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DESIGNING THE TECHNOLOGY FOR TURBIDITY SENSOR-BASED AUTOMATIC RIVER SEDIMENTATION MEASUREMENT

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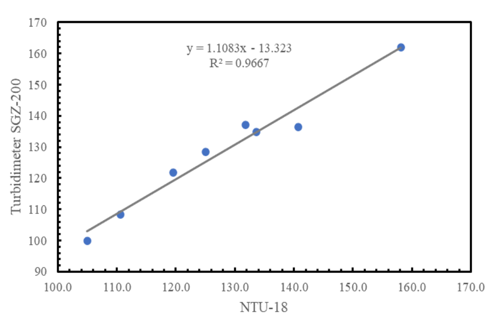
Graphical abstract



Abstract

Sedimentation measurement has been quite difficult to do as it requires more time for and more activity in water management, thus affects the quality and quantity of obtained data. The purpose of this study was to create a set of devices capable of automatically measuring sediment and flow characteristics. The phases of this research were the determination and assembly of all the device components, creation of a program for converting data into numbers, sampling, and device testing. The results of the device testing, which were obtained from calibration and conversion tests, indicated that the devices had been well tested. The calibration and conversion curves showed the R value was close to 1. As for the unit conversion equation of NTU and ppm, it was y = 11.71x – 1037.2. In conclusion, with the successful creation of this automatic measuring devices, the turbidity and flow velocity-based sedimentation measurement is expected to be the solution to issues demanding efficient and practical data retrieval.

Keywords: Turbidity sensor, sedimentation, calibration, Arduino sketch, conversion

1.0 INTRODUCTION

Sedimentation is an occurrence where an amount of soil material is carried away by the river water flow coming from erosion upstream and then deposited in the lower reaches of the river. The sediment is deposited in a place where the pace of the stream slows down or stops. The extent of sedimentation depends on the physical characteristics of a watershed [1]. Sedimentation rate is the amount of soil and its material covered by water from an erosion spot in a watershed, which then join a river or body of water [2]. The sedimentation rate of a watershed plays a vital role, which is being the basis for the watershed management plan. Based on this rate, the step of applying the right soil and water conservation techniques is determined so that the sedimentation rate value is in accordance with what has been planned [3].

Sedimentation leads to the occurrence of turbidity or decrease in water transparency. Due to turbidity, the direction of the light path transmitted in the water changes when it is in contact with the particles in the water. If the turbidity is at a low level, then the light deviating from the original direction is just a little. Sedimentation analysis or turbidity analysis is carried out by studying optical properties causing light in water to disperse and be absorbed by colloidal and suspended particles instead of being transmitted in a straight line [4]. Light scattered by such particles as sludge, clay, algae, organic matter, and microorganisms enables the detection of the particles in streams or water [5].

The measurement of sedimentation produced through erosion is very important for technical operators to know in the field. The method to estimate the extent of sedimentation or the rate of watershed sedimentation can be carried out directly through the quantification of sediment coming out with river flows through watershed outlets or through the approach of the watershed sediment delivery ratio (SDR) based on the predicted value of erosion taking place in the watershed [3]. For the direct measurement, the transport discharge of suspension sediment is obtained in a conventional way, by taking water mixed with sediment (suspended load) as the sample and calculating the concentration of the sediment. The sample is then analyzed with evaporation and filtration methods in the laboratory to obtain the sediment concentration. Requiring more time for and more activity in water management, thus affecting the quality and quantity of data obtained, sediment measurement has been quite difficult to do [6]. The recording of the data of this measurement is prone to being lost and might result in improperly recorded data. Given this, there is a need for a system easing the measurement and managing to neatly record the data of water sedimentation stored in the database.

In recent years, various studies designing sedimentation measures using the type of in situ turbidity sensor have emerged and the use has been gaining ground. These designs have been proven to manage to handle the existing problems in the field, such as those in the studies involving the ATMega16A-PU microcontroller-based turbidity measuring instrument system [7] and the prototype of water turbidity monitoring system [8]. For the development of water turbidity sensors, several other researchers conducting research with concepts of optics as the bases for their studies, i.e. Low-Cost Turbidity Sensor for Low-Power Wireless Monitoring of Fresh-Water Courses [9], Design and Build a Water Turbidity Measuring Instrument Using Phototransistors and Infrared LED's Based on Arduino Uno [10], and Early Warning of Floods Based on Water Turbidity Levels of Upper River with Turbidity Sensor SEN0189 and Transceiver nRF24L01+ [11]. Most of the measurements applied the method of taking a sample of water not tested in the laboratory from the field.

