Low-cost, low-energy sensors for assessing plant health in stormwater biofilters.

Capteurs à bas coût et faible consommation pour évaluer l'état de santé des plantes dans les biofiltres pour l'eau pluviale

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RÉSUMÉ

Les biofiltres pour eaux pluviales peuvent fournir une myriade de services qui améliorent la vie urbaine en utilisant une zone relativement petite. Plusieurs villes ont adopté ces systèmes à grande échelle, mais l'entretien de la végétation peut être coûteux. Les administrations municipales sont souvent chargées d'inspecter et d'entretenir les biofiltres afin de s'assurer que les plantes sont bien établies et en bonne santé. Des inspections moins fréquentes pourraient être possibles en mettant en œuvre des capteurs d’humidité du sol peu coûteux qui transmettent des données au gestionnaire d’ouvrages sans fil. Nous présentons un prototype de capteur connecté à un Arduino capable de fournir aux gestionnaires des indications pour visiter le biofiltre dans le cas où le média filtrant est devenu inapproprié pour supporter des plantes (c'est-à-dire trop humide ou trop sec). Nous fournirons un accès sans fil à ces informations, ce qui améliorera la capacité des gestionnaires d’ouvrages de décider du moment où des ouvrages spécifiques doivent être gérés.

ABSTRACT

Stormwater biofilters can provide myriad services that improve urban life using a relatively small area. Several cities have adopted these systems on a wide scale, but maintenance of vegetation can be costly. City governments are often responsible for inspecting and maintaining biofilters to ensure plants are established and healthy. Less frequent inspections could be possible by implementing inexpensive soil moisture sensors that convey data to the asset manager wirelessly. We present a prototype Arduino-connected sensor capable of providing cues for managers to visit the biofilter in the case that the filter media has become unsuitable for supporting plants (i.e., either too wet or too dry). We will provide wireless access to this information which will improve the ability of asset managers to make decisions on when specific assets should be managed.

KEYWORDS

Soil moisture sensor, stormwater biofilter, real-time monitoring, water sensitive urban design

1 INTRODUCTION

Stormwater biofilters, a widely adopted type of water sensitive urban design (WSUD) system rely on healthy vegetation to remove pollutants (Bratieres et al. 2008, Payne et al. 2014, Read et al. 2008), maintain infiltration (Le Coustumer et al. 2012), support biodiversity (Kazemi et al. 2011, Winfrey et al. 2018), and improve aesthetics (Dobbie 2016). Plant health and hydraulic performance should be monitored frequently during the establishment phase (Payne et al. 2015), requiring site visits that increase maintenance costs. Remote, real-time monitoring of soil moisture may provide cues to WSUD asset managers to inspect sites that are not performing as designed in the place of costly, frequent visits. Low-cost, low-energy soil moisture sensors connected to commercially available microcontrollers present an opportunity to monitor individual biofilters in real-time.

Arduino-based sensors are inexpensive, highly customizable, and relatively easy to implement. However, there is little information on the accuracy of these sensors and whether they can provide enough information to inform maintenance decisions in WSUD. Resistivity-based sensors can be constructed with any conductive material capable of measuring voltage; soil moisture is approximated as a function of the electrical conductivity across two electrodes. There are many issues with using resistivity-based sensors to determine volumetric water content (e.g., temperature dependence, soil salinity, soil cation exchange capacity (CEC), heterogeneity in soil profiles) (Robinson 2008), but there are also several advantages (e.g., ease of implementation, non-invasive, inexpensive). Biofiltration media can be relatively homogenous and in Australian biofilters it is often comprised of sandy loam or washed sand in the upper layer and coarse sand in the lower layer (Payne et al. 2015). This well-defined stratification and low-CEC soil may provide favourable conditions for using resistivity-based sensors.

We constructed an Arduino-based soil moisture sensor from raw materials and evaluated the accuracy of determining volumetric water content (VWC) of biofiltration media against the gravimetric method. Currently, we have collected preliminary data as we are refining the sensor and improving the functionality of the Arduino microcontroller to provide real-time and wireless data transfer. This extended abstract will focus on the experimental set-up and calibration.

