Mobile Unsupervised Platform for Real-Time Ocean Water Quality Monitoring

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Abstract: Increased population and industrial growth leave serious impact on marine environment, hence, effective water quality monitoring for seawaters is of high demand. Traditional water quality monitoring systems follow manual procedures like collecting water samples, testing and analyzing them in laboratories, which is not only costly but also time consuming, and ultimately affecting timely decision making. Due to recent advancements in sensor technology, sensor based environment systems are attracting the researchers and developers by offering several advantages as compared to traditional approaches. Benefiting from the technology, Mariner, a multi-sensor marine platform is developed. Mariner has the ability to monitor a range of water quality parameters, collect and forward the retrieved data to a processing center in real time in order to make timely decision. Mariner has propulsion capability, hence can move from one location to another autonomously. The proposed system is equally suitable for small as well as large water reservoirs, lakes, rivers, fishponds etc. thus promises broad applicability prospects. Real-time results of various monitored parameters were obtained successfully when tested in the Red Sea near Sharma beach. Further, three-dimensional graphs are plotted to assess the influence of depth and time on the observed parameters.

Keywords: Water quality monitoring; wireless sensors; water Mariner; remote monitoring; real-time reporting, ANOVA model

1. INTRODUCTION

Ensuring the safety and quality of water is a challenge due to excessive sources of pollutants, most of which are man-made resulting from overexploitation of natural resources, sewage and waste water, marine dumping etc. The rapid pace of industrialization, greater emphasis on agricultural growth combined with excessive use of fertilizers and pesticides, and non-enforcement of laws have led to water pollution to a large extent (Buck et al., 2018; Tosun et al., 2018). Further, rapid urbanization has severely affected the water reservoirs, especially; the developing countries are facing serious threat due to mismanagement of such precious resources. According to World Health Organization (Water Quality and Health Strategy, 2013) 90% of the untreated sewage water goes back to these reservoirs while, 70% of industrial discharges are dumped untreated in the developing countries (Pradip, 2017; Ayaz et al., 2018). It shows that not only water quality, even availability is becoming a critical challenge all over the world. Considering the situation, reliable, real-time water quality monitoring (WQM) systems and data-driven inspections are of high demand in order to detect the pollution levels. A quality monitoring system can create a big impact not only on drinking water but also on the aquaculture monitoring, agriculture process, waste water treatment, and many other applications. To evaluate the health of water resources, monitoring system should be accurate, long-term and must offer real-time data acquisition. Frequent spatial and temporal access to reservoirs can offer real-time event detection which ultimately help to understand the pollutant particles and their consequences.

Traditional lab based methods or conventional water quality monitoring systems are not only time consuming but also lack sensitivity and selectivity (Adu-Manu et al., 2017; Adamo et al., 2015). Usually, water pollution monitoring needs samples from the targeted area in order to analyze them in the lab which face higher cost and low efficiency. Delays are common during this process, even sometime samples are exchanged and if pollution is not detected in a timely fashion, the worth of analyzed results can be of no use. Other than these issues, all samples need to transport carefully in cold packs and need to analyze within few hours of collection. Even after such arrangements, it is recommended to analyze some critical parameters like pH and temperature at the collection site immediately as some biological and chemical reactions between the sample and atmosphere could readily alter the readings of these parameters (Danovaro et al., 2011). Furthermore, sterile bottles are suggested for bacterial analysis hence samples need to keep cold inside the packed boxes and should deliver to laboratory as soon as possible. To prevent water reservoir from pollution, an effective monitoring of physicochemical and microbiological parameters is required as overall quality of water is identified by its physical, chemical and biological properties. Dissolved Oxygen (DO) and biochemical oxygen demand (BOD) are two of the most used parameters to state the pollution status of an aquatic system where the concentration of DO is always considered a reliable factor to indicate its pollution level.

Water quality monitoring needs to follow scientific approach in order to detect the pollutant particles while various types of densities and tendencies of complex pollutants are considered critical for this purpose (Gholizadeh et al., 2016).

Water quality cannot be assured by measuring a single parameter hence various parameters like temperature, pH, dissolved oxygen, nitrogen, turbidity, phosphorus, permanganate index etc. should be considered. Researchers are hopeful to estimate the full monitoring coverage of large sites by focusing the heavily polluted areas as mostly water quality data are reliant on accurately identifying these key areas.

Recent developments in optical, electromagnetic and bio-sensors gaining attention for water quality monitoring due to their high sensitivity, selectivity and support to provide real time analysis. With the help of these sensors and other recent technological developments, it is possible to set up advanced, real-time even online monitoring system for water source development and utilization. A monitoring system based on wireless sensors can easily form the network, collect the required data and transfer to the host computer for further process and decision. The host computer can have the facility to display the received data directly in the form of values, stores data in database, can generate the graphs to analyze the records, supports the queries and able to indicate the signal whenever pollution level exceeds the standard or defined value. Further, when we consider commercially and scientifically developed recent monitoring buoys, these are typically very expensive hence; small even medium sized organizations cannot afford them for projects with limited budget. Compared with the traditional water pollution detection methods, developing a reliable water quality monitoring system using wireless sensors can offer several benefits like high accuracy, lower cost, remote real-time reporting, convenient arrangements, multi parametric, etc. Most importantly, a wireless sensor based water quality monitoring can be intelligent enough to accomplish all the monitoring tasks according to the changing environment.

