Journal of Physics: Theories and Applications E-ISSN: 2549-7324 / P-ISSN: 2549-7316
J. Phys.: Theor. Appl. Vol. 7 No. 2 (2023) 191-200 doi: 10.20961/jphystheor-appl.v7i2.78897

Monitoring system ammonia concentration using fiber optic sensor based surface plasmon resonance

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Received 18 September 2023, Revised 26 September 2023, Published 29 September 2023

Abstract: A monitoring system for ammonia concentration in waters has been created using fiber optic sensors based on surface plasmon resonance (SPR). Monitoring is carried out to measure the decline in water quality due to the toxic compound ammonia from floating net cages (KJA) activities used as aquaculture sites. The sensor performance was improved by replacing the cladding using gold nanoparticles to increase the sensitivity of the fiber optic sensor based on the SPR phenomenon. The sensor consists of a laser diode as a light source, optical fiber as a waveguide and OPT101 as a photodetector. The Arduino Nano microcontroller is used as a data processor, LoRa as a transmission system and the MCU node as a data receiver. The results of measuring the ammonia concentration received by the MCU node are displayed on a Google spreadsheet in real time. Testing of measuring instruments is carried out by comparing the measurement results with a UV-Vis spectrophotometer. The test results obtained an accuracy value of 94.09% for optical fibers using the dip coating method and 78% for optical fibers using the thermal evaporation coating method.

Keyword : Fiber optic, surface plasmon resonance, ammonia, floating net cages

1. Introduction

Water acts as a source of life that can ensure the health of living creatures and can be a source of dangerous diseases if its quality decreases. The decline in water quality is caused by population activities carried out around the waters (Demetillo et al., 2019). Population activities in waters such as floating net cages (KJA) as a place for fish cultivation can reduce water quality, causing pollution. The sludge of fish food waste in KJA contains nitrogen and phosphate, the decomposition of which produces nitrite, ammonia and sulfide which cause pollution if the concentration exceeds the permitted limits (Macbub, 2010).

An ammonia concentration of 1 mg/L can cause death to aquatic organisms and death to certain fish (Hibban et al., 2016). In early January 2009, there was a mass fish death in Lake Maninjau due to KJA which was caused by ammonia content that exceeded a concentration of 0.02 mg/L (Nasution et al., 2020). Increasing ammonia concentrations can affect animal and plant habitats, so monitoring the aquatic environment is very necessary to protect and ensure that aquatic ecosystems function normally (Amoatey & Baawain, 2019).

Monitoring of water conditions, especially Lake Maninjau, has been carried out to observe the total nitrogen (TN), total phosphate (TP) content using the spectrophotometric method (Kurniati & Komala, 2021). The TN and TP contents related to chlorophyll-a were analyzed using the acetone spectrophotometry method (Sutrisno & Hamdani, 2013). Measurement and analysis of test samples cannot be done in real time because spectrophotometers have quite large dimensions and are only available in certain laboratories. A simple sensor that can be used to monitor water conditions is a fiber optic sensor. Optical fibers, which were originally only used for data transfer in optical communication systems, have been used for various applications, including as sensors (Sabri et al., 2015). Fiber optic sensors have small size, high sensitivity, and low cost.

Increasing the sensitivity of fiber optic sensors to obtain more specific measurement results can be done by replacing the fiber optic cladding, namely coating it with another material (Christopher et al., 2018). Optical fibers have been coated with gelatin, TiO_2-SiO_2 and zinc oxide for measuring microplastic concentrations and air humidity (Hidayati & Harmadi, 2021; Febrielviyanti et al., 2019; Sundari & Harmadi, 2022). Based on the research that has been carried out, coating materials are still needed that have high sensitivity, high specificity and short recovery times. The coating material to replace fiber optic cladding is gold nanoparticles (Garcia et al., 2016).

The use of gold nanoparticles as a substitute for fiber optic cladding can produce plasmonic resonance on the core surface when excited by evanescent waves produced by total internal reflection (Som & Karmakar, 2010). Increasing the intensity of electromagnetic waves due to surface plasmon resonance (SPR) excitation can increase the sensitivity of optical fibers to chemical molecules attached to the surface of the optical fiber core (Lam et al., 2005). The development of an SPR-based fiber optic sensor to detect a sample in the form of specific molecules or ions has been carried out. Other research that has been carried out is sensing heavy metal ions such as mercury and phosphate ions in solution. Varying sample concentrations produce fiber optic sensors that are sensitive and selective in sensing heavy metal ions and phosphate ions (Bharadwaj & Mukherji, 2014; Yuan et al., 2019; Verma & Gupta, 2021).

