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Performance Assessment of Low-cost Water Level Sensor for Water Sensitive Urban Design (WSUD) monitoring in the Tropics

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Abstract

Water Sensitive Urban Design (WSUD) has emerged as one of the most important sustainable strategies in integrated urban water management (IUWM). Though increasing WSUD systems have been implemented worldwide, there is relatively little attention paid to monitoring WSUD systems' medium to long-term performance. The relatively limited monitoring efforts restrict the ability of public agencies and private developers to provide adequate maintenance for existing systems and to optimize the design of new systems in urban planning. The attempts to promote monitoring are mainly limited by constrained budgets, especially in developing areas. With the huge economic advantages and flexibility for operation and communication, low-cost sensors (LCS) show great potential in establishing affordable monitoring systems. In this study, the performance of a water level LCS (KIT0139) was tested and compared to the counterpart traditional sensor (OTT PLS) in a laboratory under different controlled conditions. Results reveal that the LCS (KIT0139) has good robustness as there was no significant difference between the 6 individual LCS devices under the testing conditions. Also, the LCS provides sufficient accuracy and precision compared to the traditional sensor tested, especially for water levels more than 0.05m. Calibration functions and sensitivity to water temperature were also assessed.

Introduction

Urban hydrological processes have been considerably altered by rapid urbanization, which has resulted in the increase of water-related problems including floods and water pollution (Li et al., 2021; Reu Junqueira et al., 2021). Flood risk has significantly increased in urban areas due to the combination of intensifying stormwater events brought on by climate change (Chang et al., 2021), highlighting the significance of Sustainable Urban Water Management (SUWM) principles in urban planning (Martijn Kuller et al., 2017). As a complementary approach to traditional human-engineered and centralized drainage systems, Water Sensitive Urban Design (WSUD) have been joined by including natural and semi-natural landscapes that are able to retain and purify runoff water (Gleason et al., 2021). WSUD integrates water cycle management with the built environment by retaining, filtering, storing, and utilizing runoff water resources in the urban area (Gleason & Flores, 2021). In addition to or in place of the conventional infrastructure, WSUD offers multi-functional landscapes (e.g., wetlands, bioretention basins, rain gardens, cleaning biotopes, green roofs) with numerous benefits (e.g., flood control, water purification, heat mitigation, carbon sequestration), making it the essential long-term strategy in integrated and sustainable urban water management (Keesstra et al., 2018; Tzoulas et al., 2007).

The effectiveness of WSUD systems has been extensively studied at watershed and sub-watershed scales (Bellezoni et al., 2021; Gunnell et al., 2019; Ma et al., 2021). However, such studies are mostly based on spatial models (e.g., SWMM, InVEST, MUSIC, MIKE) that focus on large-scale simulation, have ignored the real condition of WSUD systems at the site scale, and lack sufficient empirical data from field monitoring for the model validation and calibration (Hamel et al., 2021; Yin et al., 2021). The absence of field monitoring of WSUD systems is mainly due to the constrained budgets, especially in the developing areas such as Global South and most countries in Southeast Asia (Hamel & Tan, 2021). Since traditional monitoring systems can be costly and time-consuming, relatively few attempts were made for monitoring the medium- to long-term performance of WSUD systems in the Tropics (Bertrand-Krajewski, 2021; Hamel & Tan, 2021). The limited monitoring efforts restrict the ability of public agencies and private developers to provide adequate maintenance for existing WSUD systems and to optimize the design of new systems (M. Kuller et al., 2019).

Compared to traditional monitoring equipment, low-cost sensors (LCS) present great economic advantages by providing useful data at a considerably lower expense. Also, LCS often work on open-source platforms (e.g., Arduino), hence they are more flexible in operation and communication (Cherqui et al., 2020). Given their flexibility, LCS (Kumar et al., 2015). Currently, LCS technology has been emerging in many fields and showed reliable results, examples including air quality assessment (Ali et al., 2016; Morawska et al., 2018), air temperature measurement (Sun et al., 2019), water quality monitoring (Lambrou et al., 2014; Murphy et al., 2015), and agriculture (Valente et al., 2020). In this study, we aim to explore the potential of LCS in supporting the affordable and flexible monitoring network for WSUD systems, that can be promoted throughout the regional level for medium- to long-term monitoring. The main objectives are: 1) Testing the LCS with a traditional sensor (TS) in the laboratory. 2) Assessing the performance of this LCS in laboratory conditions. 3) Proposing calibration guidelines for the LCS tested for further field application.

