Smart measurement and monitoring system for aquaculture fisheries with IoT-based telemetry system

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ABSTRACT

The instrumentation design of an online monitoring device for aquaculture media is discussed in this article. The main processor in this internet of things (IoT) real-time telemetry system is an ESP32 board. Temperature, acidity level, conductivity level, dissolved oxygen (DO) level, and degree of oxygen reduction in the water were the aquaculture parameters measured. The ESP32 collects data from each sensor, groups it into a dataset, displays it on the LCD, saves it to the SD card, and then uploads it to the real-time database. In addition, an Android application is being developed for users. This device has been tested to ensure that each measured parameter is accurate and precise. The accuracy test, one of the major results of laboratory scale tests, demonstrates that each parameter has a different measurement error that represents with average error absolute. Six tested sensors/instruments were subjected to the test. Average absolute error for temperature sensor is +0.76%, pH sensor is +1.52%, electrical conductivity (EC) sensor is +10.8%, oxidation reduction potential (ORP) sensor is +14.6%, DO sensor is +9.3%, and total dissolve solids (TDS) sensor is +13.2%. This device is very dependable and convenient for monitoring the condition of aquaculture media in real-time and accurately.

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1. INTRODUCTION

Indonesia is a maritime country with 70% water area with a high potential for freshwater aquaculture. There are several problems in regulating fisheries' ecosystem conditions such as polluted water, lack of oxygen, climate change, and inappropriate use of feed. The condition of the fishery ecosystem is closely related to water quality which has several parameters including acidity, conductivity, water temperature, and dissolved oxygen (DO) [1], [2]. These parameters require intense monitoring so that water quality is always maintained. In Indonesia, the modernization of fisheries, especially freshwater needs to be done to increase the efficiency and effectiveness of aquaculture media and techniques. Fishery techniques such as aquaculture require the application of appropriate technology to be able to monitor optimally in helping fishery operators or farmers [3]–[5]. Therefore a monitoring system is needed so that it can detect unhealthy water in real-time [6]–[10]. By monitoring water quality in real-time, problems that arise can be immediately identified and resolved before they occur [11]–[14]. The way that can be done is through the implementation of the internet of things (IoT) which connects various devices, objects, and systems with the internet, so that they can exchange data automatically [15], [16].

In previous research, Teja *et al*. [17] has designed a management and automation system for aquaculture techniques in shrimp ponds. The designed system uses the ESP32 microcontroller. The same system was also designed by Islam *et al*. [18], however, uses an Arduino microcontroller with an integrated sensory system. There is also research that has been carried out by Saparudin *et al.* [19] namely designing a water quality monitoring system for high density aquaculture ecosystem. New IoT system called narrowband IoT (NB-IoT) is proposed by Huan *et al.* [20] for water quality monitoring system for aquaculture. The research of the same topic but completed with machine learning was done by Quintero *et al*. [21]. By using multiple sensor nodes and hybrid sensor/server nodes, the system is designed to be wireless with a Wi-Fi connection. Wu *et al*. [22] conducted an interesting review of intelligent and unmanned equipment in aquaculture, and also design of a chatbot with natural language for aquaculture from Rasyid *et al*. [23]. The review focuses on challenges, potential, and development process from traditional manual methods to mechanization, automation, and finally unmanned intelligent equipment.

Different from previous studies, this research focuses in devising an IoT-based telemetry system for aquaculture fisheries with an Android-based user interface. The device designed in this study is the second version of the device in the previous study [24]. In the first version, the Arsenik device is used for hydroponic farming. Whereas in this second version, the Arsenik device is used for monitoring aquaculture media for freshwater fisheries. The device designed in this study measures 6 parameters of aquaculture media, namely; suhu, acidity, electrical conductivity (EC), redox or oxidation reduction potential (ORP), DO, and total dissolve solids (TDS). The system uses real-time database from Google Firebase to store the dataset as online data. Also featured with offline data storage via SD card. The users can monitor all the aquaculture parameters by using Android app specially developed for the system in real-time every 2 minutes.

2. RESEARCH METHOD

The research method was conducted to design and test in a real-time physical condition telemetry system based on IoT. The designed system must have good perfomance from the aspects of measurement and data aquisition. The performance test is conducted by comparing the proposed device with the standardized device, i.e. a Lutron YK-2001PHA water meter. The reliability of data transmission using Wi-Fi for local connection and 4G network for remote connection. In the other hand, the Android-based UI applications is used by operators must be informatively accurate and handly. Some of the design parts of the Arsenik device version 2 of this study includes; hardware design, microcontroller program, database system, and Android application development. All of the design parts are integrated to reach the support for the operational network system.