Collecting measurement data from fiber optic sensors that have been coated with gold nanoparticles from several studies uses a UV-Vis spectrophotometer which does not yet use a digital instrumentation system. The data obtained is still in the form of the sensor's absorption wavelength so the concentration value of the molecules or ions detected is unknown. Based on the problems and previous research that have been presented, a fiber optic sensor was designed to monitor solution concentration in real time from a distance. Monitoring the concentration of the solution to be tested is ammonia which is an indicator of water pollution which causes toxic conditions for life in the aquatic environment (Ngibad, 2019).

2. Method

2.1. Fiber Optic Sensor Design and Characterization Stage

Design of the fiber optic sensor begins by peeling the optical fiber using a cutter, removing the cladding with acetone and sanding it so that there are no remaining cladding on the surface of the optical fiber. The length of the fiber optic stripping was varied along 2 cm, 4 cm, 6 cm and 8 cm. Next, the optical fiber is bent with diameter variations of 0.25 cm, 0.5 cm and 0.75 cm. After that, the optical fiber is inserted into a vacuum chamber for the thermal evaporation method. The gold synthesis solution is used for the dip coating method, where the optical fiber is dipped into the solution and withdrawn after 5 hours.

The characterization process, optical fibers with the best stripping length and bending diameter will be selected by testing their sensitivity using the BF5R measuring instrument. Tests were carried out to see the relationship between stripping length and bending diameter with the intensity of the output light propagating in the optical fiber. Testing of optical fibers coated in a vacuum chamber evaporator was carried out to compare sensitivity with optical fibers using the dip coating method.

2.2. Monitoring System Design Planning Stage

2.2.1. Hardware Design

The hardware design of the ammonia concentration measuring instrument is in accordance with the block diagram in Figure 1. In the fiber optic sensor block consisting of a series of laser diodes and an LDR, it is used as a transmitter-receiver of light that will be guided in the optical fiber. The light intensity output that comes out of the end of the optical fiber in the form of voltage is used as input for the Arduino Nano which will convert the light intensity value into ammonia concentration. Concentration data from Arduino is sent wirelessly using a LoRa transceiver connected to the Node MCU. The MCU node then sends concentration data in real time with activated WiFi to Google Spreadsheet.

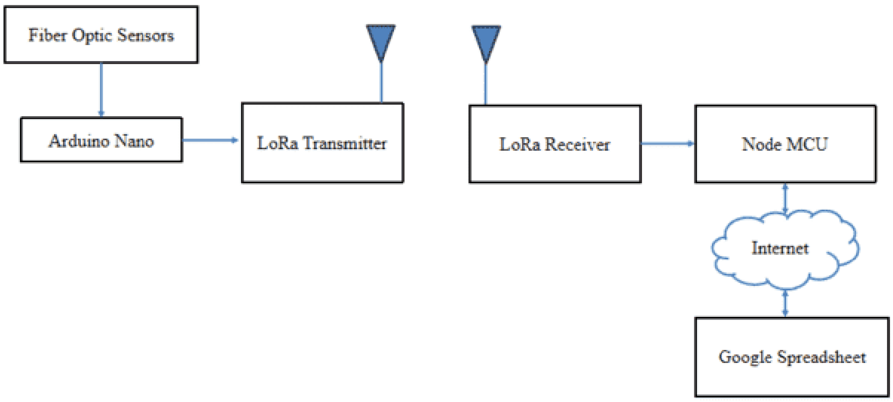


Figure 1. Block diagram system

2.2.2. Software Design

Software design begins by programming using the Arduino Nano module to read and process data from fiber optic sensors according to the flow diagram in Figure 2. Sending data wirelessly uses the LoRa SX1278 module as a transceiver which is connected to the Node MCU module. Before the data is sent, it is ensured that the ESP2866 Node MCU is connected to WiFi. Then the fiber optic sensor data is sent online to Google Spreadsheet.

