Development of an Acoustic Sensor System For Measuring Suspended Sediment Concentration

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Abstract- Suspended sediment concentration (SSC) is a vital property in understanding the characteristics of sediment transport dynamics, which is an important issue in terms of surface water management. However, its useful measurements are often problematic when employing the usual methods of determination from collected water samples or optical sensors, because analysis of water samples tends to under estimate suspended sediments, and optical sensors often become useless from biological fouling in highly productive regions. Sediment affected water resources require frequent and accurate SSC data for proper design, operation and management. The traditional method of collecting water samples is inadequate to provide such large amount of SSC data. In this view, the need to develop an acoustic sediment meter based on high frequency of 4 MHz acoustic backscatter becomes imperative. The developed acoustic sediment meter was calibrated using a standard digital meter to measure the SSC in mg/l, which would be displayed on Liquid crystal display. The specified sensitivity of the developed meter is 10 mV is to 1 mg/l at the error of ±0.04 with regression coefficient (R^2) of 0.9917. Therefore, the meter is capable of reading up to 1023 mg/litre at error of ±0.3. It is recommended that the developed meter, which is based on single-frequency acoustic system, be upgraded to multi-frequency acoustic system. Multi-frequency acoustic instruments can provide information on both particle size distribution as well as SSC. More so, it is a good practice to use more than one sediment monitoring technique in order to obtain independent SSC results.

Keywords: *Suspended sediment concentration, Single-frequency, Acoustic sensor, Calibration.*

1.0 INTRODUCTION

The transport of suspended sediment is a major issue in agriculture, environment, and engineering in that the service life of engineered facilities such as dams and navigation channels, irrigation canals, and the health of ecosystems are all influenced by sedimentation and sediment transport (Öztürk, 2017). These issues related to sediment can occur due to either excess or deficient quantities or fluxes. Excess sediment loads are the most common issue related to sediment transport rate and have been found to cause issues such as impaired navigation from channel aggradation, harm dams and water intake infrastructure, reduced photosynthesis and dissolved oxygen levels, and harmful algae blooms due to the transport of excess inorganic nutrients (Peterson et al., 2018). Also, issues can either arise from a lack of sediment transport resulting to reduction of ecological habitat, or sediment starvation as a result of erosion from structures like dams which threaten hydraulic infrastructure (e.g., flood levees, piers, and jetties) (Kondolf et al., 2014; Meade and Moody, 2010).

The measurement of suspended sediment concentration (SSC) has always been a difficult task and no single device or technique seems adequate for all requirements (Thorneet al., 1991). The SSC is a key element in stream monitoring (Chanson et al., 2008). The measuring and monitoring of SSC is critical to understanding the sediment transport dynamics of streams and rivers. The knowledge of sediment transport characteristics is an important issue in term of surface water management (Schmitt et al., 2016). Scientists, researchers, and water resource managers use the knowledge of Suspended sediment to monitor sediment discharge, erosion, deposition, and potential effects on biological processes (Peterson et al., 2018). For a better understanding and management of fine-sediment related processes, field measurements of SSC and particle size distribution (PSD) with high temporal resolution are required (Felix et al., 2018). Real-time data may serve as a valuable basis for short-term decision-making. Thus, the monitoring and evaluation of SSC is essential in determining water quality and associated hydrologic functions. To monitor SSC and local sediment transport in fluvial systems, measurements are typically gathered using cumbersome in situ samplers and thereafter analyzed by gravimetric method. The drawbacks of this technique are the relatively high effort for sample treatment and that the results are not available in real-time. Instruments based on the scattering of underwater sound have been developed for studying sediment processes for understanding of sediment transport processes (Thorne and Hanes, 2002). Although, optical instruments are presently in more common use than acoustics for suspended sediment measurements, but the potential of acoustics to provide the required parameters for assessing and developing sediment transport formulae is significantly greater (Thorne and Hanes, 2002). The basic sediment-acoustic principles are that acoustic waves passing through a water-sediment mixture will scatter and attenuate as a function of fluid, sediment, and acoustic instrument. The objective of using acoustics has been to obtain profile measurements of the suspended sediment and flow with sufficient spatial and temporal resolution to allow turbulence and intra-wave processes to be probed.