2.1. System design

Explained ini Figure 1, this system is integrated with analog sensors that are used to measure 6 aquaculture parameters. Each parameter is measured using its different probe. The probes produce analog signals according to the parameter changes. For the analog signal to be accessed by the microcontroller, each probe needs a signal conditioner.

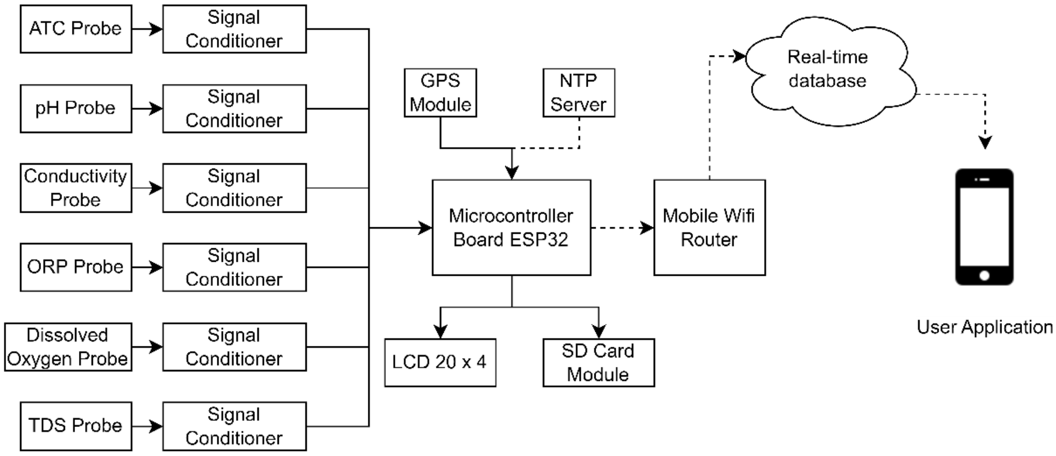


Figure 1. Arsenik version 2 system block diagram

Analog signal reading from each water sensor probe is processed by the microcontroller board. The microcontroller board also reads position data from the global positioning system (GPS) sensor module. The use of position data is important considering that the device is designed to be portable and mobile. The data read from the sensors is then parsed with the date and time data downloaded from the network time protocol (NTP) server. The data set is then stored offline on the SD card, and uploaded to the real-time database.

2.2. Hardware integration

Figure 2 shows the wiring diagram of Arsenik version 2 system. On the Figure 2, not all sensors module is presented, but only each signal out wire. The signal conditioning module on each sensor probe has an analog output signal. Therefore, the 6 water sensor modules are connected to the ADC pins on the microcontroller board.