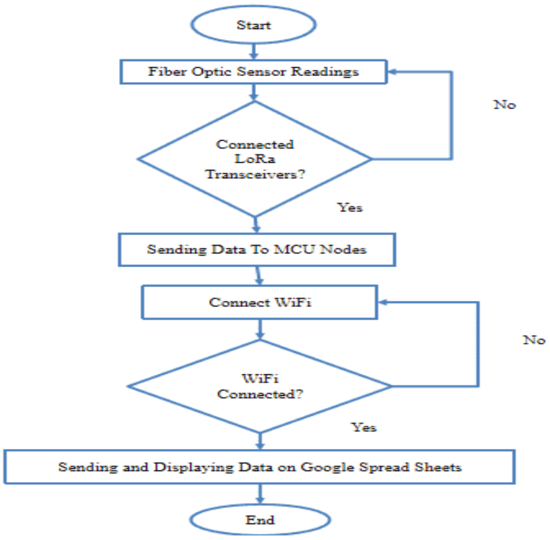


Figure 2. Software flow diagram

2.3. Analysis of Measurement Data

Data analysis is a process to determine the level of precision and precision of a measurement system. Precision (accuracy) is a measure that shows how close the instrument reading is to the true value (Santoso, 2017). The accuracy of the system can be determined from the percentage error between the actual value and the visible value.

$$Persentase\ kesalahan = \left|\frac{Y_n - X_n}{Y_n}\right| \times 100\ \% \quad (1)$$

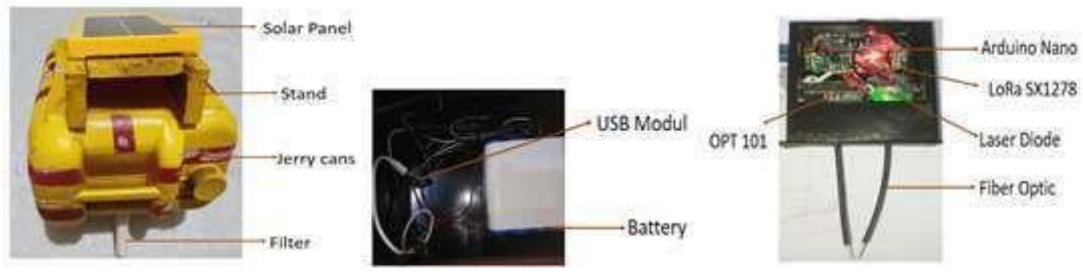
$$Persentase\ ketepatan = \left[1 - \left|\frac{Y_n - X_n}{Y_n}\right|\right] \times 100\ \% \quad (2)$$

The percentage of error in testing a measuring instrument can be determined using Equation 1. Meanwhile, the percentage of accuracy of the measuring instrument is calculated using Equation 2. Yn is the actual value on the comparison device and Xn is the value read on the measuring instrument.

3. Result and Discussion

3.1. Overall Tool Making Results

The measuring instrument for the ammonia concentration monitoring system is designed using a 10 liter jerry can as shown in Figure 3 (a). The bottom of the jerry can is equipped with a perforated pipe to protect the optical fiber from external interference. The jerry can is used as a float which contains a power circuit and a fiber optic sensor circuit. The power circuit gets a voltage source from the solar panel which converts solar thermal energy into voltage as in Figure 3 (b). The voltage stored in the battery is used to activate the fiber optic sensor. The sensor box is designed as in figure 3 (c), so that no laser light comes out of the hole where the optical fiber is installed.



(a) (b) (c)

Figure 3. (a) Ammonia concentration monitoring device frame (b) power circuit (c) optical sensor circuit

The fiber optic sensor system used as a data transmitter consists of optical fiber, LoRa transmitter, Arduino Nano, OPT 101 and a diode laser which has green light with a wavelength of 530 nm. The sensor data receiving system is placed at a distance of 100 meters from the measuring instrument. The series of data receiving components consisting of LoRa Receiver, power bank and ESP 3260 can be seen in Figure 4 (a). Data received by the ESP 3260 is sent online to Google Spreadsheet as in Figure 4 (b).

(a) (b)

Figure 4. (a) Fiber optic sensor data receiver (b) sensor data display and storage

3.2. Optical Fiber Preparation Results

Variations in stripping length and bending diameter of optical fiber on output intensity values were tested using BF5R. The BF5R output value shows that the longer the stripping length and the larger the bending diameter, the greater the loss which results in decreased guided light in the optical fiber. Stripping is done so that there is interaction of light propagating in the optical fiber with the surrounding environment. Bending of optical fibers is carried out to produce greater evanescent wave interactions compared to optical fibers without bending (Tan et al., 2020).

