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# A wireless device for continuous frond elongation measurement

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ABSTRACT

Growth rate is one of the indicators for a plant's physiological condition. Date palms are characterized by high frond elongation rates, which are mainly subjected to drought and salinity stresses. Thus, continuous measurement of these rates can provide real-time growth information, for assessing water status within the soil-plant-atmosphere continuum of cultivated date palms. This study introduces a novel device, the Palmeter, which continuously measures real-time date palm frond elongation. The Palmeter was calibrated in the laboratory and tested in a date palm orchard with a measurement resolution of 0.52 mm. A field test indicated that the Palmeter could wirelessly transmit acquired data to a signal receiver over a distance of 100 m with a success rate of more than 98%, facilitating the establishment of wireless sensor networks in date palm orchards. Neither temperature nor wind affected the Palmeter measurement within the orchard. The temporal patterns of the frond elongation measured by the Palmeter were found to be sensitive to various cultivation treatments, such as fruit load regimes, applied within a field study. Additionally, a six-volt power supply is recommended in order to reduce the Palmeter's power consumption. The feasibility and robustness of the Palmeter system guaranteed the accurate measurement of the frond elongation under harsh field conditions. Therefore, the Palmeter can be potentially applied to measure the frond elongation of date palms and perhaps other palms, such as oil palms and coconut palms, for irrigation scheduling and cultivation management in large orchards.

## 1. Introduction

Crop growth is a multi-level process, ranging from the cellular to the whole-plant level (Wuyts et al., 2015). For the purposes of crop cultivation and management in commercial fields, much attention has been paid to growth at the macroscopic level, such as canopy height (Allen and Pereira, 2009), stem diameter variation (Intrigliolo and Castel, 2006), leaf expansion (Neumann et al., 1988) and frond elongation (Tripler et al., 2011). The growth rate of a crop is subject to external environmental conditions, including both soil and atmospheric conditions. The occurrences of abiotic stresses, such as drought (Jaleel et al., 2009), salinity (Munns and Termaat, 1986) and extreme temperatures (Luo, 2011), adversely alter crop growth status. Crop development can be regarded as an integrated physiological response to the plant environment. Thus, measuring crop growth rate is an effective way to investigate the plant status under changing environmental conditions. Plant growth characteristics vary primarily depending on the species (Suk et al., 2011). Measuring certain aspects of crop growth with relatively high sensitivities to external environmental changes is beneficial for providing decision-making support for crop cultivation and management. For example, continuous shoot growth measurements of corn and de-fruited grapevines were conducted in order to support irrigation scheduling as shoot growth rates were affected by soil water status (Silva and Kay, 1996; Hardie and Martin, 2000). In addition, the trunk growth rates of peach and olive trees were investigated and continuously measured to aid irrigation scheduling as they were strongly correlated with stem water potential (Goldhamer et al., 1999; Pérez-López et al., 2008).

Crop growth rate measurements require proper devices with adequate accuracy. Continuous measurement of crop growth rates facilitates investigation into growth by providing sufficient information. However, intermittent measurement conducted by manually reading is laborious and does not provide detailed daily crop growth patterns due to insufficient growth information. Given the heterogeneity of field crop conditions, a suitable number of devices should be deployed in the field for an optimal representation of the measurements (Jones, 2004). The deployment of devices

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in the field needs to take into account costs, determined through device placement and data collection methods (Xu et al., 2005). Thus, representative measurements and economic considerations necessitate the use of wireless sensor networks in the field, requiring the device to possess wireless transmission capabilities. Currently, wireless sensor networks are used in agricultural practice for field information acquisition, which not only easily provides real-time soil, crop and atmosphere information but also substantially reduces the measurement costs (Bogena et al., 2010; Garcia-Sanchez et al., 2011; Yawut and Kilaso, 2011; Gutierrez et al., 2014). Other concerns regarding the device properties are operational stability and wireless transmission reliability under field conditions. Operational instability interferes with measurement accuracy. Low wireless transmission reliability results in data loss, possibly leading to incorrect decision-making due to insufficient measurement information. On the other hand, high robustness of a wireless sensor network device and a high success rate of wireless data transmission guarantee normal measurements. In addition, wireless sensor networks in the field are usually powered by batteries charged by solar panels. Low power consumption of the device is desired in order to extend its operational duration and to reduce the costs of the power supply (Rault et al., 2014).

In the Central Arava Valley, a hyper-arid region in Israel, the cultivation of date palm trees is widespread and largely relies on irrigation (Tripler et al., 2011). Date palm trees were reported to have high daily frond elongation under suitable cultivation conditions (Aldrich et al., 1946; Tripler et al., 2011). The frond elongation of date palm in this region was also measured by local farmers and researchers in an attempt to investigate date palm growth status in order to support irrigation management decision-making (Tripler et al., 2011; Sperling et al., 2014). Measuring date palm frond elongation is conducted by using a ruler tape. The youngest frond is selected for measurement when it is elongated straight upwards; a thread from a ruler tape is attached to the frond base with a screw. Once the frond elongates obliquely outwards, the thread is shifted manually to a new frond, without affecting the frond elongation rate. This ruler tape measurement method has a resolution of 1 mm, while requiring frequent, time-consuming manual readings.