Considering all these factors, a prototype is developed which utilizes the recent advances in wireless sensors and communication systems to provide real time monitoring of dynamic and remote marine environment. A platform called Mariner is developed and various type of biosensors, physical sensors, and chemical sensors are included. The design of Mariner and choice of sensors is made carefully in order to: minimise power requirements, weight, cost, size and overall complexity of installation and maintenance, same time maximizing the accuracy and ease of use. The designed Mariner has the capability to remain in water for short to long periods along with sensors to measure the required parameters with various sampling frequencies. These sensed readings and other relevant station information is logged through the data logger which can be stored or forwarded to any remote processing station like computer using the antenna and data-sims to analyze the recorded data.

The rest of paper is arranged as follows. The next section discusses some existing systems proposed for the similar purpose. Section 3 describes the developed prototype with all the details including the development stages, basic structure and major equipment used for this purpose as well as the targeted parameters and what sensors are used. The snapshot about the experimental setup and the retrieved results from the site are discussed in section 4. While, the last section briefly concludes the article.

2. SIMILAR EXISTING SYSTEMS

Recently, many systems and methods have been proposed to monitor water quality using wireless sensor technology due to its superiority over traditional procedures. A range of monitoring systems has been developed and being used where generally they follow four methods to analyze the water quality (Jiang et al., 2009). Artificial sampling; mostly done through laboratory analysis, automatic and continuous monitoring; which offer real-time detection facility but costly equipment is required. Next, remote sensing technology; where spectrum specifics of an electromagnetic wave are detected by following non-contact method. While, the fourth is regarding the sensitivity of aquatic organisms with respect to the presence of poisonous substances which is done by analyzing the change of organism activities in different water environments. First method is time consuming as results are delayed, second is higher in cost while both, the third and fourth methods face the problem of low accuracy.

Most of the proposed systems are proved ineffective and time-consuming as either results are delayed or not sufficient enough to take proactive action. To provide an urgent decision, a novel optical sensor based online system is proposed by (Hojris et al., 2016) which offers a fast 10-minute resolution. This sensor works with 3D images, where pictures of any sample at any location can be analyzed with the algorithms those support 59 quantified parameters based on particles dissolved in water, further classify these particles either as bacteria or abiotic with good certainty. The presence of different particles and their levels in drinking water can serve as an early warning of pollution especially in remote areas. Although, the idea of online quality monitoring using only water images can be beneficial for remote areas but the sensitivity and accuracy remains an issues and serious efforts are required to make them trustworthy.

Typical real-time water quality monitoring systems using sensor technology are proposed and tested at different locations around the globe. One of the prominent efforts is done by (Rao et al., 2013) where a low cost wireless sensing system is developed for which they used Arduino Mega 2560 for this purpose. It supports multi-parameter detection including DO, pH, conductivity, ORP (oxidation reduction potential), light and temperature. Although authors claim that, the approximate cost of whole system is around $1050 but practically it requires a computer as a gateway which also enhances the overall cost. Further, it doesn't offer solar charging hence the system rely only on limited battery power. Another similar monitoring system is proposed by (Alkandari et al., 2012) which tested at Kuwait Gulf waters and sewerage where authors attempted to deploy a sensor network on the sea surface to monitor the water characteristics including pH, Temp., pH, DO, nitrate, and ammonia. These parameters depend on the area where the network is deployed like industrial zones, petroleum refineries, or sanitation. Important thing about the proposed architecture is that, it supports to store all the collected data on an online SQLite3 database hence the environment can be monitored and controlled remotely easily e.g. web access. Although, remote online access and control support considered a significance effort yet solar recharge facility is not available and no alternate solution is mentioned in case of power deficiency.

To resolve the problem of battery life, a solar powered water quality monitoring system is proposed by (Sandra et al., 2015). The system which is based on set of low cost sensors and used to collect data from water as well as from the weather. The floating buoy was connected with the base station through the wireless connection where they used FlyPort module. While it supports the solar charging which allow the buoy to stay and keep monitoring for longer periods but it didn't offer any mobility hence monitoring coverage remains an issue.

Recently another prominent effort to develop a low cost and autonomous buoy system is done by (Schmidt et al., 2018) where they have targeted the near-shore aquaculture farms or bathing waters. The proposed buoy which is based on generic design is developed in such way that it can monitor various parameters to analyze and understand any physical, chemical and biological changes. The main target of this system is not only to minimize the development and maintenance cost but also they tried to make it as simple as possible so that a non-scientific staff can operate it. However due to targeting the simplicity and cost, the buoy remains suitable only for shallow water operations, further no solar charging and mobility facility was introduced.

3. DEVELOPED PLATFORM DESIGN

This section provides information about the developed prototype called the Mariner. The prototype is based on innovative design which is developed to address the challenges of water resource monitoring.

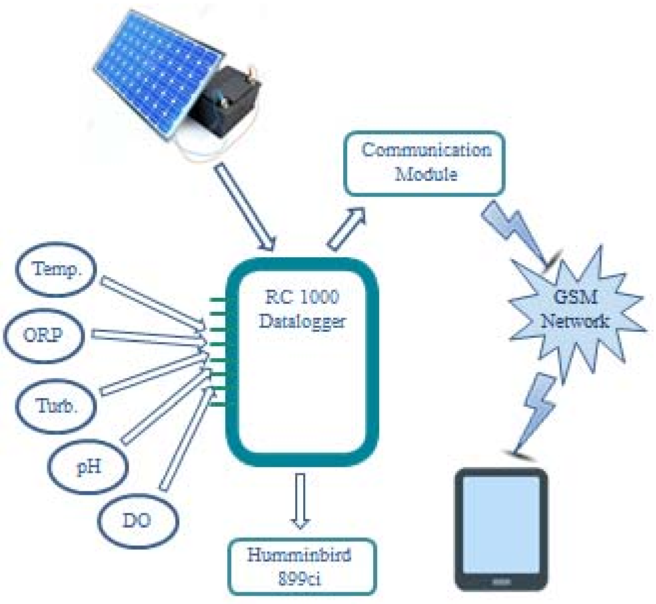


Fig. 1. Block diagram of the developed system.

