Geoderma 262 (2016) 133–139

Contents lists available at ScienceDirect

Geoderma

journal homepage: www.elsevier.com/locate/geoderma

Automating double ring infiltrometer with an Arduino microcontroller

M. Fatehnia [a,*], S. Paran [b], S. Kish [c], K. Tawfiq [a]

[a] Department of Civil and Environmental Engineering, FAMU-FSU College of Engineering, 2525 Pottsdamer Street, Tallahassee, FL 32310, USA
[b] Department of Electrical & Computer Engineering, FAMU-FSU College of Engineering, 2525 Pottsdamer Street, Tallahassee, FL 32310, USA
[c] Department of Earth, Ocean and Atmospheric Science, Florida State University, 1017 Academic Way, Tallahassee, FL 32306, USA

ARTICLE INFO

Article history:
Received 12 March 2015
Received in revised form 10 August 2015
Accepted 13 August 2015
Available online 28 August 2015

Keywords:
Double ring infiltrometer
Arduino microcontroller
eTape™
MOSFET switch
Hall effect sensor
Peristaltic pump

ABSTRACT

In this paper, we describe the designed and tested system of automated double ring infiltrometer (DRI) that we have developed using an Arduino microcontroller, a Hall effect sensor, a peristaltic pump, a water level sensor, and a constant-level float valve. The system can be used for infiltration measurements in both single ring falling head and double ring constant head methods. The precise measurements of the current method compared to previous designed systems are not affected by sunlight, and due to the method of flow measurement, remain accurate even for low infiltration values. The set-up has an easy real-time data storage on a micro-SD card without a need of a portable computer in the field. It only requires a single reservoir for both inner and outer rings to which, water can be added anytime needed without affecting the measurements. The system automatically detects when the steady state infiltration rate is reached and concludes the testing and stops measurements. The system is mounted in a portable and weather resistant box and is applied to run DRI testing in the field to check the applicability and accuracy of the portable set-up in field measurements. Manual testing was also performed in the field for comparison with the automated system measurements. Overall system architecture, and the design of hardware and software components are presented in details. The system configuration is illustrated for better understanding of the set-up.

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1. Introduction

Double ring infiltrometers are among the common test methods for in-situ measurement of the soil infiltration rate. DRI test described by ASTM D3385 consists of open inner and outer cylinders that should be manually inserted into the ground and be partially filled with a constant head of water. The infiltration rate is calculated by measuring the volume of liquid added to the inner ring to keep the liquid level constant (ASTM, 2009). The size dependency of saturated hydraulic conductivity measurements in porous media has been studied by several researchers and there have been several proposed dimensions as the minimum required diameter of test cylinders. Swartzendruber and Olsen (1961) reported that the setup with 60 and 50 cm for the outer and inner ring radius respectively was the most satisfactory throughout all the various conditions studied in a sandy soil. Ahuja (1976) reported that when an outer ring of 90 cm diameter was employed for an inner ring of 30 cm diameter, the lateral flow was practically eliminated. Bouwer (1986) suggested that a diameter of at least 100 cm should be used for accurate saturated hydraulic conductivity measurements. Youngs (1987) concluded that the results were consistent from site to site when the ring size was at least 15 cm. Gregory et al. (2005) concluded that the test employing a constant head with a double-ring infiltrometer of 15 cm inner and 30 cm outer diameters would be suitable for sandy soils generally found in North and Central Florida. Lai et al. (2010) conducted a total of 7224 numerical simulations, which resulted in a conclusion that inner ring diameters greater than 80 cm are needed to obtain reliable in situ measurement of saturated hydraulic conductivity. Fatehnia and Tawfiq (2014) by simulating 864 Double Ring Infiltrometer tests and applying M5′ model tree algorithm offered an equation for hydraulic conductivity estimation from the steady infiltration rate measurements that can be used for any ring size. They also considered the effects of head of ponding, depth of the rings in the soil, initial effective saturation of the soil, and soil type on steady infiltration rate.

Depending on the soil texture and the initial soil water condition, the necessary measurement time of the test may be undesirably long. In order to reduce the time consuming and tedious procedure of the measurement, continuous efforts have been previously done to automate the test process. One of the earliest works was done by Constantz and Murphy (1987). They utilized a single pressure transducer to develop an automated Mariotte reservoir that enabled automatic recording of water flow for constant head DRI test. Their infiltrometer was far from being automated as their method required manual water level control in both inner and outer rings. Their set-up was later modified by Ankeny et al. (1988) for use as a "tension infiltrometer." Tension

* Corresponding author.
E-mail addresses: mfatehnia@fsu.edu (M. Fatehnia), paran@caps.fsu.edu (S. Paran), kish@gly.fsu.edu (S. Kish), tawfiq@eng.fsu.edu (K. Tawfiq).

http://dx.doi.org/10.1016/j.geoderma.2015.08.022
0016-7061/Published by Elsevier B.V.

