Error processing of water level data measurements by a low-cost ultrasonic sensor

Osawa, T. M.*, Pereira, M.C.S.**, Martins, J. R. S.***

*Department of Civil Construction Engineering, University of Sao Paulo, Prof. Almeida Prado, 83 – Jardim Universidade Pinheiros, Sao Paulo – SP, 05508-070
**Institute of Advanced Studies, University of Sao Paulo, 83 – Jardim Universidade Pinheiros, Sao Paulo – SP, 05508-070
***Department of Hydraulic and Environmental Engineering, University of Sao Paulo, 83 – Jardim Universidade Pinheiros, Sao Paulo – SP, 05508-070

Highlights:

- Low-cost ultrasonic sensors are suitable for water level monitoring; Adoption of different approaches improves error data processing efficiency; Low-cost sensing presents reliability measurement due to the low errors identified.

Keywords: Water level monitoring; Error data processing; Low-cost sensor.

INTRODUCTION

Nature Based Solutions (NbS) emerges as a paradigm shift in water urban dynamics regulation and flood risk management based on a decentralized approach. Performance monitoring of those spread infrastructures requires a highly spatially distributed sensing system to understand instantaneous and long term behavior of the facilities that includes the measuring of the outflow in areas where NbS has only recently been adopted (Hamel et al., 2024). In this context, ultrasonic low-cost sensing is being widely adopted in free surface flow observations due to its technical and economic advantages ben.

Regarding the ultrasonic sensor operating mechanism and environmental exposure, the occurrence of errors is expected, and the data captured likely presents anomalies caused by variations in air temperature, equipment precision, the presence of floating materials, and experimental errors (Cherqui et al., 2020). Thus, errors of different natures require different processing approaches for improving measurement efficiency. Therefore, the objective of this study is to assess the development of an error data treatment methodology for improving the efficiency of low-cost sensor measurements of water level.

METHODOLOGY

In this study, a popular ultrasonic sensor board (US-025) is attached above a triangular-notch thin-plate weir for monitoring the outflow of a green roof. The monitoring setup is fully described by Gobatti et al. (2022). In addition, the data were obtained from four rainy events.

The data processing methodology developed is composed of three main steps: (i) air temperature simplified compensation (Panda et al., 2016; Sahoo & Udgata, 2020); (ii) outlier identification using the modified Z-score method with median absolute deviation (MAD) as a scale estimator (Bae & Ji, 2019; Yaro et al., 2023) and outlier imputation through linear interpolation (Kulanuwat et al., 2021); and (iii) data smoothing with exponentially weighted moving average (EWMA) (Bae & Ji, 2019). Each step was assessed through the calculation of the mean absolute percentage error (MAPE) and mean absolute error (MAE).

Furthermore, this study executed a sensibility analysis to determine for each event the optimized moving window size (w) to calculate the MAD in the Z-score method, the threshold value (β) for outlier identification in the modified Z-score method, and the smoothing factor (α) of EWMA.

RESULTS AND CONCLUSIONS

The first step of temperature compensation resulted in a MAPE between 1.53% and 2.21% (Table 1). In the next step, the window size (w) process optimization of the z-score method found values between 4 and 6 timesteps. These window sizes represent 40 and 60 seconds, respectively, indicating a rapid outflow variation from the green roof. In addition, sensibility analyses of β showed that the outlier proportion identified decayed exponentially until a stable behavior with β increased. When β the value dropped from 2 to 2.5, the portion of outliers identified was reduced by below 1% for all events. That low variation with a stability tendency shows that β of 2.5 unlikely identified real data as an error. Therefore, the threshold assumed was 2.5. The application of the modified Z-score method with β and w parameters obtained identified a moderate portion of outliers between 10% and 20% (Table 1) out of the total monitored period data.

The results of the imputation generated a MAPE between 0.02% and 0.04% and a MAE below 0.1 mm (Table 1). These indicators with low values were expected because this step only changes random errors, which are less frequent than other processes that systematically change the measurement values.

Events	Step 1		Step 2					Step 3		
	MAPE (%)	MAE (mm)	w (units)	β	Outliers (%)	MAPE (%)	MAE (mm)	α	MAPE (%)	MAE (mm)
7	2.21	5.7	6	2.5	16.9	0.04	0.1	0.2	0.14	0.4
9	1.53	4.6	6	2.5	14.4	0.02	0.1	0.2	0.12	0.4
15	1.72	4.6	4	2.5	12.3	0.03	0.1	0.2	0.13	0.4
16	1.69	4.6	4	2.5	10.8	0.03	0.1	0.2	0.12	0.3

Table 1 – Statistical error parameters of each step's methodology applied, and the selected input parameters obtained from sensibility analyses for the four rainy events (w: window size, β: threshold value, α: smoothing factor)

Lastly, the sensibility analyses of α resulted in a standard deviation increase as the α was reduced. That unexpected trend may be biased by the non-parametric distribution of the data. Thus, based on the author's knowledge of sensibility analyses and graphical representation, the most suitable value of α admitted was 0.2. The smoothed data resulted in a MAE between 0.3 mm and 0.4 mm (Table 1). The approximate value of MAE for the sensor uncertainly suggests that the smoothing process is relevant for processing equipment scale errors.

Thus, the error data processing methodology developed in this paper is suitable for improving low-cost ultrasonic sensor monitoring. Regarding different approaches to error correction, the low-cost sensing can be adopted even in highly sensitive uses. In addition, the relatively low errors found in this study increase the technical feasibility of the ultrasonic sensor being used in distributed performance monitoring.

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