Figure 1 highlight all the major components including datalogger, available sensors, power module and communication module as well as how these components are connected with each other. The ultimate purpose of the prototype is to automate the monitoring of water quality and management of water resources in the kingdom. The platform includes various sensors to measure water quality parameters such as pH, conductivity, turbidity, temperature, and sediment concentration near river bed. The development process of this floating platform is based on many steps as current product has many early versions as shown in figure 2. This platform is completely developed at SNCS (Sensor Networks and Cellular Systems) research center, University of Tabuk, in order to,

- Collect water quality parameters through five sensors
- Store and/or send data wirelessly to a remote location
- Capture images of sea bottom and traffic of fish schools
- Follow a trajectory to a given location autonomously or via remote control
- Stay fixed at a given position autonomously
- Withstands harsh atmosphere for an extended time
- Can be expanded easily in terms of both capacity and capability

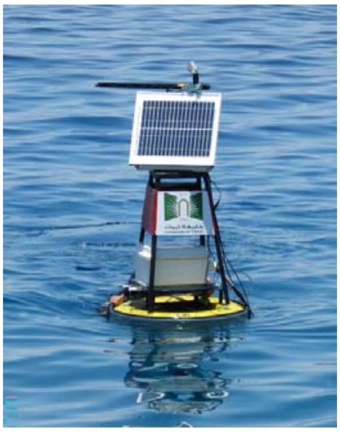
3.1 Development Stages

Mariner in current form has proved not only reliable and convenient to use but also easily portable whenever required to shift to desired site. It doesn't require highly technical staff while couple of persons can reassemble and then assemble at new location where it needs to operate. To reach the current shape, it has gone through several development stages called generations; those are discussed in following,

First Generation: The first proposed design of this Mariner was based on a single tire where whole frame including the datalogger and three sensors (Temperature, Turbidity, Dissolved Oxygen) were installed on it (figure 2-a). During early experiments, where Mariner needs to stay in water for short periods, this first generation Mariner looks fine but stability issues start to arise as the monitoring periods start to increase. In situations where Mariner needs to stay in water for hours or even days, we cannot rely on this design.

Second Generation: To overcome the stability issues and to make it more reliable, the single tire frame was replaced with 3-tires (figure 2-b). The new structure proved highly stable and robust enough as we can leave this for longer periods even for days. It can face the steeper waves as mostly need to stay around shallow water areas. The overall structure including the mast and bouncy control help the Mariner to survive in hard sea conditions. Further, two new sensors become the part of Mariner (pH and ORP) hence it can support the monitoring of five parameters in current form.

Third Generation: With this new three-tire frame, Mariner can be used for long period applications however; it can only stay on a specific location. While, single position readings are not sufficient as some applications require the values of various positions. To enhance its functionality, a new facility of a propulsion motor is introduced with the Mariner, which is powerful enough to drag the whole Mariner from one location to other (figure 2-c). This remote (called i-pilot) controlled motor, which is suggested for boat propulsion is highly suitable for this purpose as we can move the Mariner to different locations easily. This motor has the ability to provide the thrust up to 112 pounds and most importantly, it can work for longer periods on battery, which can be charged through the attached solar panel. For this purpose, a separate battery is attached outside the datalooger box to avoid any power interruption for the sensing and communication equipment.



(a): On single tire

(b): On three tires

(c): With trolling motor and humminbird

Fig. 2. Different stages of Mariner development.

Fourth Generation (Future work): We have start working to develop multiple mariners but smaller in size. These junior mariners will be used to deploy in near areas with smaller datalogger that can support few sensors like two or three according to application requirements. By using these, smaller but multiple mariners, we can create a cluster in a large area where these smaller mariners will report to main Mariner as depicted in figure 3. Regarding the mariner Jr., its basic prototype is developed already and currently under testing stage. Furthermore, main Mariner can also be reduced in size to equip with appropriate number of sensors in order to make it suitable for use in fish farms, ponds and other water reservoirs. While only five sensors are used now, same datalogger can accommodate three more whenever required.

3.2 Structure and Major Components

The current version of Mariner is based on an iron frame, three tires, sensor nodes, a solar panel, battery, an antenna, a trolling motor (Minn Kota Riptide ST 112 with i-Pilot, to offer the mobility), a Humminbird 899ci HD (for GPS and side imaging), data logger (CR 1000), application software PC200W 4.1 (to receive data), Sierra wireless Ace manager (to connect with remote device) and a communication module for real time reporting (as a gateway). The main components of Mariner with working and technical details are discussed below.

RC 1000 Datalogger: The CR1000 is one of the commonly used datalogger as it offers a broad range of measurements and control functions. It is considered reliable and rugged as can operate and survive during extreme conditions hence suggested for the long periods and remote environments, further robust enough for complex configurations as support eight ports therefore eight sensors can be connected same time. Integration of this datalogger with the Ardinue (UNO R3) make it core of monitoring system.