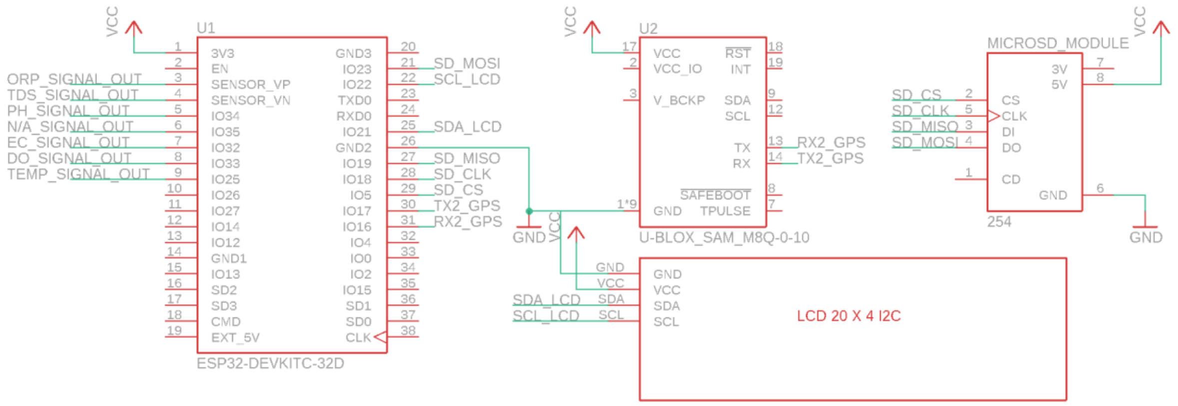


Figure 2. Wiring diagram of the system

The microcontroller board used in this design is ESP32-Devkit-C. This microcontroller is very suitable for automation systems that utilize internet or IoT networks. This board has 15 pins that can be used as ADC, there are also 2 pairs of pins for serial communication [25]. This board is used with TSMC 2.4 GHz dual-mode Wi-Fi and Bluetooth chips [26]. 40 nm low power technology offers the best performance and RF characteristics that are safe, reliable and scalable for a wide range of applications [27]. This device is equipped with position or location readings using the GPS module uBlox Neo-M8N. The NEO-M8 module uses simultaneous reception of up to three GNSS systems (GPS/Galileo and BeiDou or GLONASS) to detect multiple constellations simultaneously, providing excellent positioning accuracy in urban canyons and scenarios involving weak signals. The Arsenik version 2 is also featured with SD card module for offline data storage and LCD 20×4 for displaying all data.

2.3. Program work flow

The firmware program for this device was developed using the Arduino IDE. The program flow implemented in the ESP32 main processor is shown in Figure 3. A program begins by declaring all the libraries and all variables of the program that will be used. This process continues with serial communication initialization, the status of all input and output pins, Wi-Fi network connectivity, date and time data connectivity from the NTP server, and connectivity to the Firebase realtime database.

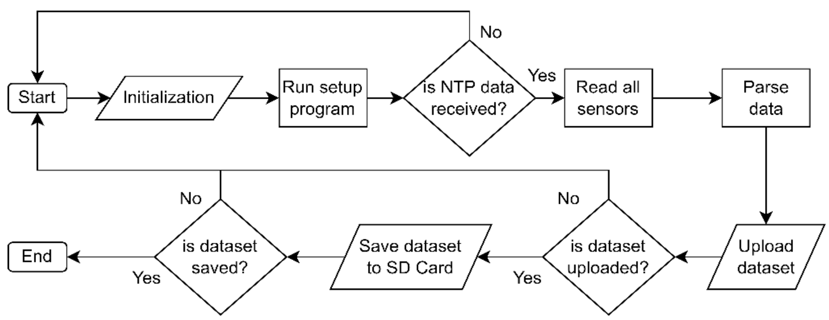


Figure 3. Arsenik version 2 program work flow diagram

The main program started as a loop. The setup starts with; check the sensors connectivity, check SD card availability, start connection to Wi-Fi network, check connection to firebase, and request data to NTP server. The process will continue if the program is received response from NTP server, if not the program will reboot.

Next process is run to the infinite loop of main program, start with reading data from all sensors, then parse them into one string dataset. Then check your network connection again to make sure your ESP32 board is connected to your Wi-Fi network and continue to upload dataset to real-time database. If the connection is lost or the server database sends an unsuccessful response, the system will reboot. But if not, the system will run to continue to save dataset to SD card. The the program will check again the availability of SD Card. If there any errors by checking or saving dataset to SD card, the process will reboot. But if its not, the process of this iteration is ended and go back to the main program loop.

2.4. Cloud server database

The device in this research uses Google Firebase. Datasets are received as JSON files and are continuously synced to each dedicated client [28]. Firebase will send a notification to the mobile application whenever your data is updated. All responses are discarded to optimize bandwidth usage unless the record in the database is updated. A feature of Google Firebase is a cloud-hosted database that compiles datasets from ESP32 and sends them to the database. The dataset is created as a string and contains comma separated values for each sensor value.

2.5. User interface application

The Android application was programmed using Android Studio Flamingo version 2022.2. The Android Studio integrated development environment (IDE) is built by Google. Android Studio uses Gradle, an advanced build toolkit, to automate and manage the build process while defining flexible custom build configurations. Each build configuration can define its own set of code and resources while reusing parts common to all versions of the app. The Arsenik version 2 application device application was written using the Java language. An application that is written as a type of native application. Native applications are developed specifically for the mobile phone operating system (source: https://developer.android.com/build). Therefore, native Android mobile apps are used in this study.

2.6. Sensor characterization

A calibration process for each sensor is necessary to measure their respective characteristics such as accuracy, precision and linearity. The first test is to calculate the accuracy of each sensor. When it comes to measurements, accuracy is the main factor affecting the performance of measuring equipment [29]. This test is performed by comparing the output of the sensor with the output of a standardized instrument. The comparison gives the error calculated by (1):

$$Error = \left|\frac{Standart\ value - test\ value}{Standart\ value}\right| \quad (1)$$

The second test is to know the precission of each sensor. Precission refers to how a measuring device consistently indicates an equal scale value over many time points. This can be calculated from the standard deviation of each test run. Standard deviation can be calculated using (2):

$$\sigma x = \frac{\sqrt{\sum_{i=1}^{n}(x_i - x)}}{(n-1)} \quad (2)$$

Then linearity is the mathematical relationship between input and output parameters that can be represented as a straight line in a graph. Linearity is closely related to the proportionality of input and output. The sensors calibrated in this device are pH sensor, water temperature sensor, TDS sensor, DO, electrical conductivity, and redox (ORP) sensor. This calibration process is also very important for finding the regression equation. Therefore, the regression equation for each sensor can be used as a reference for the calibration process of other measurement.

