

Current status and future trends of monitoring technologies for food products traceability

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ABSTRACT

This paper presents the current status and future trends of sensor technologies for food products traceability, specifically for systems devoted to be applied in the cold storage and refrigerated transport of horticultural products. The available monitoring technologies such as dataloggers, TTI, WSN, RFID, and combined approaches are evaluated and compared in terms of dimensions, sensor parameter (temperature, relative humidity, water vapor, ethylene and other gases released during the biological processes of fruit), robustness, reliability, energy autonomy, bandwidth (if applicable), connection, among others. The aim of the study consists in evaluating how these technologies can be successfully applied for traceability of horticultural products and are what the future trends in terms of technical and technological specifications that will guide the development of these systems. It is expected that the increasing use of these systems for food traceability increases food quality and safety, reducing food waste.

Keywords: Current status; Future trends; Monitoring technologies; Food traceability; Sensors.

1. INTRODUCTION

Distribution chains still have challenges to overcome, such as the lack of a monitoring system that allows monitoring the product at all stages and evaluating the remaining time of validity. This fact is reflected in the amount of food products that are wasted before reaching the final consumer, approximately one-third of the total production. In horticultural products this waste reaches 45% (Gustavsson *et al.*, 2017). Food waste arises from factors associated with distribution chains, such as inadequate transport conditions and non-compliance with storage temperatures. Another relevant point of the distribution chain where this food conservation break exists is in places of merchandise transition, namely airports and sea ports, where the containers with the perishable products are sometimes placed under high solar exposure and subjected an undesirable thermal amplitude (Badia-Melis *et al.*, 2018). As distribution has become a worldwide system it is usual that not all countries have the same regulation for the cold chain, proving to be another factor that affects food quality. Figure 1 shows the large problems faced by the distribution chains and that lead to food waste.

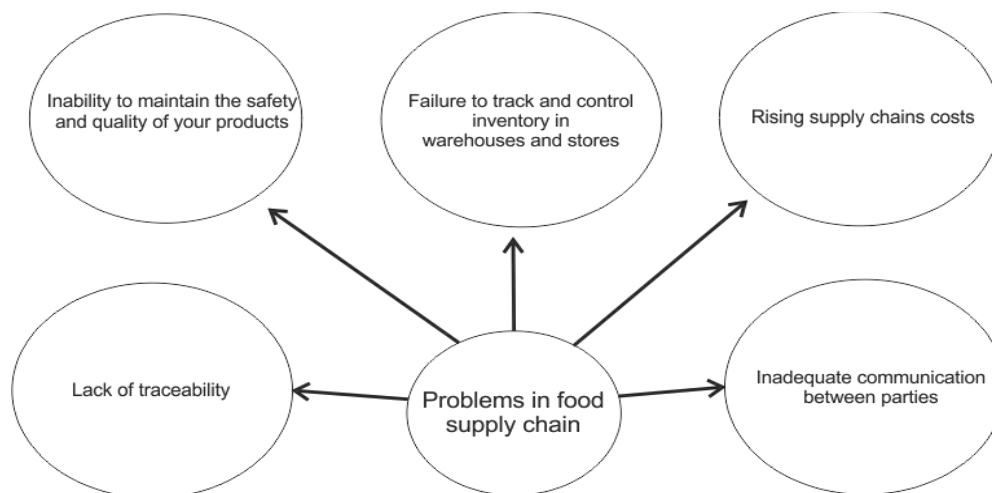


Figure 1: The main problems in the food supply chain.

Due to the different characteristics of the food products, there is no solution that solves efficiently all problems in the distribution chain. On the other hand, over time, monitoring systems, forecasting methods, computational fluid simulations, and other solutions have been developed with the purpose of monitoring and evaluating the product. Fruit and vegetable products, being of biological origin and therefore subject to senescence processes, require a more demanding control regarding storage conditions. Ruiz-Garcia *et al.* (2010) evaluated the storage conditions inside a refrigerated truck. It was concluded that the temperature was above the set point programmed 98% of the time. The location of the pallet during this period is also relevant, as proved by Margeirsson *et al.* (2012), Moureh *et al.* (2002) and Laguerre *et al.* (2002).