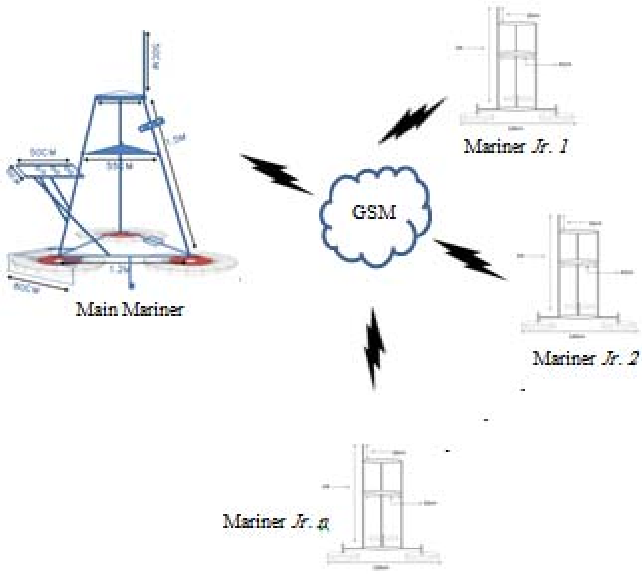


Fig. 3. Proposed design for water quality monitoring using multiple mariners.

Communication Module: Arduino board and two SIM cards (we choose STC network services), one in communication module at floating platform and other in iPad at the remote processing center, while a yogi anntena is installed to carry out this communication. Arduino is a low cost and available in a variety of boards that can be connected to create a modular framework and being used for a wide range of applications. Arduino board is simple to connect with CR1000 datalogger as only few lines of code are required. By doing so, remote transmission is available, which at once side deliver the data to make it analyse same time it decreases the burden on local storage. The flow chart of the complete process from sensing the information till delivering at process center is shown in figure 4. Here it is important to mention that due to some unwanted circumstances like bad weather or being out of coverage area, if the GSM signals are not available even for longer periods then the data logger can keep logging the sensed data and store in the built-in memory (4 MB). For example, in a situation where all the five sensors are updating the results with the sampling period of one hour (sampling frequency can be changed from minutes to hours), then after one month here will be 720 records in the text file (figure 5), which takes 36 KB of memory size. It shows that even we change the sampling period and reduce it yet the small memory can be enough to store the sensed data of many months. Further, in case of any requirement, memory card slot is available in the data logger where a card with larger memory size can be installed.

All the critical components including the datalogger, communication module, a 12 volt battery, conductivity interface for CS547 (A) and CH100 12 V charging regulator are packed inside a safe coffer, provided by the same manufacturer (Campbell Scientific) to make the sensing process weather resistant.

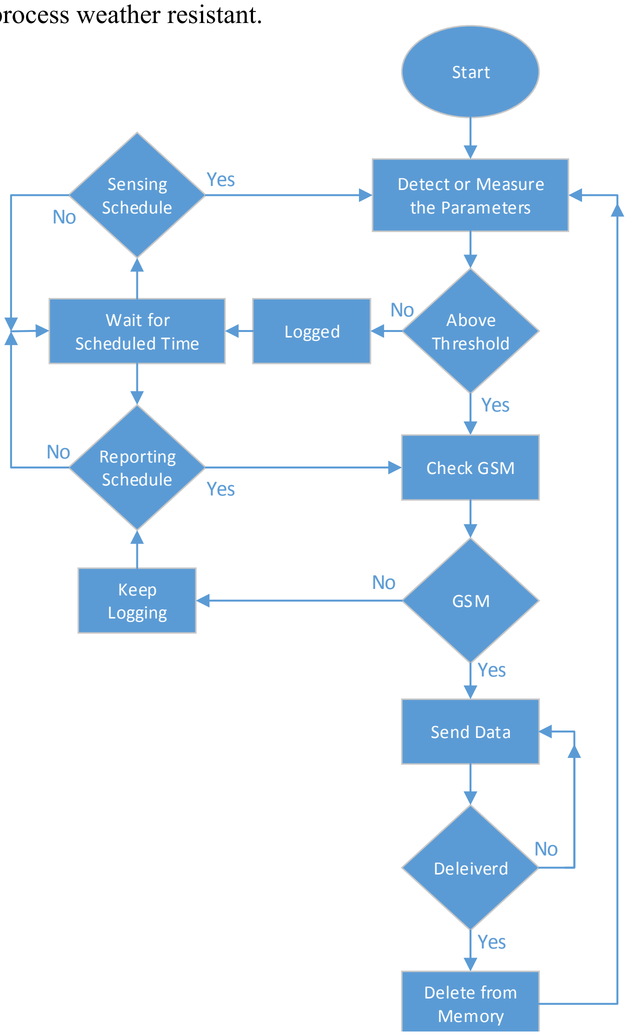


Fig. 4. Flowchart of the process from sensing the parameters to delivering the data at processing center.

Trolling motor: To move the Mariner from one position to other, Minn Kota Riptide ST-112 trolling motor is attached. It comes with i-pilot to control the motor remotely and it can drag upto 112 lbs weight while the speed of the motor can be adjusted considering the distance need to move and water direction. Other than dragging the Mariner to the required place, the GPS facility in the trolling motor can be helpful to keep the Mariner on a specific position. Movement of the Mariner with the water currents is inevitable hence it can keep the Mariner at certain location without any anchor facility.

