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Design, fabrication and testing of a low cost Trunk Diameter Variation (TDV) measurement system based on an ATmega 328/P microcontroller

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ABSTRACT

A fast-responding inexpensive dendrometer is needed for measuring daily or hourly plant growth responses to water stress. This study reports on a low-cost microcontroller driven Trunk Diameter Variations (TDV) measurement system that was designed and constructed for automating the measurement and recording of plant stem diameter. The TDV system comprises of an ATmega 328/P microcontroller, which forms the heart of the controlling circuit, a real time clock for time stamping measurements, liquid crystal display for displaying purposes and an external secure digital card and shield for storing measured data. The stem diameter variations are measured by a caliper-type sensor based on a full bridge strain gauge that is attached to a flexible arm of mild steel. When bearing bending strain, the excited full bridge strain gauge outputs a voltage directly proportional to the bending strain, hence linear displacement. The TDV sensor displacement calibration procedure was carried out using an inside micrometer from a calibration kit. The calibration of the sensor indicated a linear relationship between the displacement and the sensor's output voltage with a high coefficient of determination value of 0.998, calibration multiplier of 0.426 mm V^{-1} and an offset output voltage of 0.688 V. The TDV sensor was mounted on a smooth cylindrical dried wood away from direct sunlight and rain while air temperature was measured close to the TDV installation. Temperature sensitivity test results show that the accuracy of the sensor above 20 °C is 0.031 mm and for temperatures below 20 °C the accuracy is above 0.050 mm. The TDV system was tested on a tomato plant for 42 days, Fountain tree for three weeks and on a Citrus tree for one week under greenhouse and open-field conditions in order to evaluate its performance and suitability under different plant species and climatic conditions. The TDV system proved to be robust and produced valid results on the plant's physiological measurements, with a good storage of the measured data over the experimental period. We concluded that the TDV system is suitable for stem diameter variations measurements and water and fertilizer stress monitoring on herbaceous and woody stem plants due to its fast response (hourly or less), ease of construction and installation, and low cost (< US$60).

1. Introduction

Water scarcity is now a major threat to the agricultural sector in the world. This is because production of crops in greenhouses and open fields are now dependent on irrigation water to produce a viable crop. Water shortages are being driven by so many factors including growing populations, expanding cities (Touati et al., 2013), high production costs, recurrent droughts and climate change (Goumopoulos et al., 2014) induced low rainfall. Sound water saving agricultural practices that increase water productivity during growing seasons are now a priority to ensure the long term stability of the agricultural industry (de la Rosa et al., 2013). Monitoring plant water status is one way of optimizing the use of irrigation water. This approach utilizes measurements of some property of the crop that responds to water stress (Jones, 2004), so that irrigation will be carried out according to the actual plant needs (Patakas et al., 2005). Possible plant-based indicators which show good prospects for determining plant water requirements are trunk diameter variations (TDVs) or dendrometry (de la Rosa et al., 2013; Fernández, 2014). All plant stems or trunks indicate daily cycles of expansion and contraction which is referred to as trunk diameter variations. In order to schedule irrigation using TDVs, various useful indices are derived from TDV measurement records with maximum daily shrinkage (MDS) and stem/trunk growth rate (TGR) among the leading useful indices (Moriana et al., 2011). In order to accurately measure, trunk/stem diameter variations, dendrometers are used. Dendrometers can be classified into two categories: contact and non-contact. Contact dendrometers obtain measurements by physical contact of the stem/trunk of the plant, whereas non-contact dendrometers