A device employing a turbidity sensor and mobile web-based Arduino can take data from a level of turbidity (opaqueness) to be a measure of water quality [12]. It works by measuring the light serving as the detector of suspended particles in water to obtain the light transmission and dispersion rate and comparing the rate value with the total number of suspended solids (tss) in the water. The principles of how this turbidity sensor works are similar to those of a proximity sensor as the photodiode LED serves as the transmitter and the photodiode (receiver). This sensor utilizes the light emitted on the LED, generating light reflection, which it then reads. So, the higher the level of detected water turbidity, the less light is reflected, or vice versa [13]. After that, the data is sent to the system with a memory card attached to the device. The data is accessible through a computer or smartphone by converting the data recorded on the memory card into a data language using a program created with the language of C System Arduino Sketch [14].

The purpose of this study was to create a set of measuring devices capable of measuring sedimentation and flow characteristics automatically. The turbidity meter from this study is a breakthrough, in other words, novelty, in the world of measurement technology. It automatically varies the light output so that it is viable to measure the turbidity independently from the backlight and electronic deviation. This water turbidity measuring device, in addition to measuring turbidity, measures the flow pace, records the location, and is equipped with a real time clock. It is also a primary advantage of this device that on-site data collection is feasible. Therefore, it is hoped that in the future, turbidity measurement will be easier and more practical, the data storage will be neater, and the data itself will be more accurate.

2.0 METHODOLOGY

2.1. Location

The NTU18 device assembly was carried out at the Hydrotechnical Laboratory of the University of Lampung. The sampling locations were 8 rivers in Bandar Lampung, as shown in Figure 1.

2.2. Instrument Assembly

2.2.1. Hardware Assembly

This hardware designing included input and output assemblies, which were connected with an open-source assembly of Arduino Uno microcontrollers ATmega328 series with a 14 analog-input pin and a 16-MHz crystal oscillator (Figure 2a).

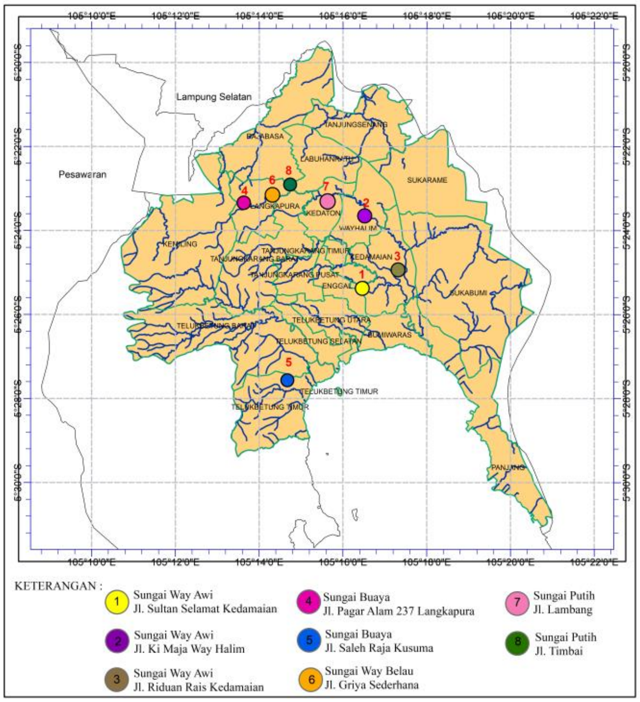


Figure 1 Sampling data locations

Arduino microcontrollers have the functions of controlling and processing data from an input device and then forwarding it to an output device [15]. The input assembly included the turbidity sensor type TS-300B (Figure 2b), water flow sensor type YF-S201 0.5 inch (Figure 2c), and a real time clock (RTC), and the position sensor type Ublox m6 (Figure 2d). As for the output assembly, it was the SIM 900A GSM/GPRS module. This SIM 900A GSM/GPRS module serves as a link between the Arduino Uno controller and the Web service [16]. The energy source of this device was powered by a chargeable power supply adapter with a capacity of 10050 mAh with a power switch on the outside. The power supply was connected to the microcontroller via a USB cable, so the device could be easily disassembled. The SD Card functioning as the data storage for the sensor measurement was connected with the RTC V1.0 data logger shield (Figure 2e). All the components of the NTU18 measuring instrument were assembled in a waterproof container attached to a pole linking the flow velocity measuring components to the water turbidity meter. The main components composing the device are shown in Figure 2.