3. IMPLEMENTATION

3.1. The field device

Arsenik version 2 device is made portable and mobile to use anywhere. Because this will make it easier for pond farmers to measure the condition of their pond waters easily and efficiently. In addition, the measurement points cover several locations in just one pond area. This is to determine the distribution of the parameters measured and the water quality of the aquaculture media. As presented in Figure 4, the Arsenik device version 2 is assembled in one waterproof and shockproof case. The controller device, mobile Wi-Fi router, and sensor probes are placed in this suitcase safely. From this suitcase case, the user can also see the measurement results directly via the LCD, in addition to the display from the application on the smartphone.

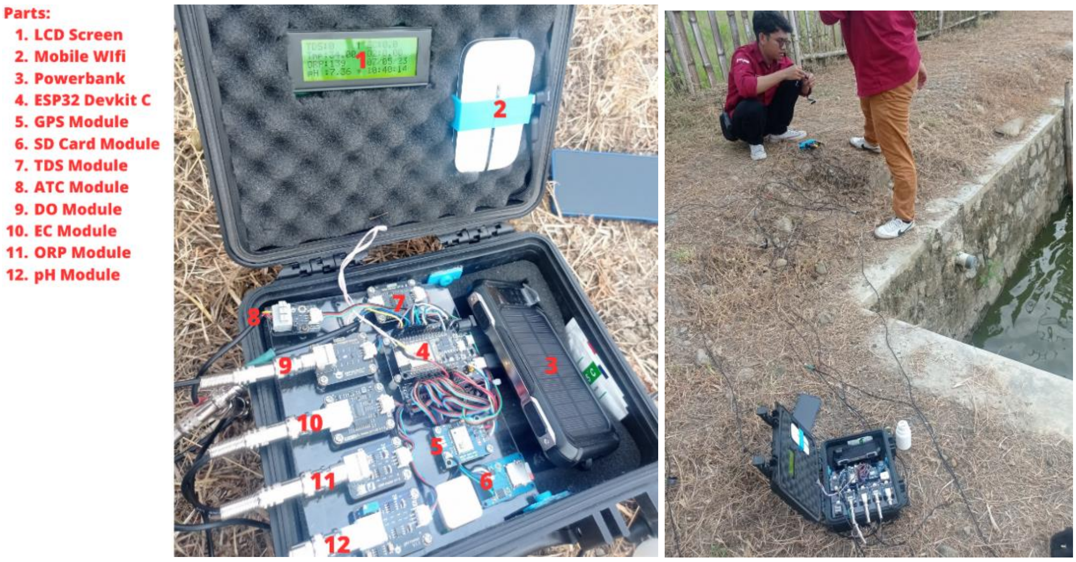


Figure 4. The field device, Arsenik version 2

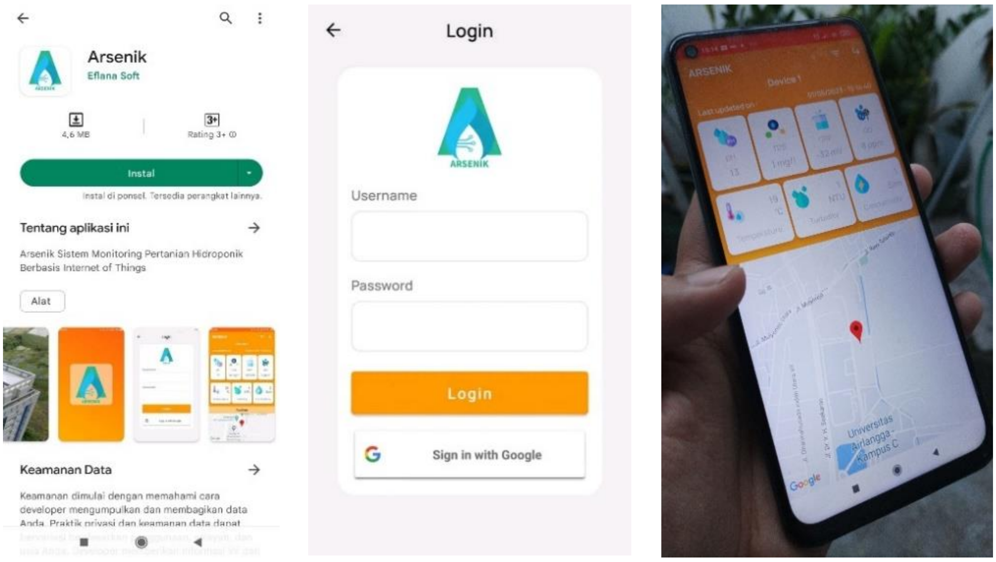
Figure 4 shows the field device visualization consisting of sensors and utilities. This device is supplied with electricity from a 5 VDC power bank equipped with a solar cell. This means that this device can be used remotely with an independent power source. From the aspect of internet connection, this device is supported by the Huawei E5776 mobile Wi-Fi router which is a 4G modem. For direct monitoring in the field, a 20×4 LCD is provided. The LCD display shows the measured parameter values, date and time, as well as SD Card storage status, GPS locking, and Firebase checks. The microcontroller board, sensors module, GPS module, and SD Card module are integrated with a PCB shield for the ESP32 Devkit-C board. The integration of this device is supplied by a power bank via USB type-C. In use, sensor probes are connected and wired to each module via a connector.

This device can be used easily by operators in the field. Operators only need to activate and check system readiness once, such as; sensors, internet connection, battery capacity. In addition, the operator needs to briefly observe the parameter values presented on the LCD screen. After that the operator can leave the device in situ, while the measurement will continue according to the specified observation period. After that, the operator can observe the parameter values from the smartphone screen from anywhere as long as it is connected to the internet. Data histiry will also be presented on the Android application. Thus, the IoT feature on this device can upload datasets to the cloud, and display them in the Android application, making it easier for operators to observe remotely.

3.2. User interface application

