Computers and Electronics in Agriculture 152 (2018) 302–313

Contents lists available at ScienceDirect

Computers and Electronics in Agriculture

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

Original papers

# SeeFruits: Design and evaluation of a cloud-based ultra-portable NIRS system for sweet cherry quality detection

Tao Wang[a], Jian Chen[a], Yangyang Fan[a], Zhengjun Qiu[a,b,*], Yong He[a,b]

[a] College of Biosystems Engineering and Food Science, Zhejiang University, Hangzhou 310058, China
[b] Key Laboratory of Spectroscopy Sensing, Ministry of Agriculture, Hangzhou 310058, China

ARTICLE INFO

*Keywords:*
NIRS
Total soluble solids
Maturity level
Internet of things
Cloud computing

ABSTRACT

Recent researches have shown that spectroscopy is a valid non-destructive technique for fruit quality detection. Yet the high cost, large volume, and complicated operation of the traditional spectral system makes it hard to be adapted to real field applications. In this paper, a low-cost, cloud-based portable Near Infrared (NIR) system called 'SeeFruits' was designed for fruit quality detection. The system was developed based on two integrated modules, DLP® NIRscan Nano EVM and ESP12-F. Main structures of hardware and software as well as the operation and workflow of the system were described in detail. A total of 240 sweet cherries were chosen as our fruit samples in order to evaluate the performance of 'SeeFruits'. By targeting maturity level as a qualitative index and total soluble solids content as a quantitative index, we compared the results between 'SeeFruits' and a benchtop NIR-hyperspectral imaging system. The 'SeeFruits' system achieved F1-score of 0.89 on qualitative task and $R^2$ of 0.83 on quantitative task. Overall, with the features of ultra-portability, cloud computing and Internet of things feasibility, 'SeeFruits' can provide a fast, flexible and friendly application for sweet cherry quality detection to nonprofessionals with satisfactory accuracy.

## 1. Introduction

Sweet cherry is considered one of the most popular fruits by Chinese consumers for its appearance, balanced taste between sweet and sour, and high nutritional value. There are many indices indicating the quality of sweet cherries, such as skin and stem color, total soluble solids (TSS) content, titratable acidity (TA), and firmness (Crisosto et al., 2003; Esti et al., 2002). Among all the quality indices, special interest has been focused on postharvest maturity as a comprehensive index and TSS as a specific index to evaluate the quality of sweet cherry (Serrano et al., 2005). TSS ranges from 11° to 25 °Brix depending on cultivar and is mainly affected by glucose and fructose levels and less to the presence of sucrose and sorbitol (Martínez-Romero et al., 2006).

However, deterioration has always been an issue during the post-harvest handling of sweet cheery fruits. Sweet cherry fruits are often harvested before reaching the perfect maturity level by many producers in China in order to prevent quality decline from deterioration. Even so, before some defects become visual (e.g. surface pitting, stem browning and decay), there could be latent decline in quality due to the loss of water, TA and TSS (Asghari et al., 2013; Bernalte et al., 2003). Compared with traditional measurement, non-destructive techniques are more suitable for fruit commodities. Nicolai et al. reviewed optical spectroscopy and imaging, mechanical techniques, radiology, magnetic resonance imaging, mass spectrometry, electronic noses and their applications for measuring internal and external quality indices of fruit and vegetables. Among all seven major techniques, optical spectroscopy outperformed other techniques on quality indices, measurement speed, overall cost and application areas (Nicolaï et al., 2014, 2007).