2.2.2. *Software Assembly*

The program was made based on its main controller, the Arduino Uno R3 microcontroller. The microcontroller was programmed in the C-based Arduino language using Arduino Sketch. As the Arduino Uno R3 microcontroller has its own compiler, the Arduino IDE, the created programs were saved with the [*.ino] extension.

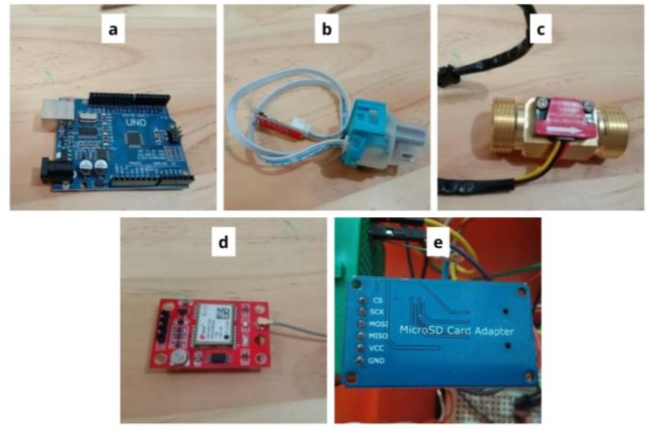


Figure 2 (a) Arduino Uno microcontroller ATmega328 series. (b) Turbidity sensor type TS-300B. (c) Water flow sensor type YF-S201 0.5 inch. (d) Real time clock (RTC) and position sensor type Ublox m6. (e) Data logger shield RTC V1.0

The files were then compiled and uploaded to the microcontroller using a USB cable so that the microcontroller would work as a system controller with the desired performance.

2.3. Instrument Testing

2.2.3. *Calibration*

To find out the accuracy of the output result of the device, it was necessary to empirically match the suitability of the component assembly through calibration factor analysis. Calibration aims to ensure the conformity of the result of the measured data to the existing international standards [17]. According to [18], the turbidity sensor is calibrated by comparing the measurement result of the referred device with that of the device to be calibrated to figure out the replicative nature of the measuring instrument.

Calibration in this study was carried out by comparing the result obtained in a measured way with that of a comparable device. It was carried out at the same time and position, so the comparison equality was met. Then, the average reading of the NTU18 turbiditymeter model was related to that of the commercial turbiditymeter model SGZ-200BS through the approach of regression analysis. The regression analysis produced the relationship curve between the two devices, which served as the output calibration factor of the NTU18 measuring instrument, thus the output of the SGZ-200BS measuring instrument was regarded as a substitute for the actual turbidity value.

2.2.4. *Conversion to PPM*

To increase the validity, another comparison was needed to be a parameter of the function suitability

of the measuring instrument. According to [19], turbidity is an indicator often used to determine the extent of suspended sedimentation in water. So, unit conversion is considered to be one of the right additional parameters for identifying the nature of the automatic sedimentation measuring instrument.
Next, the comparison between the NTU unit and the ppm unit was performed. The difference lied within the principles. It was carried out by connecting the reading of the NTU18 measuring instrument with the result of the sample water laboratory test at each sampling point to obtain the conversion factor. The sample tested in the laboratory was taken at the same time of the sampling with both turbidity measuring instruments so that the relationship between them was obtained in a balanced manner. Then, the average reading of the NTU18 turbidity meter was connected with the average of the results of the sample water laboratory tests through the approach of regression analysis, which served as the conversion factor between the two [20].

3.0 RESULTS AND DISCUSSION

3.1. Assembly Results

From the results of the device assembly, an automatic sedimentation measuring device for the turbidity sensor system was obtained. The manual of the device contains the way of using it. When the device and the data logger are on, the SD card drive is open (mounted) and a new file is created with the date-month-year format. After the new file is successfully created, proceed to the process of writing data. Then, the data from the result of the sensor reading and the time are written in the SD card drive. The sensor reading data and time are placed in a writing variable to be then written through a system created in the C language using Arduino Sketch and transferred to an SD Card program in the file successfully created earlier. After writing of the file is done, it will be closed (unmounted). The writing process of each pointer is at the end of the file so that data writing keeps growing and data accumulation is avoided. The obtained data is then converted into a water turbidity unit (NTU). The assembled measuring instrument is shown in Figure 3.

