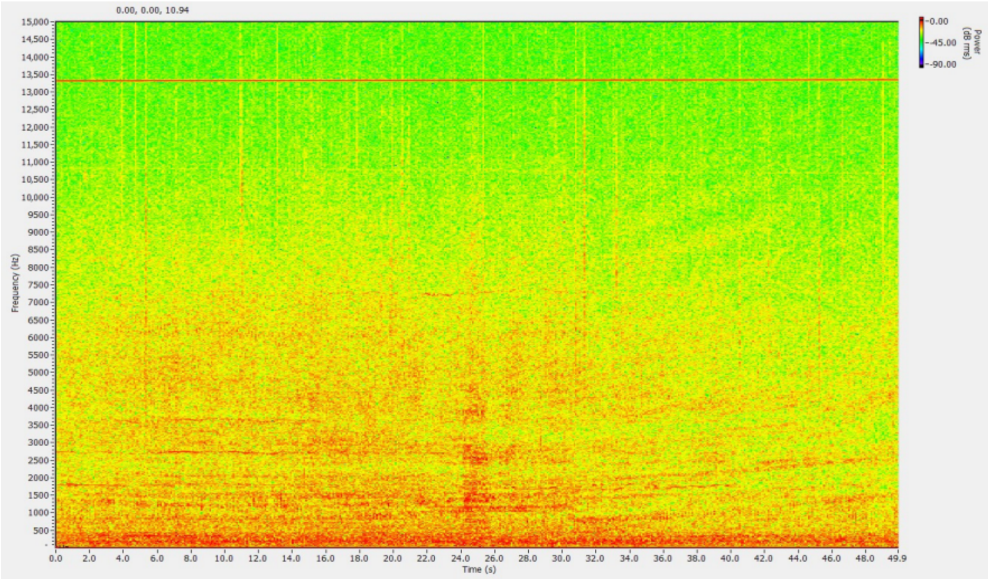


Fig: Hydrophone deployment

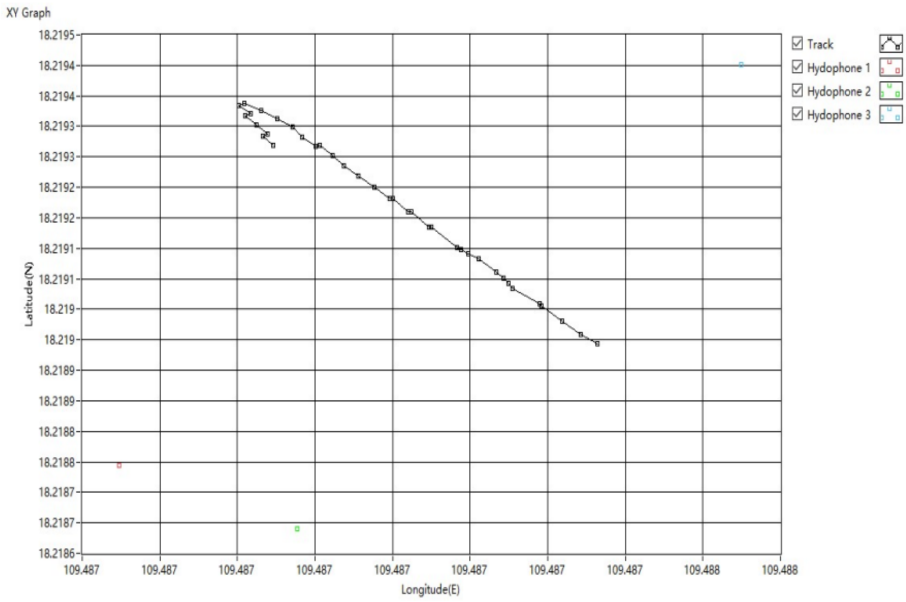
In order to track the target signal source, the three floating platforms can be deployed in a triangle configuration with an interval varying from 1 to 2 km. The motorized ship navigated within the triangular floating platforms, sailing back and forth according to a scheduled route, while the three sub-stations begin the GPS synchronous acquisition, and transmit the original hydrophone signal to the upper computer through the 4G network.

The original data collection is imported into **SignalPad** software, a data logging and analysis application developed with National Instruments.
Here is an example of time-frequency analysis of an acquisition system found by **SignalPad** software:



With the help of this figure we can conclude, the dominant sound signals frequency range.

After that, the recorded signals can be filtered by **Finite Impulse Response** (FIR) filters to remove unnecessary high- and low-frequency interference signals. After slicing the time-domain signal on **LabView**, the three groups of the signal were correlated into each other to find the cross-correlation maximum value. The timepoint corresponding to the maximum value provides the transmission time difference between the sound source signal and the hydrophone monitoring points. As there are many interferences in the actual signal, the resulting time difference curve was first smoothed and filtered. Later, the sound source position was obtained from the transmission time difference of each slice. The least squares method is used to scan the circular area grid with a radius of 4 km to obtain the source location.


XY Graph
Latitude(N)
Longitude(E)
Track
Hydophone 1
Hydophone 2
Hydophone 3
18.2195
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