GPS and Side Imaging: The Humminbird 899ci HD SI Combo is linked with the Mariner (trolling motor) to provide the GPS facility. For this purpose, a third party Ethernet adapter cable of '720074-1 AS EC QDE 700 Series' is used. The GPS module is capable for Chartplotting with built-in ContourXD map and Ethernet networking. Further, it offers side/down imaging, sonar facility with DualBeam PLUS and SwitchFire which has up to 8000 watts PTP power output. The luxury of GPS available in this Humminbird, offer the facility of Spot-Lock. This spot lock uses GPS to lock the Mariner at any desired position accurately while it can be readjusted remotely at any time.

3.3 Monitoring Parameters and Relevant Sensors

The key water parameters need to be monitored for prevention or remedial actions to maintain the water quality. The supported parameters of the developed Mariner and the sensors used for this purpose are listed in table 1. All the sensors used for these parameters are of same manufacturer, Campbell Scientific, while a short summary of their specifications is listed in table 2.

Table 1: Monitoring parameters and the WHO standard values for drinking water.

Parameter	Unit	Definition and Worth	WHO Standard
pH	potential of hydrogen (pH)	Effective hydrogen-ion concentration (i.e., pH = −log[H+])	7–8.5 (preferably ≤8)
Temperature	Celsius (°C)	Temperature impacts DO content	Drinking water supply (15 °C)
Oxidation reduction potential (ORP)	Millivolts (mV)	Capacity to either release or accept electrons from chemical reactions; influences the life span of bacteria in water.	650–700mV
Turbidity	Nephelometric Turbidity Unit (NTU)	Amount of solid matter (particles or colloids) suspended in water that obstruct light transmission	1–5 NTU
Dissolved oxygen (DO)	Parts per million (ppm) Micromoles (umol)	Amount of DO	5–6 mg/l

Table 2: List of sensors used by Mariner with their specifications.

S/N	Parameter	Sensor Model	Range	Accuracy
1	Temp.	107-L	-35° to +50°C	± 0.4 °C (-24° to 48 °C) ± 0.9 °C (-38° to 53 °C)
2	ORP	CSIM11-ORP-L	-700 to +1100 mV	±0.1%
3	DO	CS511-L	0.5 to 50 ppm	±2%
4	pH	CSIM11	0 to 14 pH, 7.0 pH ±0.2 pH (Zero Potential)	±0.1%
5	Turbidity	OBS-3+	0.4 to 4,000 NTU	2% of Reading 0.5 NTU

3.4 Advantages and Usefulness

The main advantages of developed product are highlighted below, in short, the Mariner:

- Can be easily deployed in different sites for various applications where water quality information is needed.
- Supports real time data collection.
- Equipped with a solar energy based power plant, thus it can remain on a task for extended periods of time.
- Has a scalable architecture, new modules can seamlessly be added as they are needed (sensors, batteries, solar panels, etc…)
- Can move easily from location to location as needed with the help of its on-board navigation system.
- Supports data visualization and analysis allowing quick decision making.
- Easily accessible for routine checks and sensors can be retrieved and cleaned periodically to avoid biofouling.
- Can be integrated with other similar water monitoring platforms to form a network that can monitor a wide area in the ocean.

4. MONITORING RESULTS, ANALYSIS AND VALIDATIONS

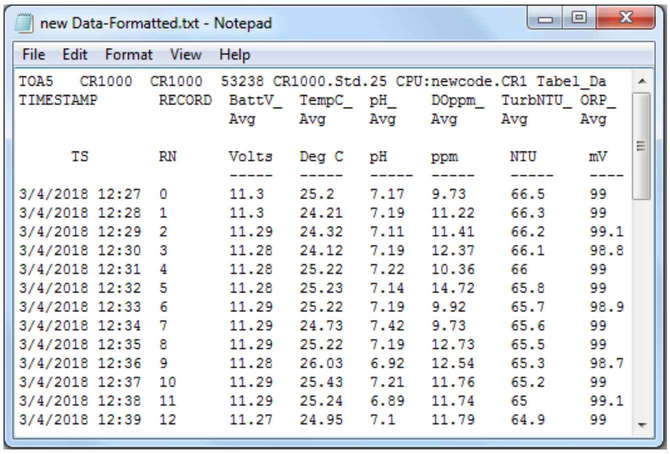
4.1 Monitoring Site and Analysis

To test the developed monitoring system, experiments were conducted near Sharma beach in the Red Sea. Monitoring the various parameters to analyze the water quality in Red Sea becoming critical as whole coastal area facing continuous biological changes especially during the last decade (Riegl et al., 2012; Badour et al., 2015). Although, the Red Sea has its own historic value and background but after the announcement of NEOM project (NEOM City, 2018) it has acquired much attention. Increased human activity, which is further expected to rise rapidly, polluting the coastal areas hence affecting the water quality in terms of temperature, turbidity, conductivity etc, ultimately leading to issues like eutrophication and coral bleaching.

4.2 Results and Discussions

A series of experiments were conducted during multiple visits along the coastal line; near Sharma beach. Results were collected with various depth levels ranged from two (or less than) meters to twenty meters. To understand the depth influence more effectively we analyse the results with three depth levels, two meter, thirteen meter and twenty meters as shown in table 3. It is worth mentioning that, the results at small depths are collected without using the trolling motor as mariner was dragged till a person can go easily. While, to collect the results at higher depths, trolling motor was attached and results are taken at different depths. Here it is important to note that recorded data at Mariner is forwarded in real time which can be stored on a computer and graphs can be plotted to analyze the parameter changes.

