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Assessment and development of optical technology for continuous suspended sediment measurement in aquatic environments

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ABSTRACT: The monitoring of fluvial suspended sediment transport plays an important role in the assessment of morphological processes, river behavior, identifying erosion and sediment loss zones and better watershed management. In order to eliminate information deficiencies and achieve a suitable database for suspended load, it is necessary to equip hydrometric stations with instruments for continuous and indirect monitoring of suspended sediment. The aim of this research is to construct and validate an optical sensor with a multi-beam ratio technology and artificial intelligence-based modeling (MLP & SVR) for suspended sediment measuring. After the implementation of the new technology, the performance of the device was evaluated in two stages, including calibration and validation. To attain this, various experimental tests were carried out in the hydraulic laboratory of the Water Research Institute of the Ministry of Energy. Reference turbidity meter and total suspended solids (TSS) were used to test the performance of the OBS technology. In the calibration stage, 70% of TSS data were used and the remaining 30% of data were used to validate optical technology. The plotted calibration curves show a very good correlation between the optical voltage recorded by the sensors and the suspended sediment concentration. Also, SVR & MLP models were employed to improve the results of suspended load prediction. The performance of the optical device and also optical device with intelligence models were evaluated through four statistical indices, namely, Mean Absolute Percentage Error (MAPE), Root mean square Error (RMSE), Nash–Sutcliffe coefficient (NSE), correlation coefficient (R) and coefficient of determination (R2). The results of this stage showed that the intelligence modeling could result in improvements in suspended load reported by optical technology. The best improvements were obtained by MLP-optical technology. The results showed that values of validation indicators for MLP model are equal to 0.023, 7.608, 0.99, 0.99 and 0.99, respectively, which indicates the proper performance of the technology

1- Introduction

IntroductioAccelerated development and some unsuitable land uses have led to ecosystem imbalances and instability. The first sign of an unbalanced ecosystem is the occurrence of soil erosion which is transported as sediment load by the rivers. Despite the importance of the suspended sediment, there is limited and unreliable information about it in Iran and some other countries. A discontinuous and traditional sampling of suspended sediment has led to undeniable errors in soil loss estimating. New methods of measuring suspended sediment are indirect methods and have been further developed in recent decades. The acoustic, laser, optical and pressure difference methods have been introduced as examples of these methods. Among the mentioned methods, the optical method is approved by many researchers. Optical turbidimeters can be applied to obtain the time series of the in-situ SSC [1]. The optical method includes light transmission methods and optical backscattering (OBS) methods. The continuous sampling method, compared to the traditional method of suspended sediment sampling has the priorities of high-frequency and inexpensive sampling. The main purpose of this study is to build a new turbidimeter considering ASTM standards in the field of OBS methods. In this regard, the technology used in the photoelectric turbidimeters with the multi-beam ratio technology -which is the most advanced in this field- was used. The new turbidimeter can be used in-situ and through the river flow which in this regard has a unique design. So, flow passes through the turbidimeter without disturbing and there will be no problems such as incomplete filling of the existing flow passage, bubbles, sediment

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Table 1. Results of the validation stage.

Coefficient	Turbidimeter and SVR model	Turbidimeter and MLP model	Turbidimeter results
Mean Absolute Percentage Error (MAPE)	0.035	0.023	0.11
Root mean square Error (RMSE)	23.644	7.608	44.54
Nash Sutcliffe (NSE)	0.992	0.997	0.97
Correlation Coefficient (R)	0.996	0.999	0.98
Coefficient of Determination(R^2)	0.992	0.999	0.97

deposition, etc. On the other hand, the cross-sectional design of the light sources and sensors is particular to has significant differences and capabilities in comparison to similar devices.

2- Methodology

The present study was conducted in two stages:

Design and manufacture of the turbidimeter based on the standards (ASTM D6698. 2014; ASTM D7512. 2009; ISO 7027. 1999, EPA 180.1, Standard Method 2130 B) for OBS turbidimeters [2-4]. To manufacture the turbidimeter, two LED lamps were used as light sources. These light sources emit electromagnetic waves at the wavelength of visible light. Also, two optical detectors were used at 90° and 180° angles to the light sources. Using the existing scientific and standard instructions, a rectangular cross-section was used for the water passage and the location of sensors and light sources. One of the advantages of using this section is the placement of sensors and light sources at two different distances. Shorter distances will be used to measure the turbidity of the high-concentrated flow and longer distances for the low-concentrated ones. So, the use range of the device will be increased in comparison to the previous turbidimeters. Also, the case of the synchronous light sources was used for the first time in this multi-beam ratio turbidimeter.

Testing and calibration stage; it was done in two steps:

I) Investigating the performance and sensitivity of the device to the different colors: Due to the fact that the sediment color is one of the effective factors in the ratio of the passage and reflection of the transmitted light, to investigate the sensitivity and performance of the device against sediments with different colors, the turbidimeter was examined using a small range of sediments with the colors from light to dark.

II) Final testing and calibration stage in the reference laboratory: In this stage, the device was tested with a range of streams with different sediment concentrations (20-1000 mg/l) in the hydraulic laboratory of the Water Research Institute of the Ministry of Energy. Sediment samples were taken through a sampler and then samples were analyzed by TSS method. At the same time, the voltage numbers reported by different sensors were collected. Then 70% of the TSS and voltage data were used for calibration and the remaining 30% of data were used to evaluate and validate the performance of the turbidimeter. Finally, in order to increase the capability of the device in measuring suspended sediment, the combination of the reported voltage from the device with the artificial intelligence modeling was used. SVR and MLP models were used for this purpose.

3- Results and discussion

The results of the investigation of the turbidimeter performance and its sensitivity to sediments with different colors showed that when the sensor and light source are located at an angle of 180° to each other and the distance between them is short, the color separation is done appropriately. On the other hand, in cases where the angle of the light source and the sensor is 90 degrees, or the light sources are used simultaneously at 90° and 180° angles, the sensor is affected by the sediment color. The results of the validation stage are presented in Table (1).

The proximity of the MAPE coefficient to zero indicates the appropriate performance of the turbidimeter. In the case of NSE, R and R^2 criteria, the proximity of the numbers to one confirms the results of the sediment prediction. Therefore, according to the results of the validation stage, the performance of the device in reporting different amounts of sediment is statistically appropriate and is highly reliable. Simultaneous use of all numbers reported by the sensors in each test as the input of artificial intelligence algorithms improves the reliability of the suspended sediment prediction. So that all the validation criteria listed in Table 1 are significantly improved when the device results are combined with intelligent algorithms. The use of MLP model has increased the accuracy in predicting suspended sediment compared to SVR model.

4- Conclusion

The purpose of this study is to localization and development the multi-beam ratio technology by designing a new OBS turbidimeter. All stages of design and manufacturing of the device have been done under the financial support of Iran Water Resources Research Company. Innovations were used in the design of the device, which were: I) Placement of the light sources and sensors at different distances, more or less in the form of a rectangular section to measure the suspended sediment of the high and low concentrated streams. II) Recording the optical sensor reaction with synchronous light sources located at 90° and 180° angles. Studies have shown that the placement of light sources and sensors at an angle of 90° to each other reduces the error related to the sediment color in estimating suspended sediment. On the other hand, the simultaneous operation of two light sources increased the accuracy of the device in predicting suspended sediment. Also, the use of artificial intelligence algorithms and the combination of different output modes of sensors (separate and combined operation of light sources) as input to intelligent models improves the prediction results significantly.

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