Figure 3 Turbidity sensor-based automatic sedimentation measuring instrument

3.2. Instrument Testing Results

Models are assembled to simulate natural conditions so that they represent the actual conditions. In this case, whatever model and approach are used, the output of the model must still be able to represent the actual natural conditions, but it is unlikely that the output of the model can be completely comparable with the natural conditions. There is always difference between the observed output and the simulated output. To optimize the parameter values of the results of the observed output and the simulated output, it is necessary to calibrate them. Laboratory tests of measurement samples are also carried out to find out the extent of the suitability of assembled measuring instruments through comparisons of different indicators.

This study's results of device testing by comparing the measurement results of the NTU18 turbidity measuring device and those of the SGZ-200 device at the 8 different locations are presented by Table 1.

Table 1 Measurement results

No.	River	Position	NTU-18	SGZ-200	Error
			(NTU)	(NTU)	(%)
1	Way Awi River	Sultan Selamat Kedamaian Street	158,1	162,0	2,38
2		Ki Maja Way Halim Street	131,8	137,1	3,90
3		Riduan Rais Kedamaian Street	105,0	99,8	5,21
4	Buaya River	Pagar Alam 237 Langkapura Street	119,5	121,7	1,81
5		Saleh Raja Kusuma Street	110,6	108,3	2,12
6	Way Belau River	Griya Sederhana Street	125,0	128,4	2,65
7	Putih River	Lambang Street	133,6	134,9	0,94
8		Timbai Street	140,8	136,5	3,11
Average					2,77

The relationship between the turbidity values obtained using the assembled turbidity meter device and the values obtained with the SGZ-200 turbidity meter is portrayed in the form of a graph in Figure 4.

In this study, the correlation coefficient (R), difference percentages, average relative difference percentage (RE), and average of the smallest squared error were used as the criteria for the accuracy of the model test.

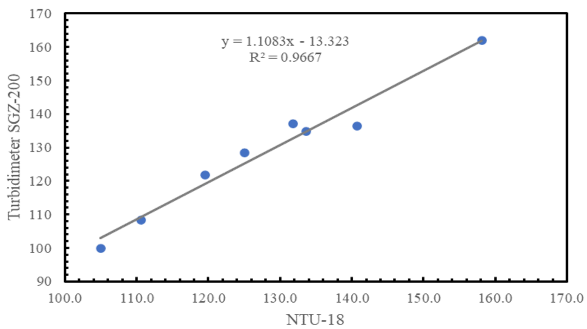


Figure 4 Graph of the relationship between the results with the devices

In Table 1, the measured turbidity values vary greatly, in the range of 99.8 to 140.8 NTU. The highest difference percentage is 5.21%, while the lowest difference percentage is 0.94%. The average relative difference percentage (RE) is 2.77%. An RE value serves to determine the average relative deviation from the measured value and the compared value of water. All the obtained difference percentages (IP) are <10%, which means that the errors were acceptable and of good value [18].

The graph in Figure 4 shows that the correlation coefficient (R), the root of the average of the squared errors (R^2), was the value referring to the extent of the attachment of the measured values of the assembled turbidity meter to those of its comparable device (turbiditymeter SGZ-200) with the result of the equation on the trend line graph being a number close to 1. The number indicates the proximity of the values obtained by both devices. The difference might only be a result of unstable sensor readings of the made device. However, on the whole, the measurement results of this assembled turbidity meter were close to those of the comparable device.

Sampling was also carried out at 8 locations of the same river and tested to identify the turbidity parameter in the Soil Mechanics Laboratory of the University of Lampung. The sampling was carried out at the same place and time as those at which the device was measured. The data obtained from the laboratory tests with the quantity method in ppm units can be seen in Table 2.