Three dimensional diagrams are plotted to assess the influence of depth as well as time on the observed responses which include DO, ORP, turbidity, temperature and pH (figure 6-10). Furthermore, the contour can be used to investigate the intervals of the said responses. Additionally, the values of responses can be predicted by using ANOVA models as given in equations 1-5. All the models have been statistically validated. It is well understood that the difference between predicted R2 and adjusted R2 less than 0.2 and the adequate precision greater than four indicates model acceptance (Zahid et al., 2018), the same was observed for all the models reported in this research work (table 4). Furthermore, as given in table 5, the higher magnitude of F-value and the smaller value of probability (>0.005) confirm the significance of the models. Therefore all the models are statistically validated and can be used to predict individual responses.



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TIMESTAMP        RECORD  BattV_  TempC_  pH_    DOppm_  TurbNTU_ ORP_
                         Avg     Avg     Avg    Avg     Avg      Avg

       TS        RN      Volts   Deg C   pH     ppm     NTU      mV
                         -----   -----   -----  -----   -----    ----
3/4/2018 12:27   0       11.3    25.2    7.17   9.73    66.5     99
3/4/2018 12:28   1       11.3    24.21   7.19   11.22   66.3     99
3/4/2018 12:29   2       11.29   24.32   7.11   11.41   66.2     99.1
3/4/2018 12:30   3       11.28   24.12   7.19   12.37   66.1     98.8
3/4/2018 12:31   4       11.28   25.22   7.22   10.36   66       99
3/4/2018 12:32   5       11.28   25.23   7.14   14.72   65.8     99
3/4/2018 12:33   6       11.29   25.22   7.19   9.92    65.7     98.9
3/4/2018 12:34   7       11.29   24.73   7.42   9.73    65.6     99
3/4/2018 12:35   8       11.29   25.22   7.19   12.73   65.5     99
3/4/2018 12:36   9       11.28   26.03   6.92   12.54   65.3     98.7
3/4/2018 12:37   10      11.29   25.43   7.21   11.76   65.2     99
3/4/2018 12:38   11      11.29   25.24   6.89   11.74   65       99.1
3/4/2018 12:39   12      11.27   24.95   7.1    11.79   64.9     99
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Fig. 5. Monitoring data as retrieved.

Table 3: Experimental design including the monitoring parameters.

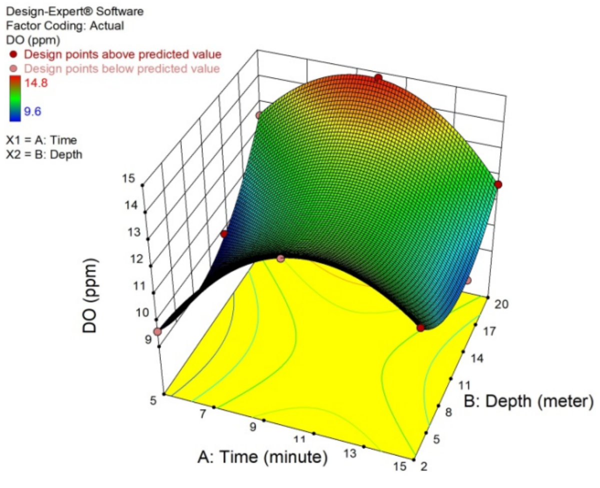
Factor 1 (Depth)	Factor 2 (Time)	Response 1 pH	Response 2 Temperature	Response 3 ORP	Response 4 Turbidity	Response 5 DO
Meter	*Minute*	*pH*	*C^0*	*mV*	*NTU*	*ppm*
2	5	6.7	25.6	48.3	74.2	9.6
2	10	7	26.2	35.2	72.4	13.52
2	15	7.1	25.7	30.9	75.9	12.2
13	5	6.6	25.1	46.1	66.3	9.8
13	10	6.6	24.9	39.7	68.5	12.6
13	15	6.9	25.2	37.1	68.6	10.14
20	5	6.5	24.3	38.2	64.1	12.52
20	10	6.6	24.4	34.5	66.8	14.8
20	15	6.8	24.3	37.3	66.2	11.7

Table 4: Model validation for responses.

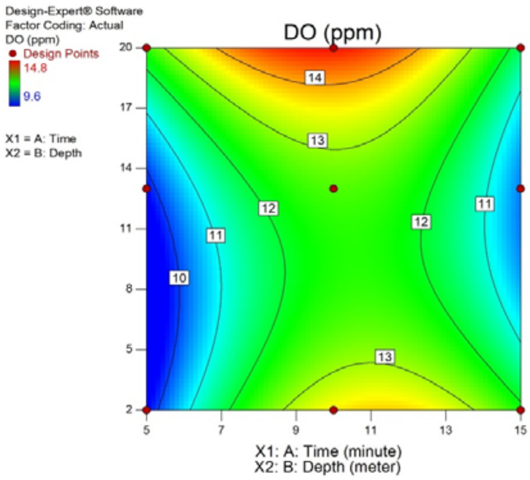
Response	pH	Temp. (ºC)	ORP	Turbidity (NTU)	DO (ppm)
Standard deviation	0.073	0.22	1.00	1.30	0.062
Mean	6.76	25.08	38.59	69.22	11.88
R^2	0.9077	0.9181	0.9876	0.9222	0.9995
Predicted R^2	0.8296	0.7907	0.8660	0.8155	0.9947
Adjusted R^2	0.8769	0.8909	0.0.9669	0.8963	0.9988
Adequate precision	15.293	12.014	21.775	14.233	102.537

Table 5: ANOVA results for full regression model of each response.

