Low-cost standalone multi-sensor thermometer for long time measurements

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Abstract. We present a portable device for long-time recording of the temperature at multiple measuring points. Thermocouple wires are utilized as the sensors attached to the objects. To minimize the production cost, the measured voltage signals are relayed via a multiplexer to a set of amplifiers and finally to a single microcontroller. The observed temperature and the corresponding date and time, obtained from a real-time clock circuit, are recorded in a memory card for further analysis. The device is powered by a rechargeable battery and placed in a rainproof container, thus it can operate under outdoor conditions. A demonstration of the device usage in a mandarin orange cultivation field of the Royal project, located in the northern Thailand, is illustrated.

1. Introduction

Temperature measurement and control play crucial roles in agriculture during cultivation as well as postharvest [1,2]. In fruit industry, an unusual high temperature of the fruit surface exposed to strong sunlight during cultivation can cause thermal death of the epidermal cells that degrades the fruit quality and annually economic loss of million dollars for the case of apples [3]. The surface temperature can be reduced by coating the fruit surface [4].

Temperature can be measured using thermometers based on various techniques including platinum resistance, liquid in glass, thermocouple, and radiation [5]. The thermocouple thermometry is one of the most widely used methods due to its low cost, high temperature limits, wide temperature ranges as well as the possibility to cooperate it into an automatic system for schedule observations [6-8]

In this paper, we present a design of the hardware interface circuit of many thermocouple wires and a microcontroller. It mainly consists of four modules: a temperature signal acquisition and conversion module, a microcontroller module, a data storage module and a display module. The thermometer is calibrated with a commercial digital thermometer with 0.1°C resolution in a range of temperature of 10 to 50°C. It is built to use for long time in outdoor conditions.

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2. Multi-sensor thermometer

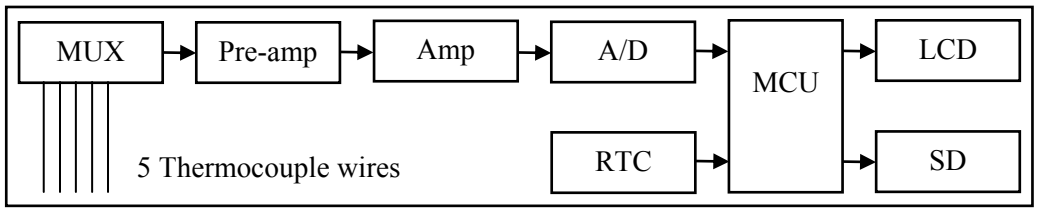

Figure 1. Schematic of multi-sensor thermometer

The circuit diagram of multi thermometer is shown in figure 1. Very weak electrical signals in an order of microvolts from multi thermocouple wires are sequentially relayed via an external CMOS analog multiplexer (MUX) to a pre-amplifier (Pre-amp) where the signals are improved to 10mV/°C. Then, the signals are further amplified (Amp) and converted (A/D) to digital signals with a resolution of 10 bits (1024 digital levels) corresponding to the signals of 0 - 5 volts. The microcontroller (MCU) calculates the temperatures using the digital signals and the calibration function and simultaneously reads the date and time from the real time clock circuit (RTC). The observed temperatures and the corresponding date and time, are recorded to a memory card (SD) for further analysis and also displayed on a flat monitor (LCD). The device is designed for low-power consumption so that it can be powered by a 12-volt rechargeable battery.

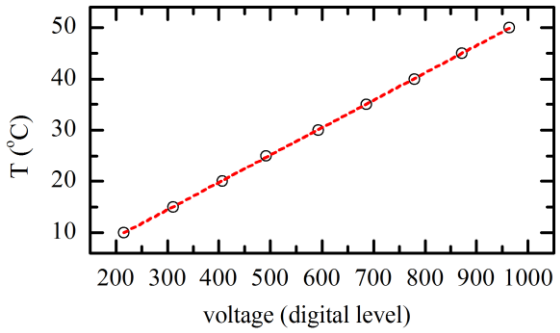

Figure 2. Example of the calibration curve of a thermocouple wire. Circles depict the reference temperature vs the digitized voltage with 10-bit resolution while and the dashed line is a linear fit of the data.