Table 2 Comparison of the measurement results in NTU and ppm units

No.	River	Positon	NTU-18	Laboratory Test
			(NTU)	(ppm)
1	Way Awi River	Sultan Selamat Kedamaian Street	158,1	162,0
2		Ki Maja Way Halim Street	131,8	137,1
3		Riduan Rais Kedamaian Street	105,0	99,8
4	Buaya River	Pagar Alam 237 Langkapura Street	119,5	121,7
5		Saleh Raja Kusuma Street	110,6	108,3
6	Way Belau River	Griya Sederhana Street	125,0	128,4
7	Putih River	Lambang Street	133,6	134,9
8		Timbai Street	140,8	136,5

The graph below on Figure 5 depicts the data from both devices linearly: The graph shows a comparison plot between the output measurement of the turbidity measuring device, NTU18, in the NTU unit and that in the ppm or mg/L unit for the same sample at the same place and time. If the data is plotted using a linear equation, then an equation providing the comparison value is obtained. The equation was obtained from data matching with a linear equation. The graph forms the trend line linear equation $y = 11.71x - 1037.2$ and produces $R^2 = 0.8984$, which indicates a regression value close to 1, a good value for the linear regression line equation.

3.3. Discussion

As discussed earlier, the purpose of this study was to create a set of turbidity sensor-based automatic sedimentation measuring instruments. The work started with the determination of the necessary components the devices, assembly of all the components, creation of a program for converting data into numbers, sampling, and testing of the devices with calibration.

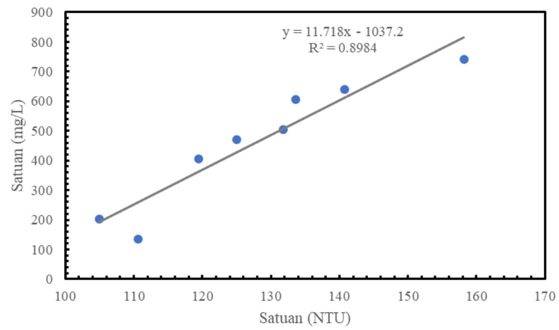


Figure 4 Graph of the relationship between the results with the devices

The results indicated that the assembly of the devices was satisfactory. The components, both hardware and software, were successfully connected and well integrated with each other. The turbidity sensor, water flow sensor, real time clock (RTC), and position sensor successfully worked and resulted in the expected output. Through the SIM 900A GSM/GPRS module, all the readings were connected to the web service successfully. The process of recording the data from the data logger and storing it through the SD card ran without any problems. It indicated that the program connected to the microprocessor using the C language was successfully integrated without any errors or bugs.

The data retrieval system works when the turbidity sensor and water flow sensor are put into the water. The sensors provide output data. This data retrieval process does not require much work at the same time. Some data such as turbidity, velocity, the date, time, and position can be obtained in an efficient way, with a single time of measurement. Through additional survey data of river conditions, this device is able to predict to what extent sedimentation takes place in it. So, the main purpose of this study, which was to make a set of automatic sedimentation measuring devices, has been fulfilled. Also, these devices can be used for multiple purposes such as flood prediction, certain field applications, and analysis of other necessary data.

It is necessary to realize that the assembled devices do not immediately give perfect results, so tests are also needed to measure their capabilities. In this study, the tests carried out on the devices were calibration and unit conversion tests. From the results of the calibration analysis, the NTU18 measuring instrument gave an estimate comparable to that of the high accuracy reference model SGZ-200BS. The character indicated by the assembly turbidity measuring instrument was directly proportional to that indicated by its comparable measuring instrument (Figure 3), thus it is inferable that the results signify that the device was well calibrated. The same goes for the results of the conversion factor analysis (Figure 4). Both indicators showed a corresponding and linear relationship, which means that the greater the turbidity value, the greater the suspended sedimentation. Based on the test results, both devices worked well. The results validate the extent of the ability of the NTU18 measuring instrument. So, as long as the sensor is not compromised to an undetected degree, this instrument is expected to always serve as a cross-correlation pair and provide useful measurement data.

4.0 CONCLUSION

This research produced a device called NTU-18 based on turbidity sensor and flow velocity that can be used for sedimentation measurement in rivers. After going through various analysis and calibration methods of this device with SGZ-200BS, this device can successfully be believed as a good device in measuring and has several advantages that are expected to be a solution for efficient and practical data collection. Problems that have been in the field can be solved with this device. Furthermore, this device can also be utilized in many ways such as prediction of flood events, certain field applications, and analysis of other necessary data.

Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper.

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