Methodology for calibration and data processing in an experimental assembly of green roofs

Méthodologie d'étalonnage et de traitement de données dans un assemblage expérimental de toitures végétalisées

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RÉSUMÉ

L'acquisition de données est un aspect clé lorsqu'on souhaite générer des estimations du comportement hydrologique. Ainsi, ce travail montre la conception et le montage d'un assemblage expérimental de toitures végétalisées, lequel semble pertinent compte tenu de l'importance croissante des techniques alternatives comme éléments du drainage urbain dans les villes colombiennes, étant donné le manque d'informations relatives à leur comportement dans un climat tropical. Cet ensemble est conçu pour contrôler les précipitations *via* un simulateur de pluie, obtenir le stockage de l'eau, l'évapotranspiration et estimer la production de ruissellement pour des événements pluvieux représentatifs. L'ensemble est programmé sous le logiciel gratuit Arduino et est équipé d'une série de capteurs de force, de capteurs de débit ultrasons et de température. Ce document vise à fournir des informations sur la méthodologie d'étalonnage de l'ensemble expérimental et du système d'acquisition de données, ainsi que sur les fonctionnalités qu'il offre pour le traitement des données acquises.

ABSTRACT

The acquisition of data is a relevant aspect when it is desired to generate estimates of hydrological behavior. So, this work shows the conception and construction of an experimental assembly of green roofs, given the growing importance of the sustainable urban drainage systems in Colombian cities and the lack of information about their behavior in tropical climates. This assembly is conceived to control precipitation through a rain simulator, to obtain the water storage, its evapotranspiration and estimate the production of runoff for typical rainfall events. The entire assembly is programmed under the free software Arduino and is instrumented with a series of load cells, ultrasound flow sensors and temperature sensors. This document aims to provide information on the calibration methodology of the experimental assembly and the data acquisition system, as well as the functionalities it offers for processing the acquired data.

KEYWORDS

Data acquisition systems, data processing, green roofs, urban systems of sustainable drainage

1 INTRODUCTION

Given the high percentage of impermeable roofs in cities, green roofs, in particular, have become an alternative to the problem of urban drainage and the consequences of urbanization processes, such as, decreased soil permeability, increased generation of runoff superficial, reduction of infiltration and evapotranspiration (Gorani, 2017). Additionally, green roofs can contribute to the aesthetic improvement of buildings and urban centers, mitigate the impact of heat island effects, improve air quality, promote biodiversity and urban runoff management (Versini, Gires, Tchinguirinskaia, & Schertzer, 2016).

Starting from the general behavior of this alternative, some variables are of hydrological interest, as rainfall height, runoff flow rate, water storage changes in the substrate-vegetation layer, evapotranspiration rate, since the latter varies depending on the water availability of the substrate, vegetation, and temperature (Calabuig Belda, 2016). That is why it is necessary to implement electronic sensors as transducers of natural phenomena to electrical signals, which are processed and calibrated in order to obtain reliable information for the variables to be analyzed (National Instruments, 2018).

Based on the foregoing and the daily needs that concern us regarding the realization of a sustainable urban drainage alternative, from the Research Group in Urban Hydrology of the Universidad Nacional de Colombia Sede-Bogotá, with the conceptual support of the Pontificia Universidad Javeriana, an experimental assembly was developed that allows studying the hydrological variables that intervene in a solution such as green roofs (Cortés-Torres, et al, 2018).

This paper aims to provide information on the calibration methodology of the experimental assembly and the data acquisition system, as well as the functionalities it offers for processing the acquired data.

2 DESCRIPTION OF THE ASSEMBLY AND METHODOLOGY OF CALIBRATION

Taking into account the variables of hydrological interest, an experimental assembly was proposed with three main structures, a rain simulator for the representation of precipitation, four loading frames for obtaining storage and production of evapotranspiration and four receiving tanks for the calculation of runoff flow (Cortés-Torres, et al, 2018) (Figure 1.a). As for the data acquisition system, we worked on a free-use programming platform for electronic systems, Arduino, which is based on C ++ language and has a community of users who work collaboratively (Duque, A. Ochoa, A. Buitrago, D. & Galindo, C., 2018). The whole assembly is instrumented with 1 YF-S201 flow sensor, 16 three-wire load cells (4 for each load frame), 4 HX711 ADC modules (1 for each load frame), 4 HC-SR04 ultrasound sensors (1 for each receiving tank), 2 DS18B20 temperature sensors (as a control variable for the production of evapotranspiration), and 3 Arduino UNO cards, two of which are communicated to the computer through the Arduino IDE software. Figure 1.b shows the block diagram of data acquisition.

