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A Low-Cost, Autonomous, and Connected Rainfall Monitoring Station

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Abstract

It is necessary to increase rainfall monitoring spatial distribution in urban areas to improve stormwater management and urban flooding forecast. However, the large-scale deployment of conventional rainfall monitoring instruments is costly. This abstract presents the implementation and test of a low-cost rainfall monitoring station. The objective is to evaluate the performance and reliability of these low-cost instruments in comparison with conventional instruments installed on the same site. Tests have shown that the designed systems can operate autonomously in the field and report measured quantities (timestamp, precipitation, output voltages) every minute. However, the low-cost optical rain gauge RG-15 has significant sensor to sensor variation and the collecting funnel of the low-cost tipping bucket rain gauge WH-SP-RG needs to be improved before installation.

Introduction

In recent years, urban flooding is becoming a growing concern [1]. High spatial and temporal resolution rainfall monitoring is a prerequisite for stormwater management and urban flooding forecast. However, the large size and high price of conventional rainfall monitoring instruments hinders the implementation of ubiquitous rainfall monitoring. Thanks to developments in the fields of open-source hardware, wireless communication technology and low-cost sensors, a promising paradigm for large scale soil, air and water monitoring appeared [2]. Using this paradigm to rainfall monitoring field [3], we designed an autonomous miniaturized low-cost rainfall monitoring station and tested it in the field.

Material and methods

Hardware

After preliminary review [4] and tests, we selected modules to build our low-cost rainfall monitoring station. Their names, functions and approximate prices are given in Table 1. The designed rainfall monitoring station can work on the long term with solar energy. The whole station costs less than 250 € including two different rain gauge systems, SD card, solar panel and LiPo battery.

Table 1. Modules used in the low-cost rainfall monitoring station.

Module name	Function	Approximate price
Arduino MKR WAN 1310	Main control board and communication	~ 30 €
Arduino MKR Mem Shield	Save data in SD card	~ 20 €
DS3231	Real time clock	~ 5 €
LiPo Rider Pro	Operate solar panel and LiPo battery, power the system	~ 15 €
RG-15	Low-cost optical rain gauge	~ 80 €
WH-SP-RG	Low-cost tipping bucket rain gauge	~ 20 €

Software

Operating codes are written in Arduino IDE language (close to C++). The system initializes all modules firstly and then enters the loop. In the loop, the system saves measurements on the SD card every minute and sends measurements to online storage every five minutes through LoRaWAN (Long Range Wide Area Network).

Experimental site

The experimental site is the GROOF (Green ROOF experimental Facility) platform at INSA Lyon, France. Figure 1 shows the three same stations and the reference tipping bucket rain gauge (resolution 0.23 mm/tip) installed on the GROOF platform.

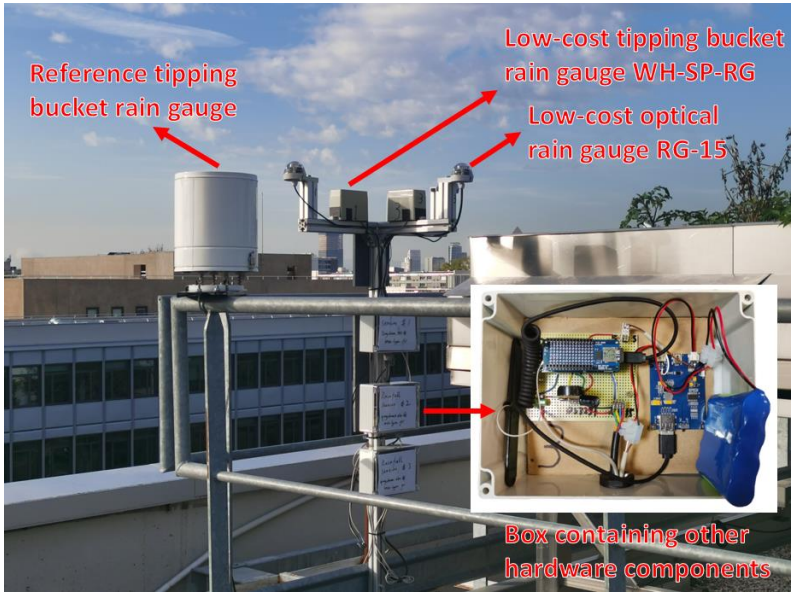


Figure 1. Low-cost rainfall monitoring stations installed on the GROOF platform.

Results and discussion

During the four months of field test from October 2022 to January 2023, the designed system was powered by outer power supply due to the insufficient solar radiation in winter. There were some losses of online data because of the nature of LoRaWAN. Apart from this, the system was able to operate autonomously and to save measured quantities (time stamp, precipitation, output voltages of battery and solar panel) on the SD card every minute correctly. The performances of both the low-cost optical rain gauge RG-15 and the low-cost tipping bucket rain gauge WH-

SP-RG are illustrated in Figure 2 and Figure 3. As shown in Figure 2, the tested three low-cost optical rain gauges RG-15 exhibit poor reproducibility and we could not fix low-cost optical rain gauge No.3.