The prospect of continuous and quantifiably accurate monitoring of suspended sediment transport informed this study. The benefits of developing the meter could be enormous, providing real-time data, which may serve as a valuable basis for short-term decision-making. Acoustic sediment meter could be deployed to provide the types, quality, and density of fluvial sediment data needed to improve suspended sediment discharge computations in research settings and in limited operational deployments. However, the objectives of the study includes to develop a low cost acoustic sediment meter for measuring suspended sediment concentration; and to calibrate the developed acoustic sediment meter.

2.0 MATERIALS AND METHODS

2.1 Materials

The development of an acoustic sensor system for measuring SSC was carried out by selecting the right materials according to the need of the system such as resistors, 7805 IC, capacitors, microcontroller (pic16f877a), Lm741 IC, Acoustic Sensor (ultra-sonic), Liquid crystal display (LCD) (16x2), Light emitting diode (led), 4MHZ crystal, button, connection wire, mother board, 9v battery, battery cap, digital weighing balance (sensitivity mg), digital multi meter, beaker (500ml), 1 litre container.

2.2 Working Principles of Suspended Sediment Meter

The functional block diagram of the system is shown in Fig.1. The device is a microcontroller-based system with an ultrasonic sensor, which consists of three parts namely: transducer, receiver and frequency to voltage converter. The transmitter transmit a sound wave at a very high frequency of about 4 MHz, the sound travel through water hits suspended sediment, this particle of different shape and size deflect back the sound which is measured as backscatter intensity. The acoustic sensor module has frequency to voltage converter system, which converted backscatter intensity to voltage. This information is feed to signal processing unit and thereafter to analog to digital converter port of microcontroller (PIC

16f877a). This microcontroller logically calibrates the amount of suspended sediment in mg/litre of water and displays it on liquid crystal display (16x2 LCD).

The basic equation relating the converted voltage (V_{out}), which is inversely proportional to suspended sediment in water, is given by equation (1).

$$V_{out} \propto 1/M_{ss} \qquad 1$$

$$V_{out} = {K_{as}}/{M_{ss}} \qquad 2$$

where: V_{out}= Output voltage (V), K_{as} = proportional constant of the acoustic sensor (mgV), M_{ss} = Mass of suspended sediment (mg),

2.3 Development of the Suspended Sediment Meter

The electronic circuit of the system is shown in Fig. 2. The approach in developing suspended sediment meters is simply an acoustic sensor generates sound frequency and measured the backscatter intensity that is inversely proportional to the suspended sediment, and then utilize a microcontroller to measure the voltage (this voltage is directly proportional to the backscatter intensity which is converted to voltage by the use of frequency to voltage converter incorporated in acoustic sensor module) within a given period to estimate the suspended sediment concentration. Thus in this design, the microcontroller measures and displays the corresponding concentration of suspended sediment in mg/litre and display it on the LCD (Liquid crystal display) as a digital output.

