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Development and evaluation on a wireless multi-gas-sensors system for improving traceability and transparency of table grape cold chain

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ABSTRACT

There is increasing requirement to improve traceability and transparency of table grapes cold chain. Key traceability indicators including temperature, humidity and gas microenvironments (e.g., CO_2, O_2, and SO_2) based on table grape cold chain management need to be monitored and controlled. This paper presents a Wireless Multi-Gas-Sensors System (WGS^2) as an effective real-time cold chain monitoring system, which consists of three units: (1) the WMN which applies the 433 MHz as the radio frequency to increase the transmission performance and forms a wireless sensor network; (2) the WAN which serves as the intermediary to connect the users and the sensor nodes to keep the sensor data without delay by the GPRS remote transmission module; (3) the signal processing unit which contains embedded software to drive the hardware to normal operation and shelf life prediction for table grapes. Then the study evaluates the WGS^2 in a cold chain scenario and analyses the monitoring data. The results show that the WGS^2 is effective in monitoring quality, and improving transparency and traceability of table grape cold chains. Its deploy ability and efficiency in implantation can enable the establishment of a more efficient, transparent and traceable table grape supply chain.

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1. Introduction

The need for traceability and transparency of agro-food chains was driven by numerous recent food safety scandals which triggered growing attentions from governments and consumers. In response, many countries have introduced stricter regulations and smarter industrial development strategies to enable better tracking and tracing of agricultural food products (Aung and Chang, 2014; Narsimhalu et al., 2015; Gogou et al., 2015; Defraeye et al., 2016). The development of IoT (Internet of Things) and WSN (Wireless Sensor Network) technologies provided more integrated and effective approaches to leverage the huge amount of complex information available nowadays and to enable more effective and easier monitoring of food supply chains (Dehghannya et al., 2010; Pang et al., 2010; Xiao et al., 2016).

Wireless multi-sensors network is a new technology that combines multi-sensors technology and WSN, embedded computing, networking and wireless communication, and distributed processing. It senses and collects information of monitoring objects and sends information to the end-user via wireless and multi-hop network, which has many advantages as low maintenance cost, higher mobility, better flexibility, and fast deployment in special occasions. It is reportedly to benefit quality and safety of products and supply chain optimization and enable quick product recalls of perishable food, which has been adopted in many sectors, such as fruit cold chain (e.g., Ruiz-Garcia et al., 2008; Guo et al., 2011; Xiao et al., 2015; Wang et al., 2015), aquatic products chain (e.g., Qi et al., 2011, 2014; Ping-Ho, 2013; Xiao et al., 2016), winemaking monitoring (e.g., Di Gennaro et al., 2013; Zhang et al., 2015), greenhouse management (e.g., Gnanavel et al., 2016; Jiang et al., 2016), and crops planting (e.g., Garcia-Sanchez et al., 2011; Coates et al., 2013). However, most of these solutions focused on temperature and relative humidity. Few previous research described traceability of gas atmosphere, such as ethylene gas (Jedermann et al., 2006).

Given that the cold chain is the key process in the agri-food supply chain to ensure food quality and freshness, key traceability indicators including temperature and other environmental condi-

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tions under which the fresh and frozen products are stored and transported need to be closely monitored and controlled (Bobelyn et al., 2006; Han et al., 2012; Trebar et al., 2015). Table grape is non-climacteric fruit and must be harvested when it is fully ripened. Therefore, they deteriorate quickly after harvest due to senescence and decay caused by pathogenic fungi Botrytis cinerea. For prolonging shelf life and postharvest decay control, table grapes in the cold chain not only require a temperature-controlled environment, but also some special treatments: for example, fumigated by SO_2 gas or SO_2 generator pads which contain sulfite salt or sodium metabisulphite. As a result, gas atmosphere in the table grape cold chain can be complex: CO_2 and O_2 gases come from the atmosphere and the respiration of table grapes; SO_2 gas slowly released by SO_2 generator pads after reaction with water vapour from humid air.

The increased CO_2 concentration or low O_2 concentration in the cold chain environment will slow down the rate of physiological activity by reducing respiration rate of table grapes, which affects the quality of table grapes significantly (Deng et al., 2005; Costa et al., 2011). SO_2 as exogenous gas will prolong table grape storage by significantly retarding the growth of those pathogenic fungi and preserving the fruit's original flavour and nutrients (Youssef et al., 2015; Carter et al., 2015). Therefore, it is important to monitor SO_2, CO_2 and O_2 gases in the cold chain which significantly affect the quality and safety of table grape. The capability of monitoring SO_2, CO_2 and O_2 gases concentration in real-time will improve shelf-life prediction and the traceability and transparency of the table grape cold chains. Existing literature review suggests that there are few previous studies, which developed effective gas concentration monitoring systems in table grape cold chains. This study, therefore, concentrates on developing a Wireless Multi-Gas-Sensors System (WGS^2) as an effective real-time table grape cold chain monitoring system.