This Arsenik application can be downloaded on the Google Play Store. As Figure 5 shows, this application is limited use. Only users who are registered and approved by the system administrator can use and access its features. Users must register their Google account in order to log in to the application. Accounts with this access are stored in Firebase Firestore.

Figure 5(a) shows a screenshot of the link to download the Arsenik app on the Play Store. This is proof that the application has been released since April 24 2023 with the last update on April 28, 2023. This application with a relatively low storage capacity of 4.58 MB can be used on the Android operating system with a minimum version of Android 5.0. Figure 5(b) shows the login screen on the Arsenik application. Users can log in with the Google account used for smartphones. Figure 5(c) is a screenshot of the main menu of the application used to monitor real-time aquaculture parameters. There are 7 aquaculture parameters shown, with date and time parameters showing when the parameters were last updated. The main menu also presents the position of the device taken from the GPS data in the device field.



(a) (b) (c)

Figure 5. Visualization of Arsenik mobile application; (a) download screen from Play Store, (b) Arsenik log in screen, and (c) Arsenik main menu screen

3.3. Sensory reading conversion

This subsection discusses the method of converting the output signal from the sensor probe module into actual units. There is 1 sensor reading whose output signal is digital, namely the DS1280 which is used to measure the water temperature ($temp$). While the other 5 parameters, the output signal is analog. The digital signal conversion from the DS1280 module is programmed by counting digital bits into decimal values. This sensor has 8 digits that must be counted, then divided by a constant value of 16. The results of this water temperature reading must be accurate because it is used as a reference in calculating the conversion of other sensor values. The conversion of the pH value depends on the output voltage of the probe and the water temperature value, which is (3)-(5):

$$Slope = \frac{(7.0-4.0)}{(V_{neutral}-1500.0/3.0)-(V_{acid}-1500.0/3.0)} \tag{3}$$

$$Intercept = 7.0 - Slope\ (V_{neutral} - 1500.0/3.0) \tag{4}$$

$$pHvalue = \frac{Slope(V_{output}-1500.0)}{3.0+Intercept} \tag{5}$$

With slope is the calculation between two point voltage; voltage at neutral pH of buffer solution 4.0 at 25 ºC ($V_{neutral} = 2032.44\, mV$) and voltage at acid pH of buffer solution 7.0 at 25 ºC ($V_{acid} = 1500.0\, mV$). Then it can be generated to calculate Intercept as (2). Then the real pH value can be calculated as (3). With V_{output} is analog voltage output from pH sensor probe module which range between 0–5 V. Same as pH, calculation for the electrical conductivity value depends on water temperature and output voltage of the sensor describe in (6) and (7):