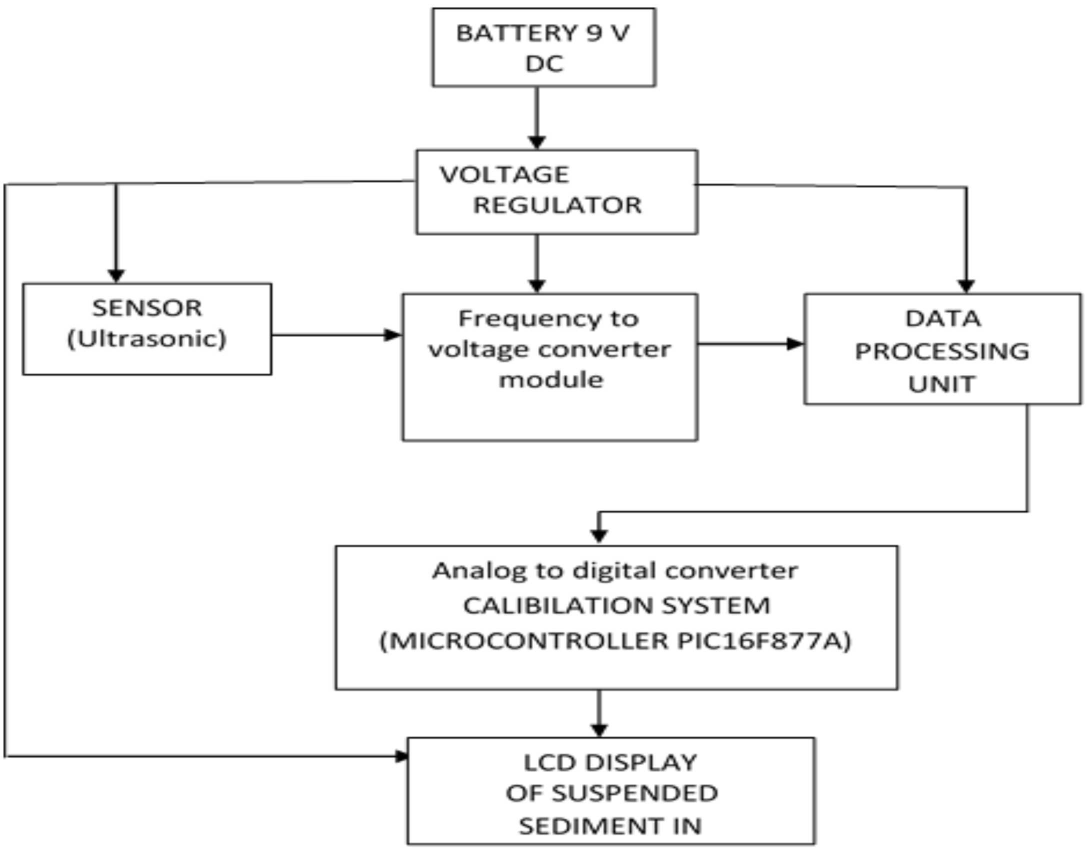

Fig.1 Block diagram of the acoustic sensor system

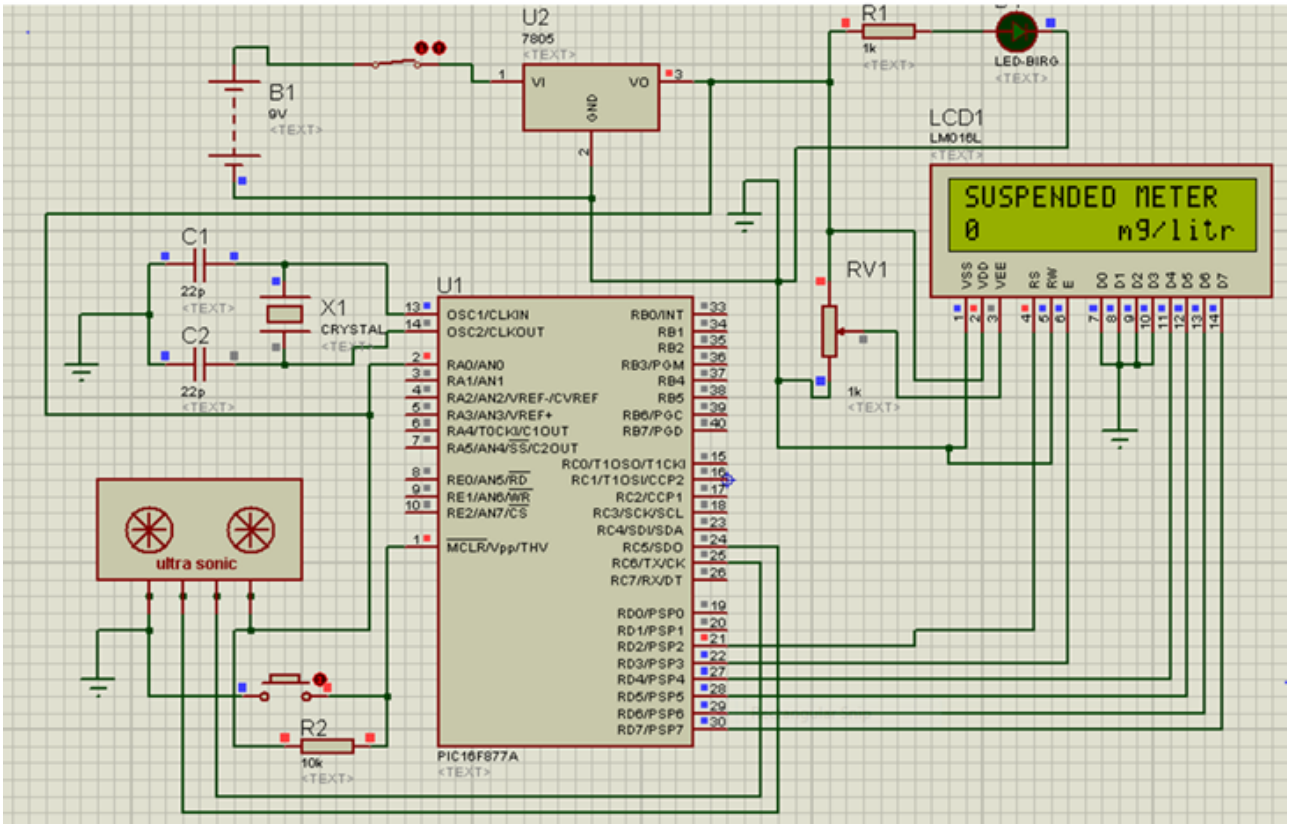

Fig. 2 Circuit diagram of the digital acoustic sensor system

2.4 Calibration of the Acoustic Sediment Meter

The reliability and efficacy of data produced by a sediment-surrogate technology are predicated on the adequacy of its calibrations (Gray and Landers, 2014). Hence, the meter was calibrated to measure the concentration of suspended sediment in mg/litre, which would be displayed on LCD. To calibrate the system different soil samples were used as sources of suspended sediment. Standard solution was prepared from 5mg/litre of water (H_2O) to 100mg/litre there after the sensor was standardise with a standard digital meter to obtain the voltage corresponding to each concentration of the suspended sediment in the solution.

3.0 RESULTS AND DISCUSSION

The circuit of the digital acoustic sensor system was developed and packaged as shown in Fig. 3. The readings of the SSC in mg/l are displayed on the LCD.

Fig. 3 Developed acoustic suspended sediment meter

3.1 Calibration

The calibration analysis of the developed suspended sediment meter showed that the output voltage from 0mg/litre to 100mg/litre was linear with a potential difference approximately 0.05V or 50mV. This was used to calibrate the meter and information obtained was display on LCD as digital output. The graphical representation of the acoustic sediment meter calibration is as shown in Fig.3.

