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Real-time monitoring of water level at low-cost for nature-based stormwater solutions asset management

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Abstract

Traditional underground drainage infrastructure (i.e. pipe networks) offers the benefit of conveying excess rainwater from urban centres quickly, but with negative impacts for receiving waters. Consequently, many cities are introducing stormwater control measures (SCMs) to retain and infiltrate excess stormwater, reducing the peaks that can overwhelm networks. Most common SCMs include swales, trenches, infiltration basins, green roofs and porous pavements. Until recently, research often focussed on the design of such systems, with less focus on long term performance and maintenance. Given the scarce data available, monitoring is a priority for Operation & Maintenance (O&M) activities, and to gather the necessary knowledge for asset management. Real-time low-cost monitoring provides an opportunity to meet this need. This communication presents an open-source water level monitoring system which is already deployed in the field. The paper also discusses key elements of design related to low-cost monitoring systems.

Keywords

Low-cost; monitoring; nature-based solution; real-time; stormwater control measures; water level.

Stormwater control measures asset management

According to Raymond *et al.* (2017) “nature-based solutions (NBS) are solutions to societal challenges that are inspired and supported by nature”. They offer great potential in addressing a variety of challenges in many domains (H2020, 2015), and providing ecosystemic services (Nesshöver *et al.*, 2017). Regarding urban water, “NBS can contribute to sustainable urban water management by increasing infiltration, enhancing evapotranspiration, providing storage areas for rainwater and removing pollutants” (Raymond *et al.*, 2017). Such solutions are often applied at or near to the source of runoff: swales, infiltration trenches, green roofs or porous roads, etc. They have emerged worldwide in the last 30 years under many names such as stormwater control measures (SCMs), best management practices or sustainable urban drainage systems (Fletcher *et al.*, 2015). SCMs are integrated within the urban landscape, most often open-air and thus have high visibility and public accessibility. Since the emergence of SCMs, operational and research questions have largely focused on their design. After several decades, there is, however, a growing concern regarding their medium and long-term performance and maintenance, putting at risk the adoption of SCMs, with local government at risk of withdrawing from SCM implementation, driven by concerns about the long-term financial and operational sustainability of such systems (Morison *et al.*, 2010). Most of the present management of SCMs is based on the run-to-failure approach, partly due to resource limitations and lack of knowledge. Shifting to proactive management in the short-term is only possible by drastically increasing the monitoring (more asset monitored more frequently). This will allow anticipating failure and providing a better understanding of their behaviour.

Toward low-cost solutions

Low-cost technologies have emerged few years ago in other fields, such as agriculture (Fisher, 2007)

and air quality (Morawska *et al.*, 2018). They are emerging now in our urban drainage community (Santos *et al.*, 2021; Shi *et al.*, 2021). Their advent opens up the potential for entirely new approaches, where numerous sensors measure various aspects of SCM state and performance, generating alerts to those involved in their maintenance. Such sensors could control changes to system configuration to optimise performance relative to operating conditions and maintenance state of the system. Delivering on this potential will require investigating new challenges and imagining innovative ways of monitoring. Among the other challenges, it will be necessary to consider the reliability of the monitoring system, the skills related to customised hardware and programming and the management of large data sets. Low-cost solutions will, however, improve monitoring possibilities with real-time data acquisition, processing, and alert, along with the increase of spatial resolution. A key challenge is to optimise the use of new technologies, rather than simply replacing the functionality of existing monitoring systems.

Regarding SCMs asset management, the review of scientific literature and operational guidelines, associated with exchanges with stakeholders, has proven that the water level is the best solution to inform on the overall operation of the system. The paper presents a low-cost and real-time water level monitoring system and discusses some of the key elements of design (Figure 1).

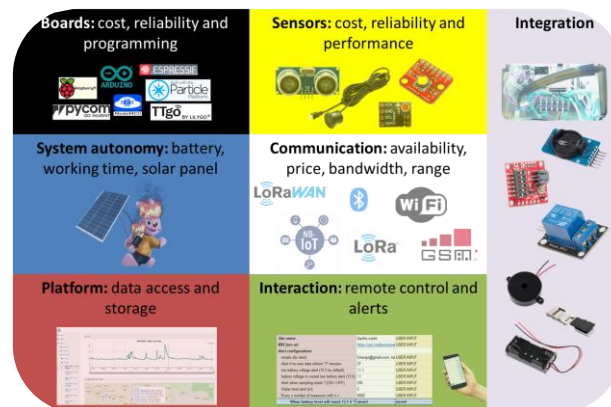


Figure 1. Key elements for the design of a real-time low-cost monitoring system

How to build a low-cost monitoring system?

Monitoring specifications and choice of the sensor. The proposed system aims to monitor the water level in SCMs to inform O&M activities. The objective is to minimize the costs of design, construction, installation, data management and monitoring system maintenance. The expected maximum water level range is below 2 m with an acceptable accuracy of 2 cm. The system provides real-time data to raise alerts (high / low water level, low-battery level, absence of new data). To reduce cleaning needs, the sensor is not in contact with the water; this constraint drastically limits the choice of sensor (Morris and Langari, 2012).