$$EC_{raw} = 1000\ x\ V_{outEC} / \frac{EC_{res}}{EC_{ref}}\ x\ 1.0\ x\ 10.0 \tag{6}$$

$$ECvalue = \frac{EC_{raw}}{(1.0+0.0185\ (temp-25.0))} \tag{7}$$

With V_{outEC} is the output voltage of the sensor conductivity module, EC_{res} is the reading resolution which is equal to 7500.0/0.66, EC_{ref} is the conductivity reference value at 25 ºC which is equal to 20.0, and water temperature ($temp$) occurred by DS1280 temperature sensor.

The calculation of redox or ORP value is only depends on ADC reading from output signal analog of the sensor module describe in (6). The ORP reading is occured by 1000 times of sampling ($ADC_{sampling}$).

ORP is a measure of a chemical species to acquire electrons from or lose electrons to an electrode and thereby be reduced or oxidised respectively. ORP is expressed in volts (V) (8):

$$ORPvalue = 1058.8 - (ADC_{sampling}\ x\ 0.4349) \tag{8}$$

The calculation of DO depends on its own sensor output voltage and water temperature (*temp*). DO is the amount of oxygen that is present in water which is (9) and (10):

$$V_{sat} = V_{cal} + (35\ x\ temp) - \ (35\ x\ temp_{cal}) \tag{9}$$

$$DOvalue = \frac{V_{outDO}\ x\ DO[temp]}{V_{sat}} \tag{10}$$

This process uses one point callibration. With V_{cal} is voltage from callibration conducted in the manufacture which equal to 921 mV, $temp_{cal}$ is temperature callibrated which is equal to 29.4 ºC, and V_{outDO} is output voltage from sensor DO module. Variable *temp* will indexed to the DO table (*DO[temp]*) to find the DO constant. Then they will be used to calculate the real DO value.

The conversion for TDS is also depends on *temp* value, which is (11)-(13). The *temp* value used as temperature compensation for its calculation. That because the change of temperature will increase the change of voltage compensation of the sensor.

$$Coef_{com} = 1.0 + 0.02(temp - 25.0) \tag{11}$$

$$Volt_{com} = V_{outTDS}/Coef_{com} \tag{12}$$

$$TDSvalue = \left(\left(133.4\ x\ Volt_{com}{}^{3}\right) - \left(255.8\ x\ Volt_{com}{}^{2}\right) + (857.3\ x\ Volt_{com})\right) x\ 0.5 \tag{13}$$

With $Coef_{com}$ is a coefficient compensation, $Volt_{com}$ is voltage compensation which depends on *temp*, and V_{outTDS} is output voltage from TDS probe module.