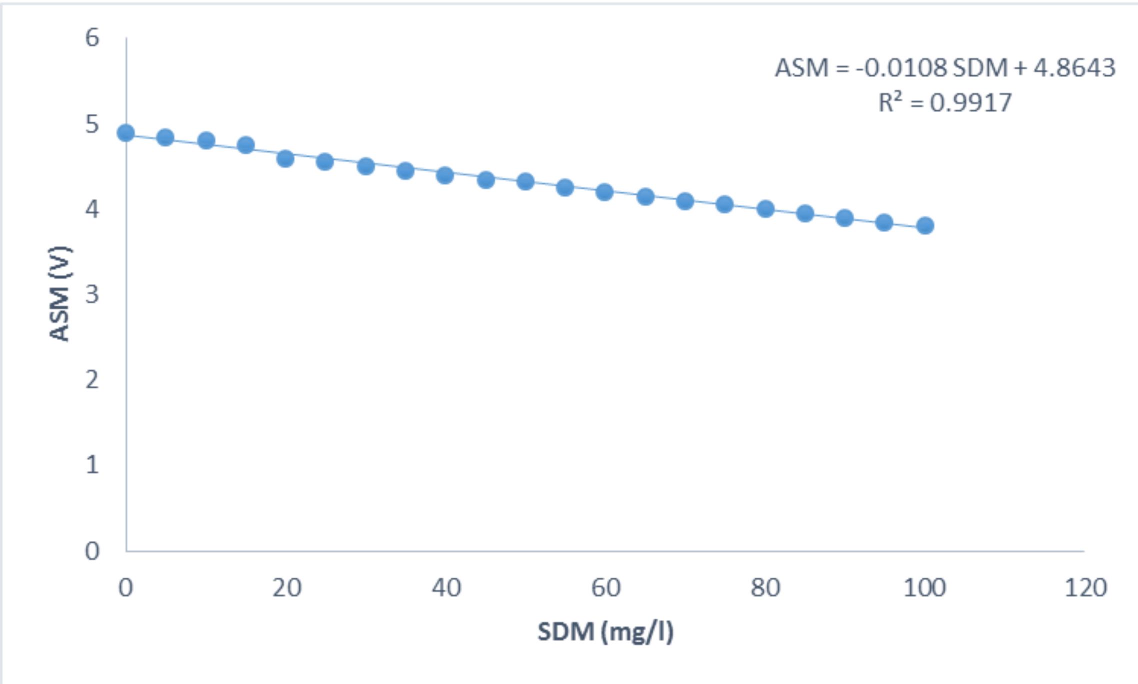

Fig. 3: Calibration graph for the developed acoustic sediment meter.

Where: ASM = Acoustic Sediment Meter, SDM = Standard Digital Meter

3.2 DISCUSSIONS

The developed acoustic suspended sediment meters comprise a small box compartment and a one (1) litre rectangular vessel with cover. The box compartment is the engine room of the meter, which is connected via connecting wires to the ultrasonic sensor hung underneath the vessel cover. The vessel is used to scoop the water sample and the cover place on top. Then the system is turn on via the red button with the indicator light indicating that the unit has been switched on. The ultrasonic sensor transmits an ultrasonic burst at 4 MHz and providing an output pulse that corresponds to the time (250 milliseconds) required for the burst echo to return to the sensor.

However, this device is calibrated using a standard digital meter used to measure out SSC of up to 100 mg/l at 5 mg/l interval and the specified sensitivity of the developed meter is 10 mV is to 1 mg/l at the error of ±0.04. Therefore, the meter is capable of reading up to 1023 mg/litre at error of ± 0.3

4.0 CONCLUSIONS AND RECOMMENDATION

4.1 Conclusion

The estimation of SSC is one of the properties needed to understand the characteristics of sediment transport in rivers; therefore, its useful measurements usually pose a problem when employing the usual methods of determination from collected water samples. Analysis of water samples tends to under sample the highly variable character of suspended solids, and optical sensors often become useless from biological fouling in highly productive regions. Acoustic sensors are now routinely used to measure SSC and water velocity. They have been shown to hold promise as a means of quantitatively estimating SSC backscatter intensity.

However, the acoustic suspended sediment meter was developed and used to measure the SSC from a river. This meter proves to be a good system that can measure the SSC from a river with high accuracy with R^2 of 0.9917 and in the terms of cost the meter proves to be a low cost with many of the benefits as compared to the other commercially available acoustic sensor meters products. So development of low cost acoustic suspended sediment meter can replace or supplement optical sensors or collected water samples methods by providing a very useful tool for SSC and flow velocity measurements concurrently using the same instrument. Generally, acoustic sensors are less susceptible to biological fouling than optical sensors thereby providing nonintrusive estimates of SSC.

4.2 RECOMMENDATION

Single-frequency acoustic systems have an inherent limitation of differentiating the change between SSC and suspended particle size distribution relative to the acoustic frequency, which is difficult to quantify, thus it is always an unknown source of error. The method requires a reasonably steady size distribution of suspended material; therefore, it is recommended that the developed system, which is single-frequency acoustic system, be upgraded to multi-frequency acoustic system. Acoustic sensors are more sensitive to large particles than optical methods, it is highly recommended, if possible, to use more than one sediment monitoring technique in order to obtain independent SSC results.

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