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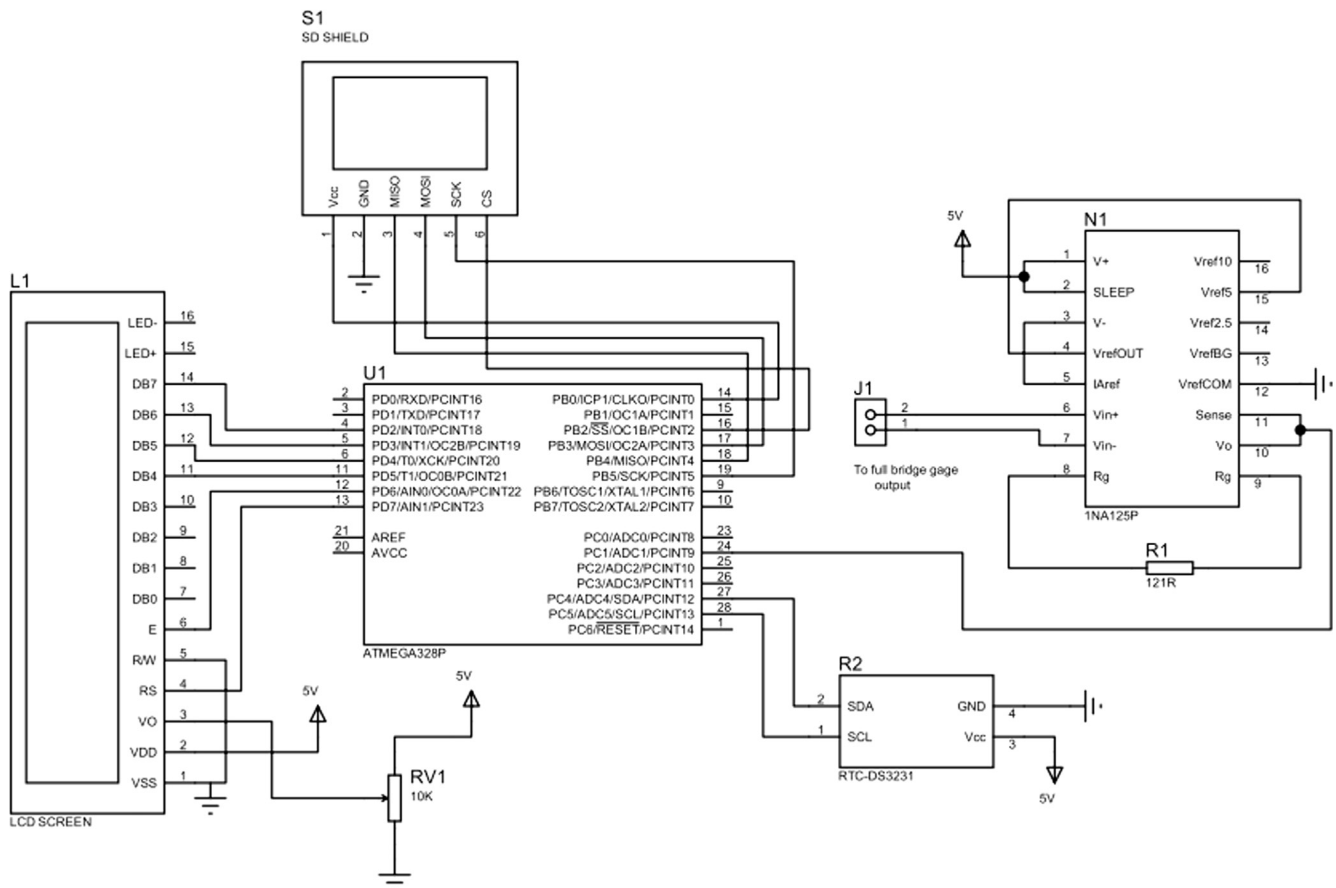

Fig. 1. TDV system control circuit schematic.

obtain measurements remotely (Clark et al., 2000; Wang and Sammis, 2008; De Belder, 2015). Contact dendrometers include conventional calipers, diameter tapes, electronic tree measuring fork (ETMF), Biltmore stick, sector fork and Samoan stick. Caliper and diameter tapes measure the diameter of plant stems/trunks assuming a circular model (shape of stems/trunks are circular). Deviation from an assumed circle will cause a positive bias and present an unpredictable directional variation in taped and caliper measurements respectively. The ETMF trunk/stem diameter measurements are affected by signal interference which is caused by bark characteristics of certain plant species. The Biltmore stick, sector fork and Samoan stick are very easy to use but their reliability and dependability prevent their use in scientific work. Optical dendrometers are the most common non-contact dendrometers. These use two lines of sight between the observation location and two tangents on the plant stem/trunk lying in the plane marking the diameter. Geometry is then utilized to compute the diameter of the plant stem/trunk (Clark et al., 2000). Most dendrometers, with the exception of automated dendrometers have a slow response and there are suitable for measuring plant growth on monthly or yearly basis. To monitor plant growth responses on daily or hourly cycles, fast-responding electronic dendrometers are required and in order to have representative measurements, at least two dendrometer sensors per branch must be mounted and replicated three to four times. The minimum cost of measuring four trees, four branches per tree, with two dendrometers per branch using commercially available fast-responding dendrometers is US $20,800 (Wang and Sammis, 2008). These high costs limit the applicability of dendrometers to improve water use efficiency in commercial orchards and open fields (Fernández, 2014), hence there is strong need for low-cost automated dendrometry equipment. One type of a precise electronic dendrometer contains a full bridge strain gauge that is attached to a flexible arm. The strain gauge electrical resistance varies in accordance with the amount of strain applied (Ortuño et al., 2010) and this property is used to measure linear displacement. Once installed on a plant, a dendrometer is connected to a programmed data logger which automatically executes scanning and storage of the dendrometer's output signals at prescribed time intervals (Fernández and Cuevas, 2010). Most advanced logging systems for dendrometry use programmable logic controllers (PLCs) which are the most ideal controllers, but these have been found to be very expensive and complicated to use. An alternative to PLCs which show good prospects are low cost Atmel picoPower ATmega 328/P microcontrollers. ATmega 328/P is a complimentary metal-oxide semiconductor (CMOS) 8-bit microcontroller with a low rated power consumption. A microcontroller has a small working memory (Garcia-Breijo et al., 2011) and storage capacity but can be used to build portable dataloggers which record and store measured data over long periods of time. These microcontrollers use an external nonvolatile memory card such as a secure digital (SD) card to record and store measured data as comma-separated values (CSV), which are easy to use and analyze with many computer applications. A real time clock (RTC) is often connected to the microcontroller to provide accurate timestamps to the measured data.

The aim of this study was to design, fabricate, calibrate and test an inexpensive dendrometry system controlled by a microcontroller and using a caliper-style Trunk Diameter Variation (TDV) sensor for measurements. Included in the design criteria were automated measurements, data collection and storage, low cost, ease of manufacture and reliable performance.

2. Description of the TDV (Trunk Diameter Variation) system

A circuit was designed to automate measurements and record plant stem diameter variations (dendrometry). The circuit is based on a