At present, the Arduino board (Arduino CC, Italy) has gained popularity as a microcontroller in electronic devices thanks to its high compatibility and low cost (Ferdoush and Li, 2014). It is able to receive inputs by controlling various digital and analog sensors. The rotary encoder, a digital sensor utilized in many applications requiring precise unlimited spindle rotation (Ellin and Dolsak, 2008), can be easily controlled by an Arduino board. In order to meet the demand of wireless transmission, the Arduino board is usually coupled with a radio frequency module, such as the Xbee module, which is based on the IEEE 802.15.4 standard, designed for wireless point-to-point and star communications (Piyare and Lee, 2013).

Based on the analysis above, it is necessary to develop a device with high accuracy and wireless transmission capability for date palm frond elongation measurement. The objectives of the present study were to assemble a device using a rotary encoder controlled by an Arduino board, in combination with an Xbee module, for the continuous measurement of date palm frond elongation, and to test the characteristics of the assembled device, such as working stability, wireless transmission capability and power consumption.

## 2. Materials and methods

### 2.1. The rotary encoder

The rotary encoder (1/4 inch, 24 pulses, EVE-GC2F2524M encoder, Panasonic Corp, Japan) is a mechanical electrical unit, incorporating three digital pins and one infinitely rotatable spindle (Fig. 1A). These digital pins consist of two signal pins (pinA and pinB) and one ground pin (pinG). Each signal pin has two states, 1 and 0, in the work mode with the square signal wave (Fig. 1B). The signal from pinA is exactly 90 degrees out of phase from that

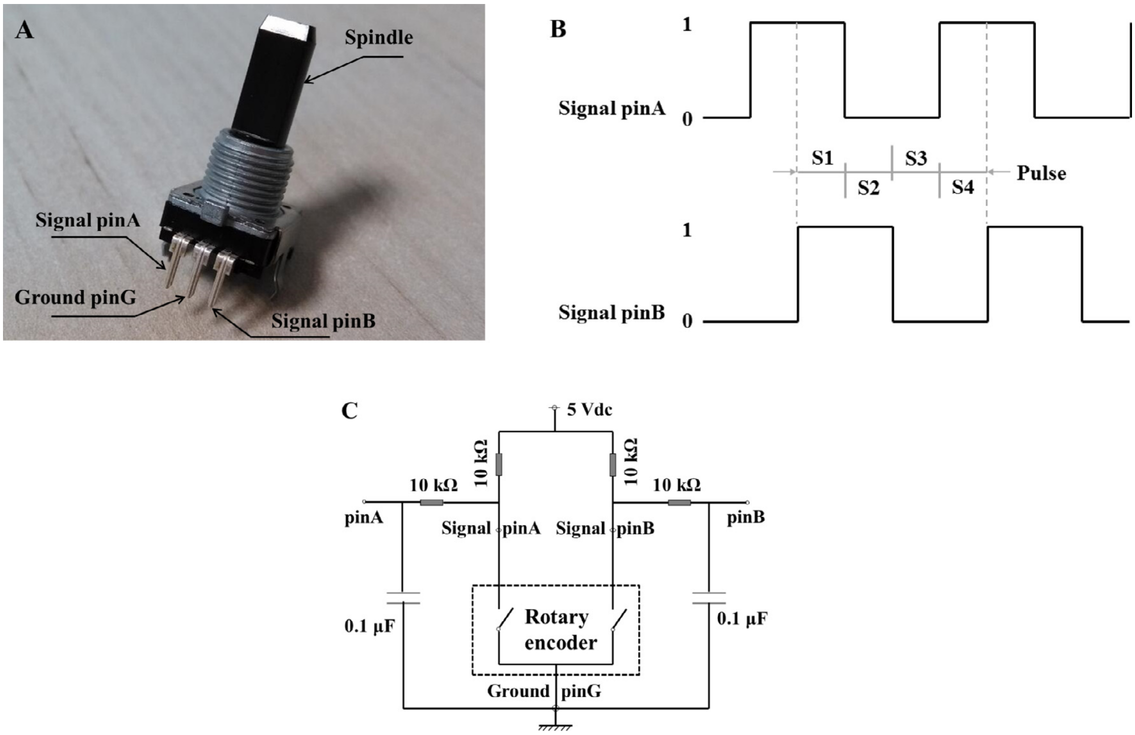

**Fig. 1.** Graphical illustration of the rotary encoder (A), the rotary encoder working principle (B) based on the state (1 or 0) combination of two signal pins (S1, S2, S3 and S4 indicate different signal state patterns) and the operation circuit of the rotary encoder (C).