4. RESULT AND DISCUSSION

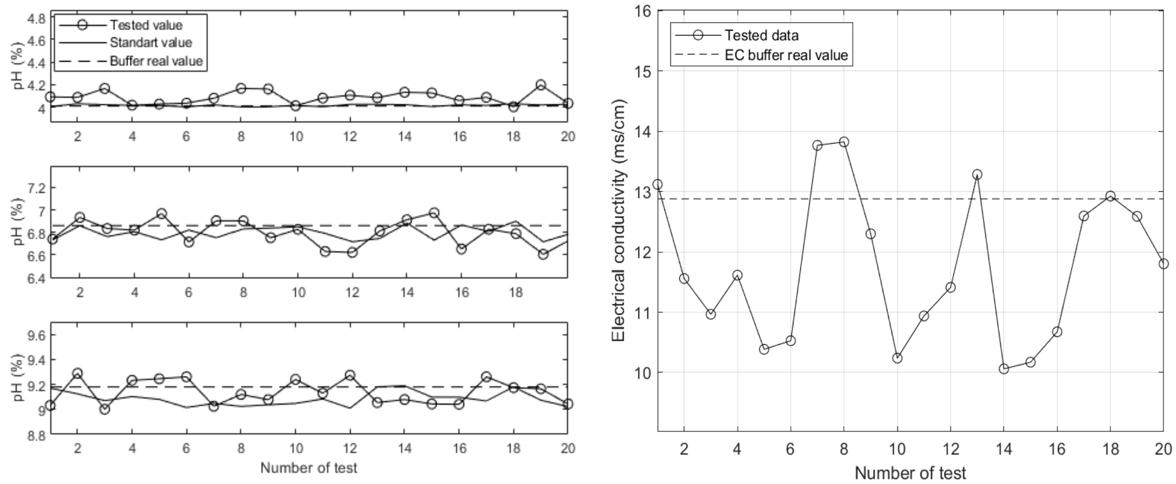
4.1. Sensory characterization analysis

The characterization process compares the results of tested measuring instrument with the results of standard measuring instruments. In addition, it is also compared with the specifications contained in the datasheet. The characterization test observes the parameters of accuracy, precision, and linearity of each sensor reading. The test method is slightly different for each sensor reading. This is because each sensor has a different measuring criterion. The standard measuring instrument used is the Lutron YK-2001PHA water meter. This water meter can measure 6 water salinity parameters, such as; temperature, acidity, DO, ORP, TDS, and EC. Each parameter is measured using a different probe. The use of each probe is the same, that is, it is immersed below the surface of the water. However, for the DO probe, it is necessary to add a filling solution of 0.5 mol/L NaOH. The test was done by obtaining tested value and standard value in 20 measurement points in a 15×20 meters fish pond.

The ORP test was carried out with a standard potassium chloride (KCl) solution of 3.5 mol/L which was varied in the solution temperature range of 10–40 ºC and 5 ºC intervals. The precission of ORP is not available because it very hard to make constant input of the sensor. Then the DO test was carried out on a solution with an average temperature of 33 ºC in the range of 13.5–17.6 mg/L. TDS testing is carried out on a solution that is set at a temperature of 25 ºC with a test range of 10–1000 ppm. Figure 6 shows the reading comparison between tested instrument and standard instrument for pH. From the figure the error is occurred by the difference of their values. Accuracy testing was carried out with varying salinity parameter values. The tested measurement results that have been converted according to the calculations in subsection 3.3. Then the error is calculated for each measurement variation. Tests were also carried out on the same media, at the same time, and with the same operator.

While precision testing is done by taking measurements repeatedly. Repetition for all sensor readings is 20 times, by comparing with standard gauge readings. Then the standard deviation is calculated to find the precision error. This precision testing method is with repeatability, which is carried out with the same instrument, the same object, the same operator, and the same time.

Shown in Figure 6(a) is the comparation reading error between the tested instrument and the standard instrument for measuring pH values. Measurements on 4.00 pH buffer solution media resulted in an average error of ±0.018. Measurements on 6.86 pH buffer solution media resulted in an average error of +0.014. Measurements on 9.18 pH buffer solution media resulted in an average error of ±0.012. So, the average pH reading error on the tested instrument is ±1.5%. Figure 6(b) shows the test results for EC measurements which were carried out by comparing the tested instrument with 12.88 mS/cm KCL buffer solution. Then the test produces an average error of EC reading is 10.8%.



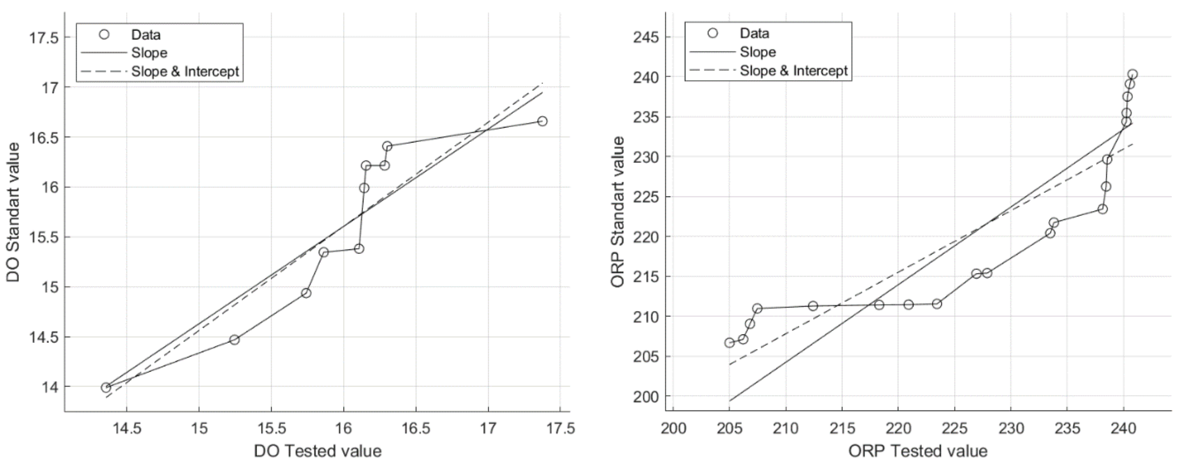
(a) (b)

Figure 6. Error test of the sensor; (a) pH reading for tested instrument and standard instrument and (b) EC reading of sensor probe Gravity: DFR0300

4.2. Linearity test

From the results of previous research, the design of version 1 of Arsenik is used specifically for hydroponic farming. Arsenik version 1 uses the same type of TDS sensor and temperature sensor. TDS sensor linearity is 99%, and water temperature DS18B20 sensor linearity is 95% [24]. Figure 7 shows the linearity test on DO reading and ORP reading. Both parameters occurred with comparison to the standard measure value.