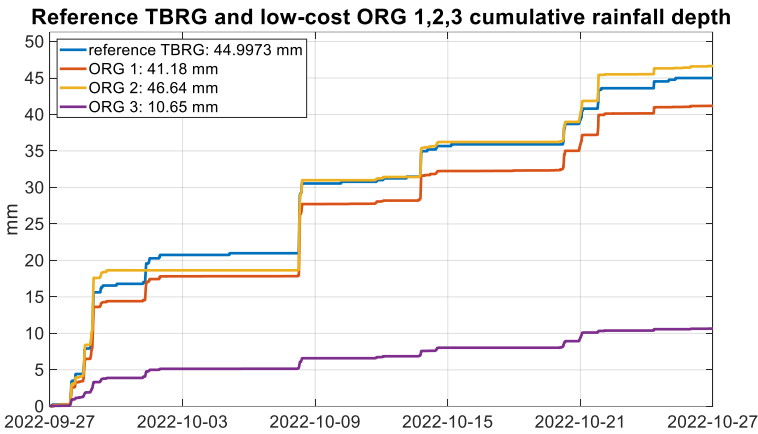


Figure 2. Cumulative rainfall depth reported by the reference Tipping Bucket Rain Gauge (TBRG) and low-cost Optical Rain Gauges (ORG) No. 1, 2, 3 from 26 September to 27 October 2022.

All tested low-cost tipping bucket rain gauges WH-SP-RG have shown similar performances. Figure 3 takes one WH-SP-RG as an example to discuss the influence of the collecting funnel design.

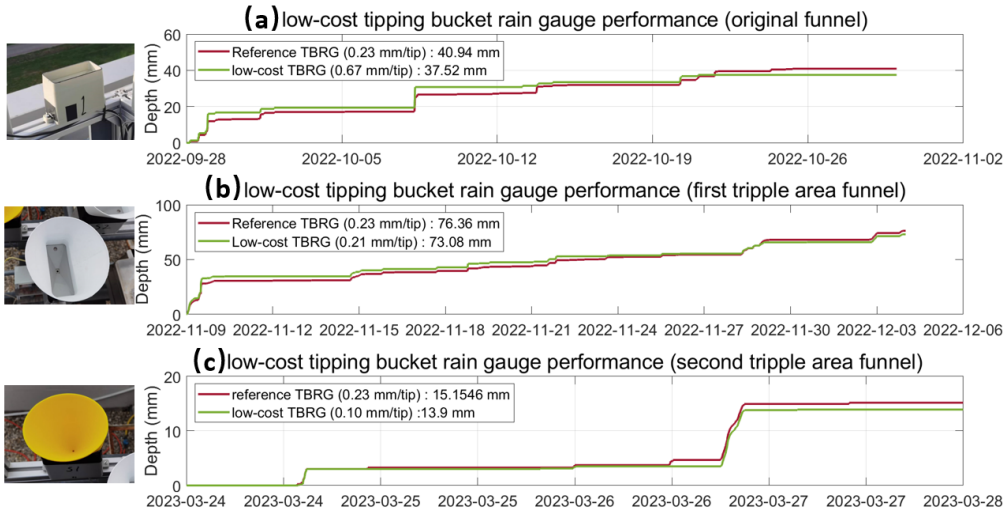


Figure 3. Cumulative rainfall depth reported by the reference and low-cost Tipping Bucket Rain Gauges (TBRG) in three setups: (a) original funnel without lubrication, (b) tripled area funnel without lubrication, (3) conical shape tripled area funnel with lubrication.

As shown in Figure 3(a), the low-cost tipping bucket rain gauge with original funnel without lubrication has a resolution around 0.60 mm/tip which is considered as insufficient for urban hydrology applications. After tripling the collecting area by adding a 3D-printed additional funnel, the resolution was improved around 0.20 mm/tip (Figure 3(b)). However, unsmooth surface and imperfect shape of the collecting area lead rainwater to stagnate on the funnel surface. A second modification was then tested: the low-cost tipping bucket rain gauge with a modified well lubricated 3D-printed conical shape funnel has a resolution around 0.10 mm/tip

(Figure 3(c)), which is consistent with laboratory calibration and appropriate for urban hydrology application.

Conclusion

We developed an autonomous miniaturized low-cost rainfall monitoring station and tested it in the field. After 4 months of test in winter season, the system could operate satisfactorily by outer power supply. However, the used low-cost optical rain gauge RG-15 has significant sensor to sensor variation. After funnel improvement, the low-cost tipping bucket rain gauge WH-SP-RG could monitor rainfall at high resolution (around 0.10 mm/tip). The station can run autonomously, is small, affordable, and is “self-monitored” as the user can check online data in near real-time (including battery voltage). The installation of a solar panel is expected to significantly increase the battery life. All these features make it suitable for deployment in ubiquitous rainfall monitoring networks.

Acknowledgments

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Biography



The author completed his Ph.D at Institut National des Sciences Appliquées de Lyon (INSA Lyon), Déchets Eaux Environnement Pollutions (DEEP) laboratory in France and his undergraduate and graduate studies at Chang'an University. His research interests lie in embedded hardware and software engineering, ranging from design to implementation. He has collaborated actively with researchers in the discipline of urban hydrology.