Figure 1. a

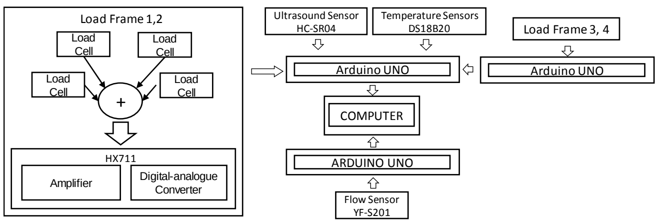

Figure 1. b

Figure 1. Experimental assembly and block diagram of the data acquisition system.

Next, the process to perform the calibration of each of the main structures and their corresponding sensors is explained.

2.1 Rain simulator

The rain simulator is built with a pair of valves that allow calibrating the input flow that transforms into the rainfall of the system. The first valve called control, allows to regulate the inlet flow for each of the precipitation intensities that are desired to be evaluated, conditioned by the pump that the system possesses; the second called opening/closing allows maintaining the same rainfall intensity for different experimental events. This information of precipitation events is measured with the flow sensor YF-S201, which uses a windmill system to send electrical pulses every time a revolution of its blades is generated. The Arduino UNO electronic card takes the reading of the pulses, which can be correlated with a series of known water volumes in order to determine the amount of water that enters the green roofs (Cortés-Torres et al., 2018). For the calibration of the sensor, six half turns of the control valve were taken and for each of them, the volume of water given by the system was measured with different opening/closing times (1, 2, 5 and 10 minutes). In Figure 2.a, it is observed that the correlation between the pulses emitted by the sensor and the water volumes measured, with the slope found after linearization, was found to be the conversion factor to find the flow rate from the pulses obtained.

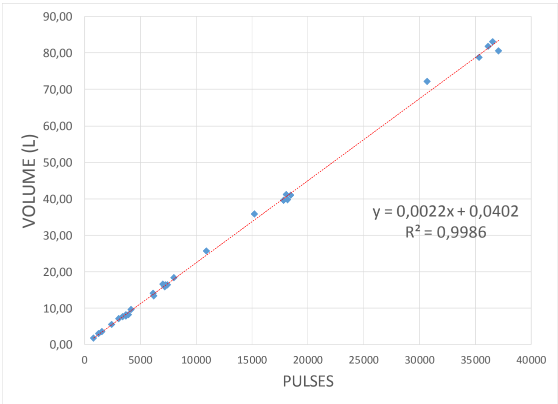

Figure 2. a Calibration flow sensor.