Figure 7(a) shows the DO linearity test which is result the linearity is 83%. The test occurred with tested instrument (Gravity: SEN0237) and standard DO instrument probe. Figure 7(b) shows the ORP linearity test which result the linearity is 80%. The test occurred with tested instrument (Gravity: SEN0165) and standard ORP instrument probe. The linearity will responsible to the measurement accuracy as shown in Table 1. Therefore, the accuracy of DO and ORP reading resulting the moderate value, but they still can be accepted as good measurement.



(a) (b)

Figure 7. Linearity result of tested instrument versus standard instrument; (a) DO reading and (b) ORP reading

Table 1. Accuracy test method with standard instrument

No.	Tested parameter	Tested instrument	Standard instrument	Test range	Average error (%)	Accuracy (%)	Standard deviation	Precision (%)
1	Temp	Gravity: DS18B20	Lutron ATC TP-07	10–50 ºC	0.76	99.24	3.6	96.4
2	pH	Gravity: SEN0161	Lutron PE-03	4.01, 7.00, 10.01	1.52	98.48	2.08	97.92
3	EC	Gravity: DFR0300	Default PH Probe	12.88 mS/cm	10.8	89.2	1.26	98.74
4	ORP	Gravity: SEN0165	Lutron ORP 14	242–201 mV	14.6	85.4	N/A	N/A
5	DO	Gravity: SEN0237	Lutron OXPB-11	13.5–17.6 mg/L	9.3	90.7	0.77	9.23
6	TDS	Gravity: SEN0244	Default TDS Probe	10–1000 ppm	1.32	98.68	6.1	93.9

4.3. System performance

The Arsenik system version 2 is assembled and portable, so it can be taken anywhere. Sensor probes are housed in a waterproof and shockproof case. This field device is equipped with a solar-powered power bank with a capacity of 10,000 mAh so that it can meet the electricity needs of the device with an operating voltage of 5 V. The DC current requirement for the device includes; the ESP32 Devkit-C module being around 247 mA, the GPS GY-Ublox Neo M8N being around 42 mA, and the six DFROBOT sensor modules being around 18 mA in total. With a power source from a power bank, the device can stand by for more than 32 hours.

The GY-Ublox Neo M8N GPS module can lock the device's position within 7-11 minutes, in open field conditions. As for 4G internet connection, device connection to mobile Wi-Fi can be achieved in less than 2 minutes. As for connecting to Firebase and to the NTP server, it took about 1 minute each. Therefore, from the aspect of internet connection, Arsenik version 2 can be immediately ready to use after 3–4 minutes.

5. CONCLUSION

The need for an appropriate technology in aquaculture techniques aims to increase the efficiency and effectiveness of freshwater fisheries. With the Arsenik device version 2, the work of pond operators in monitoring aquaculture media becomes much easier and more practical. Pond operators become more aware of water quality accurately. Monitoring of aquaculture conditions based on detailed measurement of 6 parameters shows the true quality of aquatic ecosystems. In this study, a device for monitoring aquaculture conditions has been created using a field device, a real-time database, and an Android-based application. One of the major results of tests on a laboratory scale, the accuracy test shows that each parameter has different measurement error that represents with average error absolute. The test was conducted to 6 tested sensors/instruments. The temperature sensor has 99.24%, pH sensor has 98.48%, EC sensor has 89.2%, ORP sensor has 85.4%, DO sensor has 90.7%, and TDS sensor has +13.2%. The test also shows high accuracy, precision, and linearity in the parameters of temperature, pH, DO, and TDS. While the parameters show a medium level of accuracy and precision, such as; ORP and EC. This shows that the calibration method is not too good. From the database side, a real-time database has also been designed using Google Firebase features. Where this cloud server besides storing measurement datasets in real-time, also data about application users. In terms of the user interface, the Android-based application created is also easy to use, informative and practical. With this application, pond operators can remotely monitor pond conditions in real-time. Phisically, the compact and safe form of the device makes this device suitable for use in the field under any conditions.

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