2 METHODS

2.1 Sensor Construction

The resistivity-based soil moisture sensor electrodes were comprised of two 2-mm diameter, 100-mm long titanium rods set 25 mm apart and separated by HDPE on one end and open on the other end (Fig. 1). The electrodes were soldered to copper wire and connected to an Arduino Uno digital and analogue pins in order to switch the direction of current to simulate an H-bridge using resistors (Fig. 1). This setup is used to diminish effects of electrolytic corrosion on either electrode by forcing both to serve as anodes half of the time. Future iterations of this sensor will be fitted with mobile connectivity, lithium polymer battery, and waterproof enclosure, resulting in a total cost of AUD$150.

2.2 Sensor Calibration

The Arduino platform reports information in 10 bits of resolution. Consequently, the Arduino will output the entire range of possible voltage it measures on a scale of 0–1023. These bits represent the voltage reading of the sensors, which are usually run on a 5V power source. Considering the intrinsic electrical resistance, the highest voltage reading that the sensor can return is not typically equal to the power source voltage. The Arduino platform applies a linear relationship between bits and voltage for those readings between 0 and 1023. In resistivity-based soil moisture sensors, higher voltage corresponds to higher soil moisture (e.g., lower resistance between electrodes when more water occupies pore spaces). It is important to note that rather than determining accurate VWC of the filter media, the goal of the study is to measure soil moisture conditions that indicate whether the filter media may not support plant growth (i.e., above permanent wilting point or ~15% VWC) or whether the media has become clogged (i.e., above field capacity, ~40% VWC).

Calibration 1. The first version of this soil moisture sensor was calibrated using biofiltration media *in situ* at a site on the Monash University Clayton Campus for a student research project. The sensor was inserted vertically into the top layer of filter media until the voltage reading stabilised. Multiple measurements were made in areas with varying amounts of water added to provide a range of soil moisture conditions. Next, soil moisture for that sample was determined using the gravimetric method by collecting a soil sample of known volume and subsequently weighing, drying, and re-weighing the sample and determining VWC as the difference in volume before and after drying divided by the volume of soil sample (Reynolds 1970). A calibration curve was constructed by plotting sensor voltage readings against VWC determined by the gravimetric method. Calibration results indicate that the sensor was unable to predict soil moisture.

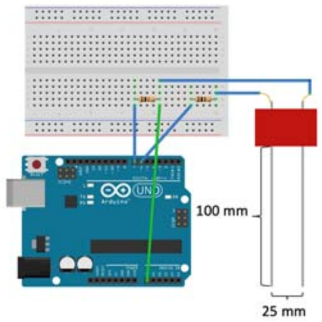

Figure 1. Basic circuit diagram of Arduino-based sensor node with soil moisture sensor (red block with grey electrodes). Power source, SD card reader, and 3G module not shown.

Calibration 2. The sensor was tested in the lab using similar methods described above, but with a larger range of soil moisture values represented in test columns containing field-collected and unused filter media. Calibration curves were developed for each filter media type.

Nine samples of field-collected filter media were prepared in 91-mm diameter PVC columns as follows: 1) 100-mm tall columns with one end sharpened were numbered and weighed prior to collection. 2) After removing debris and mulch from the surface, the sharpened end of the PVC column was inserted into the biofilter media then removed with a shovel to preserve an intact surface on the bottom of the column. 3) Tightly woven cotton cloth was affixed to the column with plastic zip ties to maintain the bottom surface of the filter media while columns were transported to the lab. 4) All samples were dried in a drying oven then weighed. 5) Eight of the nine columns were saturated for 2 hours in a shallow water bath with cotton cloth retaining the sample. The remaining column remained dry (0% VWC) until measuring with soil moisture sensor. 6) The soil moisture sensor and a temperature sensor were inserted vertically into the dry column and one of the saturated columns immediately after removing from the water bath. Bit values and temperature of the samples were recorded. 7) In order to represent a range of soil moisture values, subsequent soil moisture and temperature measurements were made 2 m, 30 m, 2 h, 4 h, 1 d, and 10 d after removing samples from the water bath. 8) Immediately after recording sensor readings, soil moisture was determined using the gravimetric method. Similarly, nine samples of unused filter media were used for calibration.

2.3 Monitoring plant health

To determine relevant readings for monitoring plant health, the wilting points of several common plant genera used in biofilters were determined through a literature search. These wilting points corresponded to specific VWC, which correspond to bit values based on our calibration curve.