With regard to the fruit maturity classification, authors of Ref (Khodabakhshian et al., 2017; Olarewaju et al., 2016; Rungpichayapichet et al., 2016) established different chemometrics models based on NIR Spectroscopy, using TSS, TA, dry matters as quality indices, in order to determine maturity level of mango, avocado and pomegranate comprehensively. And all their models achieved satisfactory accuracy (0.75 and above on test set). As for quantitative regression of specific fruit quality index based on NIRS, de Oliveira et al. investigated TSS and TA in three different fruit species (Passion fruits, tomato and apricot). The analysis of the best models (Partial Least Squares, PLS) reached $R^2$ of 0.93 respect to TSS in apricot. The results indicated NIRS could be used to detect the quality of fruits with

*Abbreviations:* NIRS, near infrared spectroscopy; IoT, internet of things; TSS, total soluble solids; TA, titratable acidity; SOC, system on chips; DMD, digital mirror device; RTOS, real-time operation system; LAN, local area network; WAN, wide area network; Hyper-NIR, NIR-hyperspectral imaging system

* Corresponding author at: College of Biosystems Engineering and Food Science, Zhejiang University, Hangzhou 310058, China.
*E-mail address:* zjqiu@zju.edu.cn (Z. Qiu).

https://doi.org/10.1016/j.compag.2018.07.017
Received 13 November 2017; Received in revised form 21 May 2018; Accepted 8 July 2018
0168-1699/ 

thin skin and intact homogeneous pulp with a high level of accuracy (de Oliveira et al., 2014). The similarities of mentioned structure between apricots and sweet cherries were the reason why we chose sweet cherries as our test samples. Similar results can be found in palm fruits and Valencia oranges as well (Magwaza et al., 2013; Manickavasagan et al., 2014).

With the miniaturization of electronic components, the size of spectral equipment is becoming smaller and smaller. Much attention was focused on handheld spectral equipment, since it is the ideal option for fruit quality detection in field compared with benchtop ones. Marques et al. developed a PLS model of TSS in mango, reached $R^2$ of 0.83 and 0.88 on train set and test set respectively, thanks to portable NIR spectrometer (Marques et al., 2016). Barnaba et al. used a portable acousto-optic tunable filter (AOTF) based NIR spectrometer to evaluate TSS in grape, and the $R^2$ of their model was 0.89 (Barnaba et al., 2014). Sánchez et al. monitored multiple physical-chemical quality indices (including TSS and maturity) of mandarins during on-tree ripening, reasonable results were achieved (Sánchez et al., 2013). Das et al. developed an ultra-portable wireless smartphone spectrometer for fruits ripeness based on UV-LED, targeting chlorophyll. But the evaluation of their equipment on actual samples was not mentioned (Das et al., 2016). The performance of the portable NIR spectrometer in the above articles is promising and considered on the same accuracy level as traditional benchtop equipment. However, the mentioned equipment usually needs follow-up software to analyze the spectral data before the results can be interpreted. Besides, other external devices are generally necessary in order to complete the detection procedures, like light source, power supply and storage unit. Not being able to integrate as a standalone system makes it unfriendly to non-professionals.

Due to the limitation of storage and computing capability of the local SoC (System on Chip), some researchers utilized a limited number of features when modeling as a means to ease the burden of SoC for portable spectral equipment. For example, the linear combination of extracted characteristic bands (Hori et al., 2010; Lin et al., 2014). However, such processing will inevitably lead to the loss of spectral information. With the rapid progress of internet of things (IoT) and Cloud Computing (Rao et al., 2012; Zhao et al., 2016), along with the development of machine learning algorithms, real-time applications based on underlying sensor data can be guaranteed. Once the data processing model is deployed on the cloud, there is no more limitation on storage or computing capability. The astonishing propagation of sophisticated, modularized electronics across the globe (Scheeline, 2010), promotes the overall cost of hardware equipment to become lower and lower.

In this paper, we demonstrated a highly-integrated, Cloud-based, low-cost and user-friendly portable NIRS system (prototype) with its key components and main structures. For the purpose of evaluation, the system was used to predict the maturity level and TSS content of sweet cherry samples. We named the system 'SeeFruits' since it has the potential to become a universal application for fruit quality detection, which offers a fundamental framework for future related research.

## 2. Development of 'SeeFruits' system

The traditional spectroscopy system is generally suitable for laboratory environment due to its high cost, large volume and complicated operation. In order to develop a low-cost, portable and user-friendly spectral detection system, which can be adapt to the on-site scenario, we chose DLP® NIRscan Nano EVM and ESP8266Ex as our basic modules for further secondary development.