The stripping length and bending diameter of the optical fiber selected is the optical fiber with the greatest output or with the smallest loss. Loss that is too large can affect measurements such as reducing the range of measured data. In this study, the optical fiber used as a sensor was a stripping length of 2 cm and a bending diameter of 0.25 cm.

3.3. Fiber Optic Sensor Characterization Results

The next characterization is to test the fiber optic sensor by looking at the relationship between the ammonia concentration and the sensor output voltage as in Figure 6. Testing is carried out on coated optical fibers using the dip coating method and the thermal evaporation method. Optical fibers with the evaporation thermal coating method have higher regression values than optical fibers with the dip coating method. Indication of the cause of graph 6 (a) is more linear than graph 6 (b) due to cladding degradation on optical fibers using the dip coating method.

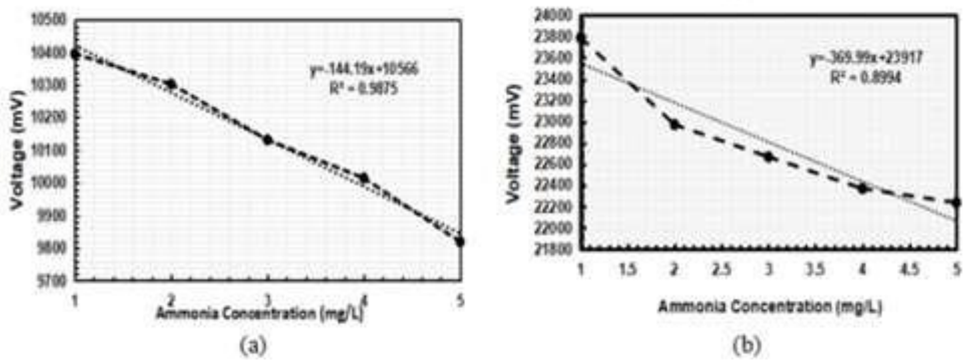


Figure 6. (a) Optical fiber with thermal evaporation coating method (b) Optical fiber with dip coating method

Measurement of variations in the concentration of the ammonia solution was carried out using a UV-Vis spectrophotometer. The ammonia solution was added to 0.5 ml of Nessler's solution before the spectrophotometric test was carried out. The graph in Figure 7 shows the relationship between concentration and absorbance value observed at a wavelength of 364 nm. The transfer function obtained from the graphic plot is used to determine the unknown ammonia concentration value. The graph of the relationship between ammonia concentration and absorbance value shows that the graph plot is not in the linear area, so the spectrophotometer data will affect the accuracy of fiber optic sensor measurements.

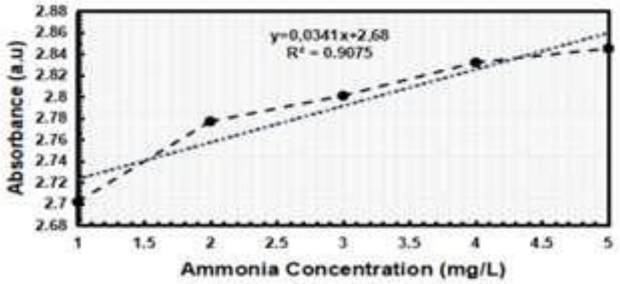


Figure 7. Graph of the relationship between ammonia concentration and absorbance value

3.4. Laboratory Scale Test Results

The next test of the fiber optic sensor was using Lake Maninjau water samples at six different measurement points. Sampling was carried out in the villages of Koto Kaciak, Duo Koto, Bayur, Maninjau, Sungai Batang and Tanjung Sani. The sample was taken to the laboratory to measure the concentration value using a sensor that had been made with two optical fibers with different coating methods.

Measurement of ammonia concentration in lake water was also tested using a spectrophotometer. The spectrophotometer is used as a comparison tool for measuring ammonia concentration with a fiber optic sensor as seen in Figure 8. The highest accuracy of the ammonia concentration value from the measuring instrument made with a spectrophotometer is the measurement at point 3 Nagari Bayur of 78% and 94.44% for the two fiber coating methods. optics. The difference in concentration values displayed by the instrument and the spectrophotometer is caused by changes in weather in Lake Maninjau. The graph of the characterization results of the fiber optic sensor and spectrophotometer which is not in the linear area is also the cause of the highest sensor accuracy only at measurement point 3.