infiltrometers, can be used to measure the unsaturated hydraulic conductivity of the soils (Fatehnia et al., 2014). Matula and Dirksen (1989) developed a semi-automatic system for constant head DRI test that regulated water applications to ring infiltrometers within ± 1 ml. Their double ring was composed of a water level sensing device, a water supply device, and a time registration with an electronic stopwatch. The water level in the outer ring was regulated adequately with a carburetor float and the water level in the inner ring was controlled through an arrangement of a float and photosensitive transistor working with a LED. The automated constant head and self-regulating single ring infiltrometer set-up described by Prieksat et al. (1992) was based on the work of Constantz and Murphy (1987) and Ankeny et al. (1988). Their set-up used pressure transducers for determining water flow out of Mariotte reservoir, adopted data-logger for recording the data, and used a bubble tube to regulate the height of water ponded above the soil to ± 1 mm. To improve the precision of water flow measurement, flow rates were calculated from changes in water height in a Mariotte reservoir with time using the difference in pressure between two pressure transducers, one at the top of the Mariotte reservoir and one at the base (Ankeny et al., 1988). The infrared water level distance measurement sensor system utilized by Milla and Kish (2006) could be used for both falling and constant head DRI tests by mounting on either the rings or the Mariotte reservoir, respectively. Their system included an infrared distance-measuring sensor and microcontroller that was programmed to collect water level measurements at various time intervals. Sensor measurements and a time stamp were stored to EEPROM and transferred to a desk or a laptop computer following fieldwork. In semiautomatic constant head single ring infiltrometer set-up of Lazarovitch et al. (2007), flow through low-pressure two-way electric solenoid was measured via continuous weighing of a water reservoir using a suspended s-type load cell. The flow information was also monitored and controlled by a laptop computer, which also automatically calculated the soil hydraulic properties from collected data. When the flow reached a steady state, measurements were terminated. Arriaga et al. (2010) developed a simple DRI for automated data collection under falling head conditions by utilizing a small pressure transducer that was connected to the data-logger via a terminal board. Their system was not fully automated and the operator had to concentrate on maintaining the water levels similar in both inner and outer rings and refill them as necessary. Ong et al. (2012), revised the work of Maheshwari (1996) by using a combination of pressure transducers, microcontroller, and open-source electronics. They created a system that could be used for both constant and falling head systems. Their system removed the need for Mariotte tubes, automated the water delivery and data recording, and gave the user the option of choosing DRI water supply system to be either pressurized, pump, or gravity fed. An LCD screen enabled user interface and observation of data for quality analysis while doing the test.

2. Description of apparatus

In this research, we developed a low cost fully automated DRI using an Arduino microcontroller, a Hall effect sensor, a peristaltic pump, a water level sensor, and a constant-level float valve that can be used for both constant and falling head systems in both double and single ring infiltrometers. Arduino is a widely used open-source single-board microcontroller development platform that has flexible, easy-to-use hardware and software components (Ferdoush and Li, 2014). In the current set-up, an Arduino is used for interfacing with sensors and as a data-logger. Although Arduino has been applied several times by hydrologists and environmentalists for interfacing with sensors (Hicks et al., 2012; Kruger et al., 2011; Queloz et al., 2013), its application in DRI automation is totally new (Ong et al., 2012; Fatehnia, 2015). Various electrical and mechanical equipment applied in the current design, as depicted in Fig. 1, are explained in this following section.

2.1. Arduino

In this set-up, interfacing with the water level sensor, Hall effect sensor, peristaltic pump, and also storing the water flow data in real-time on a micro-SD card was done via the Arduino microcontroller. The Arduino is an open-source hardware platform designed around an 8-bit Atmel AVR microcontroller, or a 32-bit Atmel ARM with a clock speed of 16 MHz. Arduino has a USB interface, 14 digital I/O pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz ceramic resonator, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller. The microcontroller can be powered by a laptop with a USB cable or by an AC-to-DC adapter or 6–20 V battery. Arduino-compatible custom sensor expansion boards, known as shields, can be developed to directly plug into the standardized pin-headers of the Arduino board. They enable Arduino to connect to several sensors (Ferdoush and Li, 2014; Hut, 2013).

The Arduino motor shield was stacked to the Arduino board in order to communicate with the peristaltic pump. The Adafruit motor shield has the TB6612 MOSFET driver with a current capacity of 1.2 A per channel and 3 A peak current. The motor shield was used to drive the peristaltic pump system. It has a fully-dedicated PWM driver chip onboard that handles all the motor and speed controls over I2C.

An Arduino data-logging shield was also used to have a real time record of the water flow on a micro-SD card. This eliminated the need for using a laptop computer in the field while the data could be used later for retrieval and could be easily imported into conventional processing and plotting software like Excel. The applied Adafruit data-logging shield has a real time clock (RTC) with a battery backup that keeps the time even when the Arduino is not being supplied with power. It also has an on-board 3.3 v regulator that works as a reference voltage for the microcontroller and AD converters and at the same time, supplies power to activate the SD memory card.

2.2. Peristaltic pump

To pump water from the reservoir into the inner ring, a peristaltic pump was used. Peristaltic pumps are a type of positive displacement pumps. They move fluid by using a set of rollers fixed to a motor shaft to force fluids through a flexible tube. This procedure allows precise "metering" of fluid flow through the pump (Hamidi et al., 2013). By counting the number of rotations of the pump roller system it is possible to precisely determine the volume of water passing through the pump. In these pumps, the fluid is contained within a flexible tube fitted inside a circular pump casing. In the casing, a rotor with a number of rollers and shoes attached to the external circumference of the rotor compresses the flexible tube. By each turn of the rotor, the part of the tube under compression is pinched thus forces the fluid to be pumped to move through the tube (Latham, 1966). The pump provides highly accurate, metered volumes of fluid per cycle that is independent of the water supply hydraulic head.

2.3. Hall effect sensor

Hall effect sensors can be used for proximity switching, positioning, speed detection, and current sensing applications. To measure the sequential pumped volume of the water that supplied the inner ring and represented the infiltration rate of the soil material, a Hall effect sensor was utilized. A Hall effect sensor is a transducer whose output voltage varies in response to a magnetic field (Ramsden, 2006). Fig. 2 shows the Hall effect sensor used for flow measurement in series with a resistor and attached to the backside of the peristaltic pump. In order to provide the magnetic field variations for sensor performance, two small rare earth magnets were attached to the pump rotor with opposite poles. Readings of the sensor was calibrated in the laboratory by