Response	pH	Temp. (ºC)	ORP	Turbidity (NTU)	DO (ppm)
Sum of squares	0.31	3.34	240.29	120.03	24.82
Mean square	0.16	1.67	48.06	60.02	4.96
F-value	29.50	33.65	47.79	35.57	1307.62
p-value prob > F	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050
Remarks	significant	significant	significant	significant	significant



a) 3D response surface

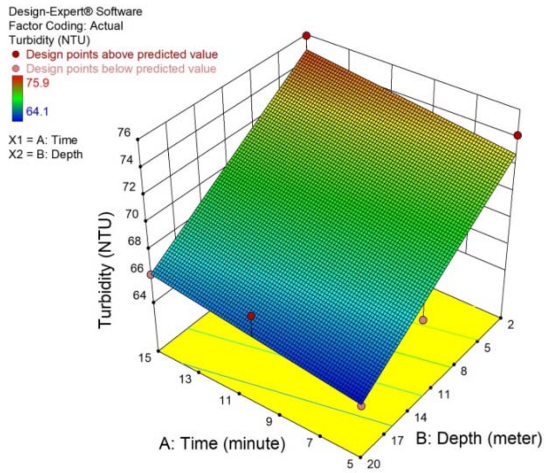


b) contour diagram

Fig. 6. Dissolved Oxygen (DO) effect verses time and depth.

$$DO = +0.74760 + 2.41127 * x_1 - 0.22021 * x_2 - 0.019138 * x_1 * x_2 - 0.10587 * x_1^2 + 0.021823 * x_2^2 \quad \ldots (1)$$

where x_1 and x_2 represents time and depth respectively



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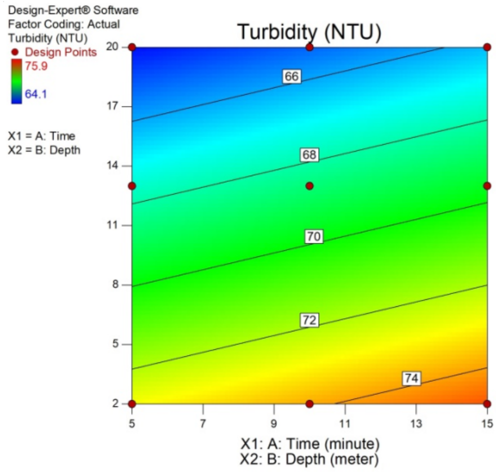
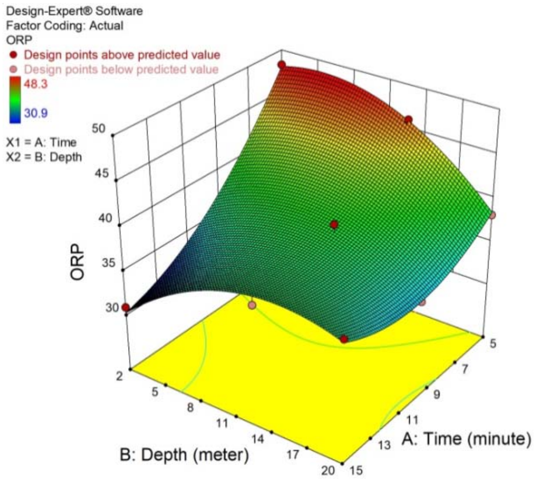


b) contour diagram

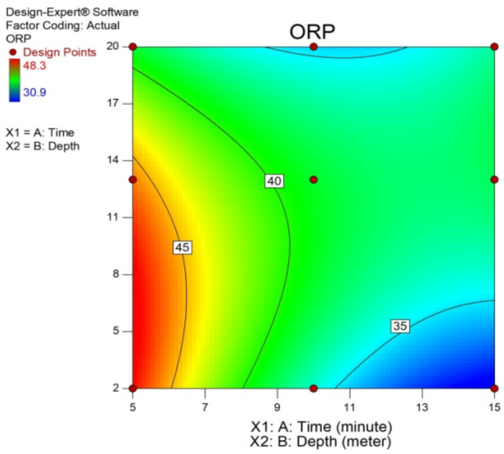
Fig. 7. Turbidity effect verses time and depth.

$$Turbidity = +72.78920 + 0.20333 * x_1 - 0.48003 * x_2 \quad \ldots (2)$$

where x_1 and x_2 represents time and depth respectively



a) 3D response surface

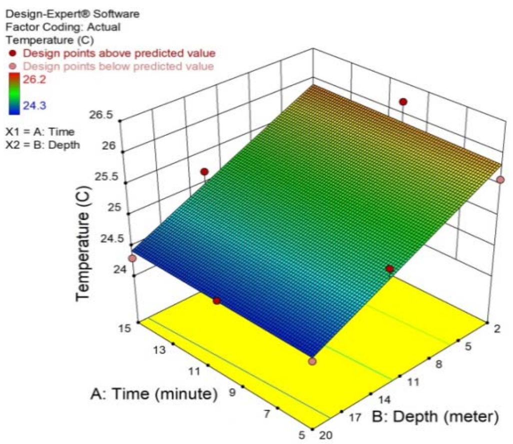


b) contour diagram

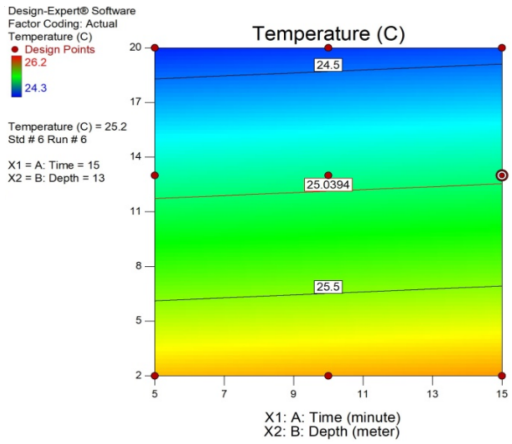
Fig. 8. Oxidation-Reduction Potential (ORP) effect verses time and depth.