### *2.1. DLP® NIRscan Nano EVM*

DLP® NIRscan Nano EVM (Nano for short) is a complete evaluation module offered by Texas Instruments (TI), Dallas, Texas, United States. It was designed to meet other developers' demand to develop a high performance, affordable (999 USD from TI store) NIR spectrometer with 228 bands optimized for operation at wavelength between 900 and 1700 nm. DLP2010NIR Digital mirror device (DMD) along with DLPC150 digital controllers are two core components of Nano. There are numerous microscopic mirrors arranged in rectangular array on DMD's surface corresponding to 854 × 480 image orthogonal pixels. All of them are programmable to be in an 'on' or 'off' state controlled by registers of DLPC150. Instead of using a traditional linear array InGasAs detector, Nano only contains a larger single point 1 mm detector. Therefore, the overall cost is sharply reduced. By sequentially scanning through the columns of the high resolution DMD, a particular wavelength of light (Green[1] arrow in Fig. 1(b)) is directed to the detector and captured. The process is fast enough to generate similar results when compared with a linear array detector.

One of the great advantages of Nano is that it maintains high degree of integration within a compact size (62 mm long, 58 mm wide, 36 mm tall). The evaluation module is equipped with a powerful Tiva TM4C1297 microprocessor, a 32 MB SDRAM for additional code and buffer storage. The scan patterns will be streamed to the DLPC150 for controlling DMD. Nano can be powered either by its own micro-USB interface, or an external lithium battery. With two self-contained lamps as a light source and a micro-SD card slot for offline data storage, only one Nano module is capable of carrying out NIR analysis. In addition, Nano's physical layer also supports a variety of data transmission protocols such as USB, Bluetooth and UART. Furthermore, all these interfaces can be accessed from Nano's microprocessor board. The communication workflow and command package of different interfaces are elaborated in the official documentations, which greatly facilitates all developers in speeding up secondary developmental work on Nano-based instrument development. Taking into account the versatility of the communication with other peripheral devices, we finally chose UART interface for further development.

### *2.2. ESP8266Ex and ESP-12F*

ESP8266Ex is currently one of the most widely integrated Wi-Fi SoC solutions in the Internet of Things (IoT) industry, provided by Espressif Systems Pte. Ltd., Shanghai, China. Apart from having complete Wi-Fi capabilities, ESP8266Ex integrates enhanced version of Tensilica's L106 Diamond series 32-bit processor and on-chip SRAM, antenna switches, RF balun, power amplifier, filters and power management modules. ESP8266Ex can perform either as a standalone application or as the slave to a host MCU. The flexibility of ESP8266Ex allows it to be applied to any micro-controller as a Wi-Fi adaptor through SPI/SDIO or I2C/UART interfaces or interfaced with external sensors and other devices through the GPIOs.

There are many highly integrated Wi-Fi modules available from the ESP8266 family, provided by Ai-thinker Team with the official retail price of 2.6 USD. We chose ESP-12F as our Wi-Fi Module for the purpose development due to its richness of GIPO pins (22 pins), small package size (6 mm × 24 mm × 3 mm) and friendliness to breadboard (see Fig. 2).

As for software development, Espressif officially released two kinds of SDK, Non-OS based and RTOS based, for developers to choose from, offering a series of API references and programming guide. These high-level functions make it much easier for developers, who aren't familiar with the underlying structure, to access the core features of the chip, hence, shorten the development cycle. The Free-RTOS architecture based ESP8266 RTOS SDK is more efficient in resource allocation while handling multi-threaded, multi-tasking applications in real-life scenarios, lowering the risk of encountering bugs. In addition to the official SDK, thanks to ESP8266Ex's popularity among the world, many third-

[1] For interpretation of color in Figs. 1, 3, 7, 9, the reader is referred to the web version of this article.