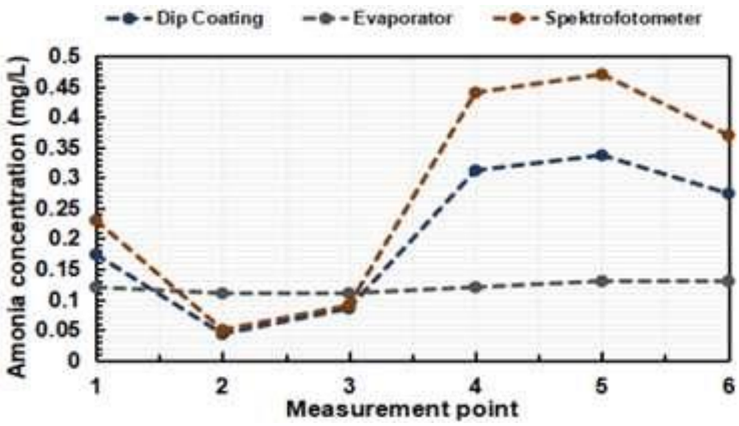


Figure 8. Comparative graph of ammonia concentration measurements with a spectrophotometer and fiber optic sensor

3.5. Field Scale Test Results

Field-scale fiber optic sensor testing was carried out directly at Lake Maninjau to monitor ammonia concentrations as seen in Figure 9. Monitoring of ammonia concentrations for optical fibers using the dip coating method was carried out on August 26 2023 from 08.00-11.02 WIB. Monitoring could not be carried out after 11.02 WIB because the designed tool could not prevent water from entering the component box caused by rain and storms that occurred on Lake Maninjau. Monitoring of ammonia concentration for optical fibers using the thermal evaporation coating method was carried out on August 27 2023 from 08.00-11.41 WIB. Sending sensor data stopped at 08.38-11.04 WIB due to rain that occurred on the lake. The accuracy of the ammonia concentration value in the measuring instrument made with a spectrophotometer is 78% for the optical fiber thermal evaporation coating method and 94.09% for the dip coating method.

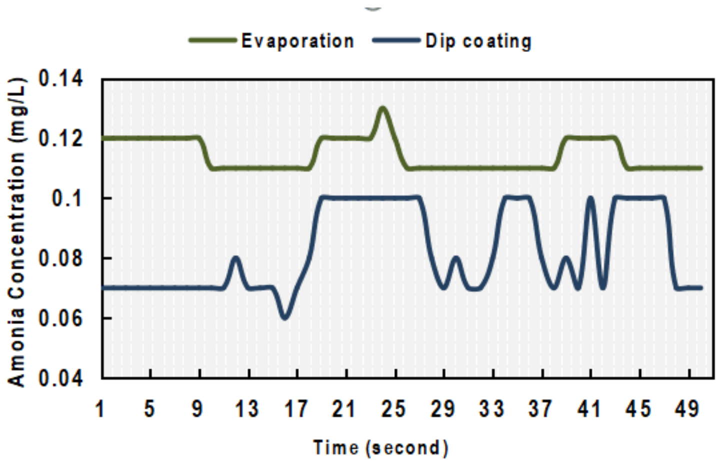


Figure 9. Comparative graph of monitoring ammonia concentrations in Lake Maninjau

4. Conclusion

An ammonia concentration monitoring system using surface plasmon resonance-based fiber optic sensors in waters was successfully created using optical fiber with a stripping length of 2 cm and a bending diameter of 0.25 cm. This research uses two types of optical fiber, namely optical fiber with the thermal evaporation coating method and the dip coating method. Fiber optic sensors with the dip coating method have a percentage accuracy of 94.09% and 78% for the thermal evaporation coating method. Fiber optic sensors with the thermal evaporation coating method designed are still less sensitive to ammonia concentrations so they require a more precise coating technique. Data accuracy in ammonia concentration monitoring system research requires a comparison tool with high accuracy, so that it can make it easier to analyze sensor output data.

ACKNOWLEDGEMENT

Thank you to the applied research grant from Andalas University, Faculty of Mathematics and Natural Science 2023, which has funded this research.

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