$$ORP = +66.60536 - 4.51021 * x_1 + 0.081091 * x_2 + 0.090304 * x_1 * x_2 + 0.12733 * x_1^2 - 0.048437 * x_2^2 \quad ...(3)$$

where x_1 and x_2 represents time and depth respectively



a) 3D response surface

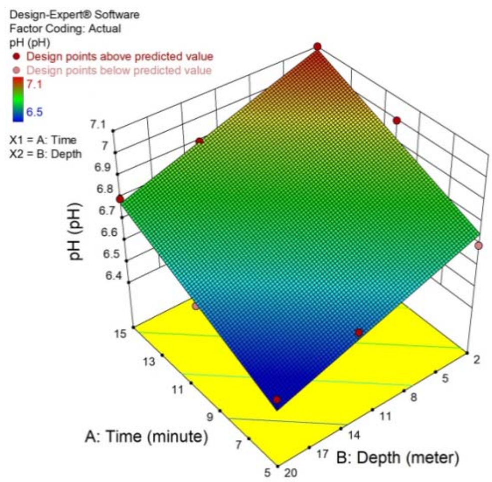


b) contour diagram

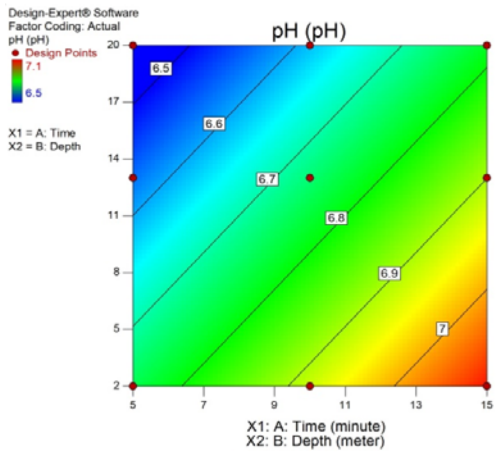
Fig. 9. Temperature effect verses time and depth.

$$Temperature = +25.96916 + 0.00666667 * x_1 - 0.082119 * x_2 \quad ...(4)$$

where x_1 and x_2 represents time and depth respectively



a) 3D response surface



b) contour diagram

Fig. 10. pH effect verses time and depth.

$$pH = +6.62139 + 0.033333 * x_1 - 0.017072 * x_2 \quad ...(5)$$

where x_1 and x_2 represents time and depth respectively

Table 6: Experimental validation of ANOVA models.

Response	Predicted	Experimental	Error (%)
pH	6.82	6.52	4.39
Temperature	25.37	26.18	3.19
ORP	39	40.62	4.15
Turbidity	70.98	68.21	3.90
DO	12.38	11.9	3.87

The results of various parameters collected during the visits are presented in the above mentioned graphs. In case of dissolved oxygen (figure 6) and pH (figure 10), the effect of depth level is slightly varying and doesn't make serious effect. However, for temperature (figure 9), depth shows considerable difference which also depends on the monitoring time and month. While, in case of turbidity the results are clearly different as depth of water increased. Here turbidity (figure 7) remains higher at upper water layer or we can say with less depth and turbidity starts to decrease as depth start to increase. While ORP (figure 8) results keep changes from location to location and time to time but doesn't depends seriously on the depth.

ANOVA models for each response were developed and statistically validated, as well as an experimental validation study was also performed (Table 6) on randomly selected depth and time (i.e. 10 minutes and 8 meters). It was observed that expected results from ANOVA models were in close agreement with the experimental results and error was less than 5%, hence these ANOVA models are experimentally validated for specific sites. However, it is suggested to further investigate the acceptance of the ANOVA models by performing experimental work at different locations and conditions of the sea (or any water reservoir).

5. CONCLUSIONS

Reliable monitoring and evaluation of water quality are critical due to increasing pollution. The recent developments in sensor technology and other open source platforms allow observing various environmental and water quality parameters with reduced cost and data logging requirements. Gaining the benefits from these advances, this paper presents a multi-sensor mobile platform to monitor oceans and water reservoirs. Recent observations show that the coastal areas around Sharma city are at serious pollution risk due to increasing activities along the shoreline especially after the launch of NEOM city project. To monitor this coastal line, Mariner can be ideal for continuous reporting by considering the geographical characteristics. This platform can cover a large area with real-time reporting while having various types of sensors that can be replaced easily according to area and application requirements. Lower cost and simplicity are its other characteristics as it can be ideal for small and short term projects without requiring specialized persons to operate. The monitoring system can help to characterize new aquaculture sites to evaluate their potential for various applications like fish farming, irrigation, desalination etc. Furthermore, not only sea environment but it can be highly suitable to monitor fish farms, lakes and rivers by taking the water quality readings in an easy way, ultimately helping the community and the individual's income.

As a future work, aside from working on its fourth generation we are planning to develop an android application which allows the user to visualize the monitoring information in real time by connecting with the server.

ACKNOWLEDGMENT

The author would like to thank Dr. Raed Mesleh for his continuous support throughout the duration of the project; Mr. Zahoor Ahmad for providing the technical support; and Tabuk province authorities as well as the city Sharma Coast Guards. The author appreciates the guidance and financial support for this project by the SNCS Research Center, and Deanship of Research, University of Tabuk, under project No. S-1439-163.

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