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Application note

A new optoelectronic sensor for monitoring fruit or stem radial growth

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ABSTRACT

A new device for continuous measurement of fruit or stem growth on the basis of an optoelectronic reflex sensor and a microcontroller board was developed and successfully tested under open field conditions.

The principle of the system is based on the detection of alternating narrow white and blacks bars printed on a flexible tape, which is tightened as a loop around the measured object and slides under an infrared reflex sensor in response to the object's radial growth.

The design of this new sensor allows continuous, long term measurements without the need of periodic maintenance or physical adjustments of the measurement device.

The new system measures changes of fruit or stem perimeter rather than diameter, thus yielding a more relevant information about the growth of objects which are intrinsically not of perfectly circular cross-sectional shape. The described sensor is very lightweight and does not require any mechanical frame or support structure. The tested prototypes had a measurement resolution of 0.5 mm of perimeter, corresponding to a resolution of about 0.16 mm of diameter for a spherical object. The cost of the sensor is very modest, as it consists of only few and inexpensive components.

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1. Introduction

Growth dynamics are an important aspect in numerous plant studies, both for horticultural crops and natural ecosystems. Radial increments of trunks or branches are widely used indicators of plant vigour, whereas fruit growth constitutes a fundamental physiological parameter in horticultural production (Opara, 2010). The dynamics of fruit growth depend on the plant's genetic potential (variety, clone, rootstock), its physiological condition (e.g. crop load, health status), as well as on environmental factors such as light conditions, atmospheric evaporative demand and supply of water and nutrients. The role of some of the factors affecting fruit development has been reviewed by Corelli-Grappadelli and Lakso (2002) for deciduous tree crops, by Iglesias et al. (2007) for citrus, by Léchaudel and Joas (2007) for mango and by Bower and Cutting (1988) for avocado.

Monitoring fruit growth is therefore essential for interpreting the effects of environmental conditions or agronomic practices on the productivity of fruit crops. Similarly, the radial increase of trunks or stems constitutes a valuable parameter for understanding plants' growth responses to changing environmental conditions (Drew and Downes, 2009), including the potential assessment of tree water stress (Fernández et al., 2011).

A variety of methods is available for the measurement of fruit or stem size, ranging from manual instruments such as measuring tapes or calipers to fully automated systems. These latter rely frequently on the use of linear variable differential transformers (LVDTs). As an alternative to LVDT's, strain gauges (Beedlow et al., 1986; Link et al., 1998) or linear potentiometers (Morandi et al., 2007) have been proposed. Commercial sensors are available for each of these techniques. Although, upon proper calibration and temperature compensation, their accuracy and resolution allows measurements down to a range of less than 10 µm, their use has remained largely confined to scientific applications because of their considerable costs. These sensors require moreover support frames, which in the case of fruit measurements need to be attached to the tree canopy so that they don't burden the fruit with their weight. A further limitation of most commercially available systems is their restricted range of sensor displacement, requiring regular physical adjustments of the frame during long-term measurements.

This study describes a new method for monitoring the radial growth of fruits or stems, based on a low-cost optoelectronic sensor, which is suitable for long term monitoring without the need for regular maintenance or adjustments, therefore overcoming some of the above mentioned constraints. Details are given about the operating principles of the new sensor and results of laboratory and field tests are provided.

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2. Materials and methods

The measuring system consists of two basic elements: a narrow flexible tape with a pattern of white and black bars and an optoelectronic sensing unit consisting of an infrared reflex sensor with transistor output. The sensor used in this work is the reflective sensor Vishay CNY70 (Vishay Semiconductor Gmbh, Heilbronn, Germany), which integrates an infrared LED and a phototransistor into a compact, single housing (Fig. 1, left).

With its light source and detector arranged in the same direction, the device can sense the reflective IR beam from nearby objects. The sensor has an operating wavelength of 950 nm and is insensitive to visible light due to an incorporated daylight filter.

The transfer efficiency of optocouplers can be affected to some degree by ambient temperature and aging (operating time). Transfer efficiency is expressed by the current transfer ratio (CTR), which is the ratio of the collector current to the forward current. The datasheet of the Vishay CNY70 optocoupler (Vishay Semiconductor, 2009) displays the variation of the CTR with temperature, reporting a range from 0.90 at −20 °C to 1.03 at 45 °C, relative to its CTR at 25 °C. The reduction of the collector current as result of aging is quantified as less than 10% in 10,000 h of operation for currents under 40 mA (Vishay Semiconductor, 2002). These effects of temperature variation and/or aging on the output signal of the optocoupler are modest in comparison to the amplitude of variation of the collector current achieved by the alternation of the black and white bars of the reflective tape and therefore don't compromise the functionality of the system.