The calibration of the temperature and the digital level of the voltage read by the microcontroller is performed for individual thermocouple wires immersed in a thermostating water bath (PolyScience) and the temperature from a commercial thermocouple (FLUKE) with a resolution of 0.1°C is used as the reference. For all of thermocouple wires, the digital level of the voltage (read by the microcontroller) increases linearly with the reference temperature in the tested range of 10 – 50°C, e.g., as in figure 2. The R-squared value of the linear fit is about 0.9998.

3. Outdoor usage

The portable multi-sensor thermometer is utilized for long-time recording of the temperature in the mandarin orange cultivation field of the Royal project, located in the northern Thailand. One of the objectives of the project is to study the effect of surface temperature on the growth and quality of the mandarin orange so that the temperature is continually recorded in an interval of a few months.

To operate it under outdoor conditions, the thermometer is placed in a rainproof container which fixed on a stand with a height of one meter, as shown in figure 3. The thermocouple wires are attached

on mandarin oranges by using a thin sheet of glue paper. All observed oranges are located at different positions on the tree, i.e., some oranges are exposed directly to the sunlight while the others are under the shadow.

Figure 3. Example of the multi-sensor thermometer used in a mandarin orange cultivation field of the Royal project, located in the northern Thailand. The device is set in a rainproof container (the white box) fixed on a stand with 1 m height. The Inset shows a thermocouple wire attached on the surface of an orange.

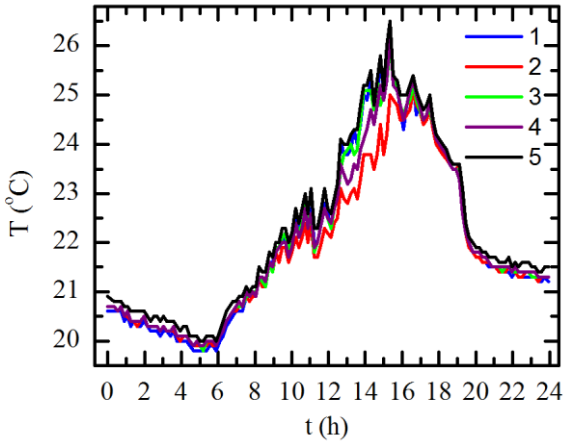

Figure 4. Example of the surface temperatures of five mandarin oranges recorded by the multi-sensor thermometer. The graph shows the data during 24 h starting at the midnight.

Figure 4 illustrates an example of the temperatures at five different points recorded in the memory card every 10 mins for an interval of 24 hours at 18th July, 2015. Starting from the midnight, the temperature, ranging between 20.6 - 20.9°C depending on the measuring points, gradually decreases to a minimum of 19.8-20.0°C at 6:00 am around the sunrise. Then the temperature increases with fluctuation to a peak of 25.0-26.5°C at 3:20 pm. Subsequently, it gradually decreases to 24.0-24.2°C at 6:00 pm. After the sunset, the temperature rapidly dropped to 21.7-21.9°C at 8:00 pm. before it gradually decreases to 21.3 - 21.5°C at the midnight.

Fruits those exposed directly to strong sunlight have a higher surface temperature (e.g. curves 1, 3, 4, and 5 in figure 4) which degrades the fruit quality. The details of the long-term temperature

observation and a reduction of the surface temperature to improve the fruit quality by coating the fruits with kaolin clay are reported in [4].

4. Discussion and Conclusion

We have presented a portable multi-sensor thermometer for long-time recording and demonstrated its outdoor usage in a mandarin orange cultivation field of the Royal project, located in the northern Thailand. The results show that this device is an appropriate tool for continued observation of the surface temperature of the fruits during the cultivation field since it automatically measures and records the temperature for further analysis. We expect that the portable device is also useful for temperature observation in other applications, especially, where an investigation of a long-term effect of the temperature is required.

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