3 PRELIMINARY RESULTS AND DISCUSSION

Calibration 1 Results. The sensor was unable to determine the difference between wet and dry soil under these conditions! However, this test was not appropriately calibrated using a relevant variety of soil moisture conditions to ensure a large enough range of voltage responses that could be distinguished by the Arduino.

Calibration 2 Results. The calibration of sensors in both filter media types resulted in very similar calibration curves (Figure 2). The method used to calibrate sensors seemed to provide good linearity (R^2 = 0.91 and 0.95 for unused and field-collected filter media, respectively). However, in future tests, we will test soil moisture between 3 d and 10 d to increase the likelihood of capturing VWC values in the range of typical wilting points in our calibration.

Plant health monitoring. Biofilter plants often undergo long dry periods in substrate that has a tendency to dry out. Plants are often stressed at roughly double the wilting point (Muerdter et al. 2018). When selecting a relevant value for management, two times the highest wilting point should be selected as a trigger for determining whether additional irrigation should be provided. Wilting point of common biofilter plants ranged from 0.05 – 0.15 m^3/m^3 VWC (De Kroon et al., 1996; Davis, 2019; McVean, 1966; Macinnis-Ng et al., 2009; Griffin and Hoffmann, 2011; Akhter et al., 2003); in the case of a biofilter containing *Melaleuca* sp., a relatively drought-tolerant genus with a wilting point of 0.15 m^3/m^3 (Macinnis-Ng et al., 2009), an appropriate trigger value would correspond to a reading of 470 bits (0.29 m^3/m^3). Considering that saturated filter media had a VWC of 0.35 m^3/m^3, this range for triggering management is not realistic. More research should be done to determine levels of soil moisture that are likely to trigger plant stress and are appropriate for real-time weather conditions.

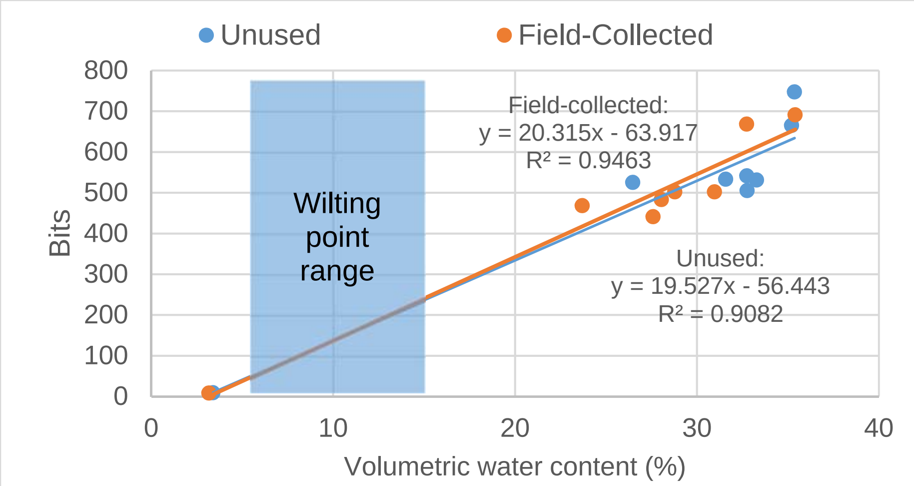

Figure 2. Calibration curves from Calibration 2 for unused and field-collected filter media volumetric water content.

Further considerations. One major consideration in implementing these systems is the time required to set them up, approximately 150 hours in this study. As more of these sensors and monitoring systems are tested by working/research groups such as the Urban Water Group at Monash University, the development time decreases dramatically. However, the initial time to develop open source, "do-it-yourself" sensors is a major barrier to adoption. When more studies like this demonstrate the accuracy capable of these low-cost, low-energy sensors, the barriers to adoption diminish.

4 CONCLUSIONS

Low-cost, low-energy sensors like the one described in this extended abstract have primarily been used by hobbyists for gardening and indoor plants. Similar to commercially available irrigation systems that use soil moisture sensors to determine optimal watering amounts and times, this sensor could be used to provide cues to irrigate specific biofilters, during extended dry periods. The sensor could also help determine whether specific biofilters are not receiving runoff as designed following a rain event. Biofilters that do not infiltrate runoff (i.e., reach field capacity) within a few days following a rain event may be targeted for inspection as well. Soil moisture data could be used by WSUD managers to help determine the cause of failure and better allocate resources.

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