The purposely designed flexible tape with a narrow pattern of parallel black and white bars acts as the reflecting medium for the sensor (Fig. 2). The width of the black and white bars determines the resolution of measurement. Tapes with 0.5 mm wide bars were used in this work.

The cost of the CNY70 is of about 0.8 € and the total material cost of the sensor assembly, including the reflective tape, does not exceed 1 €. As for the data acquisition system, there are various options, ranging from low-cost microcontroller applications to high-end commercial dataloggers. The implementation of low-cost data acquisition systems has been described by various authors (Fisher, 2007; Fisher and Gould, 2012; Fisher and Kebede, 2010; Thalheimer, 2013), which also report details about the costs of the required components.

The principle of operation of the system consists in positioning the tape as a loop around the object of measurement. The loop holder consists of the reflective sensor itself and a U-shaped plastic strip attached on top of its sensing side, leaving a narrow slit between the strip and the sensor (Fig. 1, right). The tape is inserted into this slit with the bar pattern facing towards the sensor. As the object of measurement grows, the tape is forced to slide through the loop holder and the resultant alternation of white and black bars is detected by the optoelectronic components and translated into counts by an appropriately programmed microcontroller.

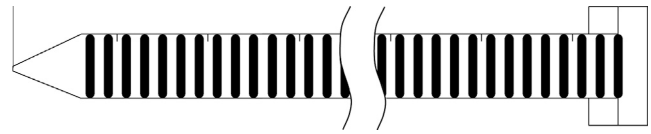

Fig. 2. Flexible tape with pattern of black and white bars for the detection of movement by the optoelectronic reflex sensor.

To enable the sensor to detect the black and white bars, its field of view is restricted to approximately the same width of the bars. This is achieved by gluing two small rubber pads onto its sensing side, such as to leave only a narrow central gap (Fig. 1, centre).

The microcontroller is programmed to activate the sensor at regular intervals and to measure the intensity of reflected radiation. The gradual movement of the white and black bars in front of the sensor creates a sinusoidal wave output. The software of the microcontroller assigns a state of LOW or HIGH to the sensor output, according to predefined threshold values, thus reflecting the changes of black and white bars. Two distinct thresholds are defined, one for the transition from LOW to HIGH and one for the transition from HIGH to LOW, so that the resulting hysteresis permits the unambiguous detection of changes between the two states (Fig. 3).

The determination of the appropriate threshold values is therefore essential for the reliable functioning of the system. The threshold values can vary from sensor to sensor due to slight individual differences in their assembly.

The microcontroller is programmed to add each revealed change of state to a counter variable and to save its value at regular intervals over time. In the present work the microcontroller board used was an Atmel Atmega 328P-PU configured for the Arduino integrated development environment, with peripheral components for power supply and serial data transmission, an external EEPROM for data storage and a real time clock (RTC) with alarm function for enabling the power saving sleep mode between successive measurements. This configuration allows long term monitoring of growth with very low energy consumption. Only two resistors are required for interfacing a CNY70 sensor to a microcontroller. A schematic of the sensing circuit is presented in Fig. 4.

The flexible tape, which slides under the sensor as a result of fruit or stem growth, was produced by printing a bar pattern with a laser printer on sheets of glossy, white polyester film (Folex BG 72WO, 0.125 mm thickness) and cutting tapes of approximately 7 mm width. One end of the tape has a wider part which serves

Fig. 1. CNY70 optoelectronic reflex sensor in its original form (left), with the rubber pads (centre) and with the U-shaped plastic strip acting as loop holder (right).

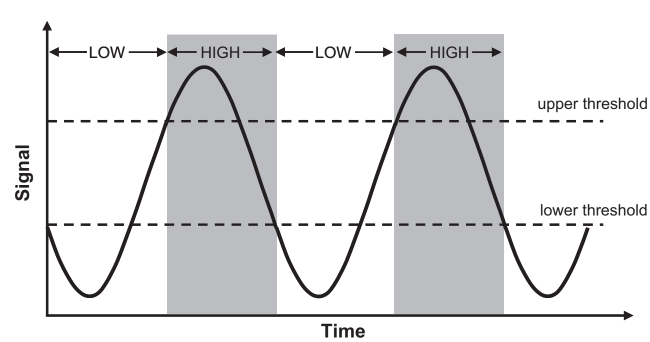

Fig. 3. Ideal output pattern of the optoelectronic sensing device and corresponding logic states (white or grey background) assigned by the microcontroller according to the chosen upper and lower thresholds, assuming continuous measurement and constant movement of the reflective tape.

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