This paper is organized as follows: Section 2 presents system analysis and architecture design of WGS^2. Multi-gas-sensors development and signal processing for table grape cold chain are demonstrated in Section 3. Section 4 details the WGS^2 system testing and evaluation in a real cold chain logistics. This paper concludes with the discussions and suggestions for future research.

2. WGS^2 system analysis and architecture design

2.1. Cold chain example and field study method

In this research, two sample table grape cold chains are discussed to illustrate a long distance chain and a short distance chain in China (see Fig. 1), because China is large in area and the grape has been widely planted all over China. One sample table grape cold chain is from Xinjiang province to Guangdong province in China. The other sample table grape cold chain is from Hebei Province to Tianjin city in the North China.

A systematic literature review, a field observation and an interview were conducted to extract the monitoring requirements of the WGS^2 and the factors that may influence the safety & quality of table grape cold chain. The interviews were conducted face-to-face with 5 cold chain managers and 20 infield cold chain workers from both example cold chains over 7 days. All of the interviewees have over 3 years of working experience in the table grape cold chains. Each interview lasted for around 40 min. Interviewees were asked about their working routine; whether they record gas information; how they estimate the shelf life of table grapes; whether they knew about wireless gas monitoring and if so whether they have used it before; and what kind of information they think are supply chain traceability information.

2.2. Business flow analysis and traceability information requirements of the WGS^2

The field study also helped to clarify the business flow of the table grape cold chain. The business flow of a typical 'seedless grape' cold chain is shown in Fig. 2. The cold chain process starts from the farm and ends with on-the-shelf retail with the following stages:

- Step 1: Grape harvesting. Usually the harvesting happens during a non-rainy cooler times of the day (<25 °C) (usually early morning) to prolong the cooling time of the table grapes.
- Step 2: Ordinary/Refrigerated transportation. Table grapes are transported immediately via ordinary or refrigerated transport to the refrigeration warehouse for further processing. During

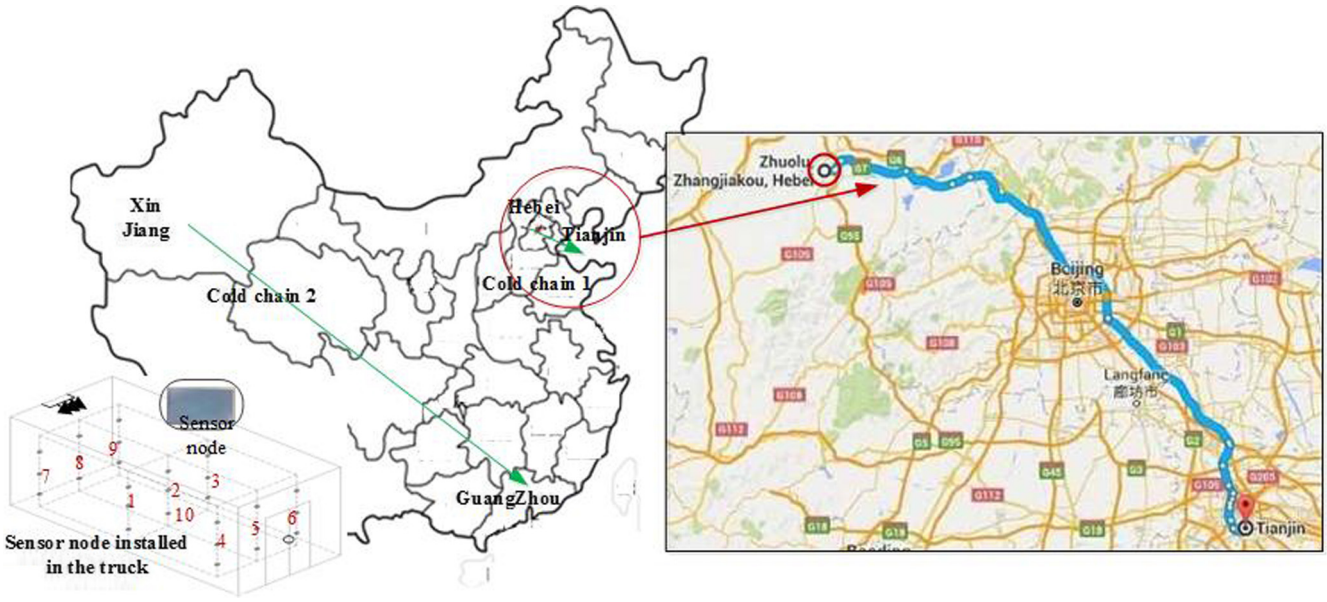

Fig. 1. The mapping for table grape cold chain.

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