As water level is one of the most essential parameters in water quantity monitoring, which indicates the performance of WSUD systems in stormwater retention, we first started the lab testing with the water level sensors. There are mainly two types of water level sensors: contact and non-contact sensors, including pressure transducer, ultrasonic sensor, laser sensor, capacitive devices, etc. (Loizou et al., 2016). Among them, the submersible pressure transducer and ultrasonic sensor are the most commonly used in the literature because of their good accuracy and flexibility (Zhu Q., 2021). Considering the field application, ultrasonic sensors are easy to be disturbed by the factors such as air temperature, wind, and rainfall (Ouychai, 2015; Zhang et al., 2019). Thus, the submersible pressure transducer with the anti-corrosion surface matches better with our requirements. Based on the literature and consideration of further field application, two pressure water level sensors including a LCS (KIT0139) and a TS (OTT PLS) were selected for lab testing. In this study, we assessed and compared the performance of selected LCS and TS in laboratory conditions before the field deployment.

Methodology

Six LCS (KIT0139) and one TS (OTT PLS) were tested in the lab. The lab testing platform (Figure 1) mainly consists of one acrylic water column, seven water level sensors, one microcontroller (Arduino MKR1310 board), one water temperature controller (Heated Circulators machine), one water tank, two pumps and the online control platform (Arduino IDE software). To assess the influence of the variation in wetting and drying conditions which is common in flashy stormwater catchments on the sensors, the LCS was divided into two groups with three sensors in each group. As shown in Figure 2-1, group B of LCS was positioned at the 0m level (always submerged in water), while group A was at 0.3m level with a variety of

dry and wet conditions. Additionally, testing three LCS of each group at the same time aimed to check if there is a distinct difference between the individual LCS models.

The sensors were tested for a measuring range of 0~1.7m, under three water temperatures (25°C ,30°C ,35°C). Each experiment included one complete cycle of filling the water column to the maximum height of 1.7m (upper limit) with an increment of 0.1m, followed by emptying to the minimum height of 0m (lower limit) with a decrement of 0.1m. After reaching each water level, there was a 10-second stabilization time before recording 100 readings from the LCS and 10 measurements from the TS. The reference water level was measured visually with a graduated ruler (1mm mark). In addition, the water temperature was recorded by OTT PLS during the water level measurements.

All the sensors were calibrated based on the Ordinary Least Squares regression (OLS). The performance of both LCS and TS were assessed by its accuracy (errors between the measurements and reference values), precision, uncertainties, and sensitivity to water temperature. A framework for evaluating the performance of LCS and TS in lab testing experiments is shown in Figure 2.

After being tested in the lab, the water level LCS and TS were installed in a pilot. The pilot is a conventional rain garden launched by PUB (the national water agency of Singapore) since 2017. More results on this field application will be shown during the Symposium.

Results

Accuracy & Precision & Uncertainties

After OLS regression calibration (linear regression), errors for LCS were within [-15, 15]mm, while large errors generally occurred over [0-0.1] m. The accuracy (represented by mean error) is 10mm. After zooming in the range of [0-0.1] m where the large errors occurred, we found that below 0.05m, errors were random and relatively higher than other water levels, indicating that the LCS (KIT0139) is more applicable above 0.05m water level.

Sensitivity to water temperature

The accuracy and precision didn't show significant change under different levels of water temperature. To further explore the influence of water temperature. A comparison of calibration equations (slopes + intercepts) under different water temperature degrees was conducted. The results indicated a minimal influence of temperature on calibration; no trend between the equations (slopes + intercepts) and water temperature was found across the 25-35°C range.

Comparison of calibration lines

Errors introduced by applying calibration equations from other temperatures and other sensors compared to the original calibration line of each dataset were explored. Our results suggested that the calibration should be done for each sensor, but not for each temperature.

Field implementation of the water level monitoring system

Figure 4 shows the field deployment of the water level monitoring system. Field calibration will be done regularly, and field calibration equations will be compared with the lines in the lab experiment as well.