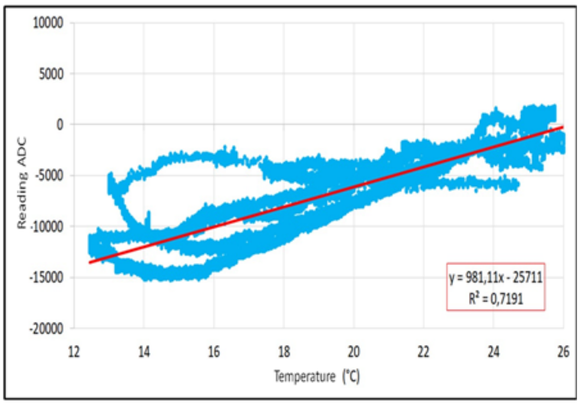

Figure 2. b Correlation of load cells and temperature

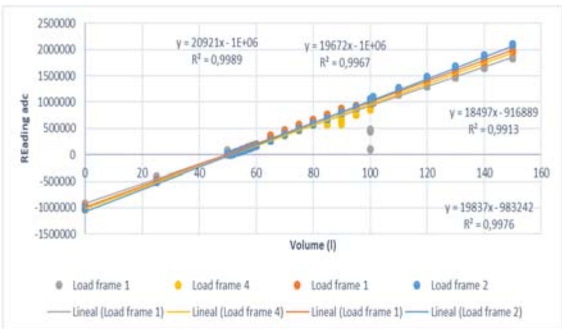

Figure 2. c Calibration of load cells

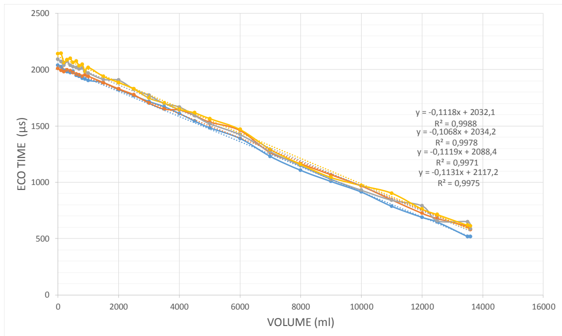

Figure 2. d Calibration ultrasonic sensor

Figure 2. Calibration curves for the sensors of the experimental assembly.

2.2 Load frames

Each load frame is composed of a support table, a green roof plot of 1m^2 of area, a tilt controller and two load sheets that contain sensors or load cells, the three-wire type cells work in pairs to form a complete Wheatstone bridge configuration and work by quantifying the variation of the electrical voltage from the mechanical deformation of a strain gage that acts as a resistance. This value is read by the digital-analogue converter (ADC) HX711 and performs the transformation of an analogue signal to digital for further processing on the Arduino UNO card. The maximum load capacity provided by the system is 200 kg. Initially, a temporary stability test was performed in which variations were found in the readings of the cells at zero volume, caused by temperature variations. Once this phenomenon was identified and generating the corresponding smoothing for the data collection (Figure 2.b), the calibration of the cells was carried out by means of the readings delivered by the analogue-digital converter to the card, comparing known volumes in a range of 50 to 150 litters, given that this is the weight range expressed in volume of water that un green roof can have in a plot of 1m2. With the linearization of this curve an equation was obtained to apply within the program (Figure 2.c) (Cortés-Torres, et al, 2018).

2.3 Receiving tanks

The receiving tanks were each instrumented with an ultrasound sensor HC-SR04; the runoff flow is measured as the volume of water occupied in the tank, associated with the time it takes the ultrasonic wave between the output of the emitter, colliding with a surface and return to the receiver. These sensors were calibrated, from known volumes from 100 ml to 13.6 l; in this way, the greater the volume registered in the sensor decreases the time recorded by the sensor (Figure 2.d); a calibration with volume deltas of 100 ml up to the first litter was carried out, in order to increase the precision in that range since it is where the drainage is located.

3 DATA PROCESSING

With the data provided by the acquisition system, it is possible to perform a hydrological behavior analysis of green roof plots of 1m2. Given the opening steps of the control valve, it is possible to evaluate the precipitation intensity ranging for each load frame between 37,8 mm/h and 111,1mm/h. On the other hand, green roofs with a maximum of 200 kg per loading frame can be evaluated from the load cells; and ultrasound sensors give a maximum capacity of 13.6 litters.

Following the above, hydrographs can be obtained for each green roof plot, for each desired precipitation event. In this way it is possible to estimate peak flows and peak times, in order to analyze the green roof configuration that can minimize flow and maximize time. On the other hand, from the data of the load cells, it is possible to obtain the percentages of saturation of the substrate-vegetation layer, the time to the maximum saturation and the generation curve of evapotranspiration. This will contribute to the analysis of the antecedent dry weather periods when a series of precipitation events are considered.

4 CONCLUSIONS

Thanks to this design, it is possible to evaluate a broad spectrum of green roofs, modifying their basic characteristics such as the thickness of the substrate, the composition of the substrate, the plant species and the angle of inclination, without counting the intensity of precipitation, and in this way to achieve several possibilities for a hydrological evaluation of this type of sustainable urban drainage systems.

On the part of the data acquisition system it is clear that the calibration of sensors that digital masters deliver better results because their data are more homogeneous, contrary to what happened with the load sensor that delivers an analogue signal and its processing is more complicated: given its susceptibility to temperature variations during the day, it is a priority to characterize this behaviour in situ, in order to stabilize the readings thrown by the load cell.

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