Power management and communication. Power management and communication are key elements of the system. To avoid frequent site visits, the system needs to be self-powered. Low power management is a frequently discussed topic and can involve a variety of hardware or software solutions. Easy-to-implement solutions include decreasing the measurement time, increasing the sleep time between measurements, and decreasing the communication consumption. LPWAN (low-power wide-area network) communication facilitates minimum energy consumption and maximum range for communication, when compared to cellular (GSM) communication. These solutions are however often one-way communication, with a limited bandwidth (Mekki *et al.*, 2019), which is acceptable for the present project (no image or video to be sent). Based on the existing coverage, the LoRaWAN technology is used where available (no subscription fees) or alternatively Sigfox (subscription fees).

Optimal measurement cycle. Each measurement cycle can be broken down into two phases: an active phase and a sleeping (passive) phase. The active phase consists in the initialisation (powering of the sensors), the measurement, the communication of data, and a termination (power down of the sensors). During the sleeping phase, the system consumes as little energy as possible until the next active phase. The number of cycles per hour represents a trade-off between power management (more

measures mean more energy consumption), communication constraints (LPWAN often limits the number of messages per day) and the monitoring requirement. In the present case, a measure is sent every 15 minutes. The duration of the measurement phase is very important because of its high-energy consumption. It is again a trade-off between the quality of the measurement (improved when using the median of n measurements) and the total measurement duration (n times the duration of one measurement). This trade-off is highly depending on the sensor chosen and the measurement performance expected.

Testing the sensor and the measurement procedure. Following laboratory tests (Cherqui *et al.*, 2020), the ultrasonic sensor JSN-SRT04 has been chosen because (i) it is one of the most commonly available sensors, (ii) it is waterproof, (iii) it is easy to install, and (iv) it provides an expected accuracy within a compatible range of measure. The fact that a sensor is very commonly used is very important because it implies mass production and consequently very low cost (<\$7 AUD for the JSN-SRT04), but also a large community of users and potentially a high number of open-source projects and extensive knowledge to aid deployment and troubleshooting. According to the lab results, the sensor shows low variation between repeated measurements: approximately 0.01 m. It has thus been decided to calculate the median of 25 measurements (maximum measurement duration of less than 10 seconds). The total active cycle lasts less than 20 seconds: initialisation, measurements (distance, air temperature, air relative humidity and battery voltage), communication and termination. The system is thus active less than 3% of the time when using a 15-minute time step (20/920 seconds).

Field installation. The system is encapsulated in a 100 mm PVC pipe in order to provide a cheap waterproof case and make it less noticeable, with the aim of reducing the risk of vandalism. The enclosure also allows easy removal/replacement without changing its location. Figure 2 presents the system deployed on site. The system runs on three AA rechargeable batteries and a 0.5 W solar panel.



Figure 2. System installed on the field (on the left of the pole) and photos of the encapsulation system made for easy fixing and removal without changing the location of the sensor.

Performance of the system. Data can be accessed in real time using the online platform <http://mind4stormwater.online>. One of the first system deployed in the field has been running for more than a year and has provided almost continuous time series. Figure 3 presents the water level and battery voltage (peaks of voltage are due to the solar panel) time series. According to initial tests without the solar panel, the system can run more than two weeks without sun.

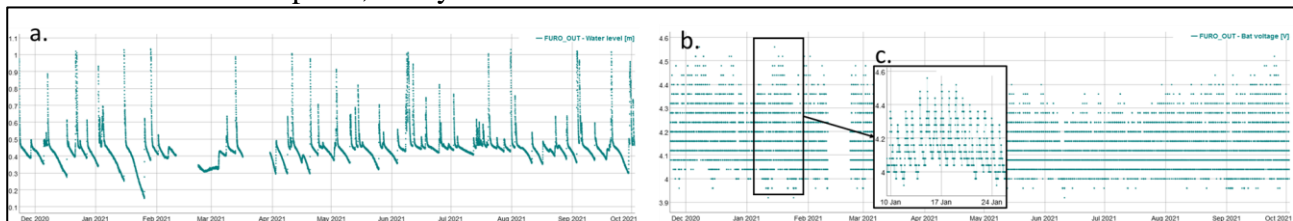


Figure 3. Data gathered in real time for an Australian monitoring system installed in a wetland in Melbourne: water level (a) and battery voltage (b.) with a zoom (c) to see the daily pattern.

Conclusion

Several low-cost water level monitoring systems have been successfully deployed under real *in situ* conditions both in Melbourne (Australia) and Lyon (France). Key design elements are i) choice of the sensor, ii) measurement cycle, iii) power management, and iv) communication. Other low-cost systems have already been built, showing the flexibility provided by DIY development of monitoring systems and open-source material. Nature-based solution asset management offers new opportunities for the water sector. Existing thinking and practices will need to be adapted to such particular assets, leading to new research and business prospects. It is already clear that more monitoring will be

required to shift from a run-to-failure approach to a proactive management. At the same time, low-cost technologies are opening new potentials for the monitoring of asset with the miniaturization and falling costs, allowing better spatial and temporal resolution. Such technologies can be the start of this “out of the box thinking”.

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