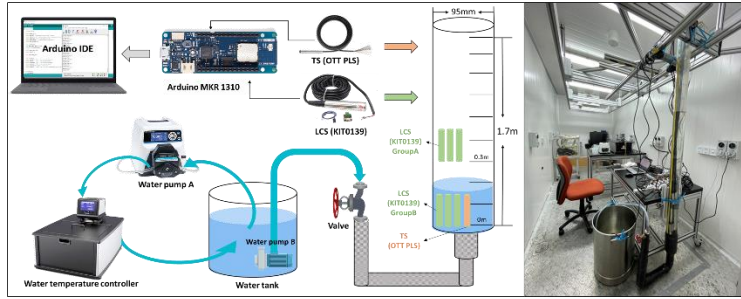


Figure 5 Experimental setup in the lab. 6 LCS and 1 TS were tested in a water column over a range of 0 – 1.7m, with 3 LCS at 0m water level and 3 at 0.3m.

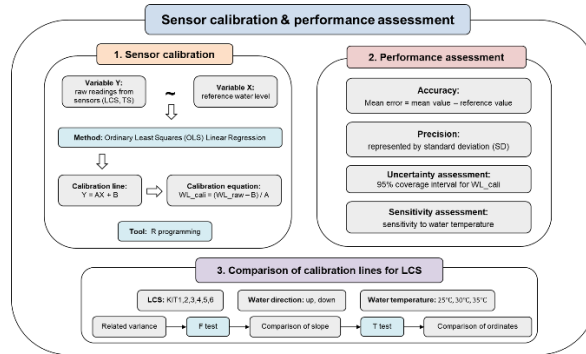


Figure 6 Framework of evaluating the performance of LCS and TS in lab testing experiment. The performance of the LCS and TS was assessed by their accuracy, precision, uncertainty assessment and sensitivity to water temperature.

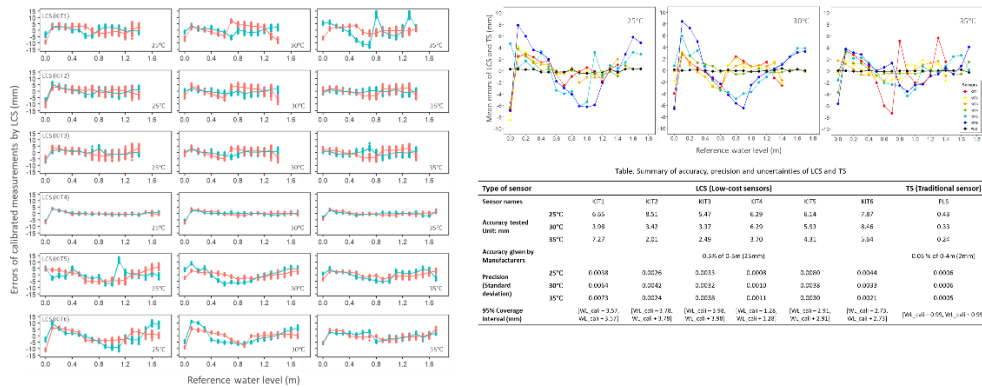


Figure 7 Errors and mean errors introduced by the LCS compared to the TS. Numerical values of accuracy (mean error), precision and uncertainties are shown in the table.



Figure 8 Field implementation of the water level monitoring system in NIE rain garden in NTU, Singapore. One water level LCS, one water level TS and one temperature LCS were installed in the outlet sump.

Conclusion

To explore the potential of low-cost sensors in Water Sensitive Urban Design (WSUD) monitoring, we conducted lab experiments assessing the performance of the low-cost water level sensor KIT0139 and comparing it to the TS (OTT PLS). Results indicate that the LCS (KIT0139) provides sufficient accuracy and precision especially in measuring more than 0.05 m water levels. More results on field application as well as the real-time online data transmission based on LoRaWAN technology will be shown during the Symposium in October.

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Biography



The author is a Ph.D. candidate in the Asian School of Environment at the Nanyang Technological University (Singapore) since 2021. The author completed her MS.C. at Fudan University (China) and her undergraduate studies at Nanjing Normal University (China). Her research interests lie in the area of evaluating nature-based solutions for urban water management, developing low-cost and real-time monitoring systems for Water Sensitive Urban Design (WSUD) features.