But, why is food preservation necessary? The globalization of trade routes causes many products to be transported over long distances but reaching the final destination with quality and safety. As mentioned by Rediers *et al.* (2009), conservation is, first and foremost, essential to maintain optimum product quality, as it reduces several physiological processes, such as perspiration and respiration. This can be accomplished by the reduction of temperature that decreases the growth rate of microorganisms. Solving these issues involves the implementation of monitoring systems that allow the producer to analyze the conservation environment to which the product is subject. The real-time knowledge of this data facilitates the decision making, leading to optimized distribution chain. In this context, Internet of Things (IoT) is one of the solutions that can be implemented. The connectivity of the devices with the Internet allows the establishment of wireless sensor networks (WSN) and, in this way, permanent monitoring is possible. This study presents the relevant publications in food monitoring, as well as the technological trends in communication and sensing that have been tested and implemented in the market.

2. CURRENT STATE

In the cold chain, any perturbation in the temperature, regardless of duration or severity and the stage at which it occurs, may compromise the whole chain and all the efforts made up to that point (Mahajan *et al.*, 2014). The study carried out by Ruiz-Garcia *et al.* (2009) shows that the temperature oscillations inside a conservation chamber caused by the on-off cycles leads to variations between 3 and 6°C. Other parameters such as the temporary opening of the doors of both the truck and the camera and the loading of the products also influence the temperature variation (Carneiro *et al.*, 2017; Göransson *et al.*, 2018). The environmental temperature is another factor that determines the time necessary for the total cooling of the product, as evaluated in Redier *et al.* (2009), who also demonstrated small temperature variations during the transport of endive.

The implementation of traceability systems has long attracted the attention of traders, and over time practical and accessible solutions have been developed that allow a rapid assessment of the state of conservation. In recent years, several projects have focused on the development of hardware required for traceability, predictive validity models, QTT (Quality oriented Tracking and Tracing) and FEFO systems such as Chill-On, PASTEUR, FRISBEE, DANAHMAT and Intelligent container. The following table shows the duration and focus of these projects.

Table 1: Similar projects in traceability systems for food supply chain.

Project & Reference	Duration	Focus
Chill-On (Olafsdottir <i>et al.</i> , 2010)	2006-2010	TTI with chemical detection and RFID interface
PASTEUR (Hoofman, 2013)	2009-2012	RFID tag with multiple sensors (temperature, humidity and gas detection)
Intelligent container (Jedermann <i>et al.</i> , 2014)	2010-2013	Prototype container for QTT and FEFO
FRISBEE (Gwanpua <i>et al.</i> , 2015)	2010-2014	Simulation and creation of database for temperature mapping and models of life time
DANAHMAT (Jevinger <i>et al.</i> , 2014)	2013-2016	Concepts for dynamic labeling capable of determining validity

Despite efforts, these systems have not been implemented on a large scale. But, in contrast, devices such as Time-Temperature Integrators or Indicators (TTIs) and data loggers are used. Although they do not provide real-time monitoring, allow to record the temperature history throughout the chain and the subsequent analysis of the results.

The origin of the IoT remote to the year 1999, with the creation of a network of objects interconnected using Radio Frequency IDentification (RFID). But IoT offers much more possibilities of sensing and acting with the use of low power microcontrollers. In addition to this class of cyber-physical systems, also communication protocols that allow the sending of data must pointed out (Nukala *et al.*, 2016).

3. TIME-TEMPERATURE INTEGRATORS/INDICATORS (TTI)

Temperature indicators as a function of time are devices that allow, in a simple way, food control by the trader and the consumer through changes observable to the naked eye, such as a change in color or shape. These devices can record the total or partial temperature history of a product from the producer to the consumer. There is a high diversity of these indicators that resort to a variety of physical-chemical properties (Selman, 1995). The rate of change is temperature, light or humidity dependent, i.e. the parameter accumulation influences a variable such as the deterioration reactions responsible for deteriorating product quality (Pavelková, 2012). The indicators can be classified according to their operating principle.



Figure 2: TTIs classification relatively to working principle.

When active, the state change is irreversible. Its activation may be presented as a deformation, a change of color or change in the intensity of the coloration. The rate of visibility change depends on the temperature and its variation (Biega, 2017). These indicators can also be grouped into three categories.

- **Critical Temperature Indicator (ITC)** indicates exposure above or below a reference temperature. The denaturation of an important protein above a critical temperature or the development of pathogenic organisms are situations in which these indicators prove usefulness.
- **Temperature / Critical Time Indicator (TTIC)** are useful for indicating abnormalities in a distribution chain and in products, important in quality or safety, and are initiated when temperatures above the critical temperature are being measured. Examples are the increase in reactions in microorganisms or the enzymatic activity that is triggered at a certain temperature.
- **Temperature Time Indicators (ITT)** provides a continuous indication of temperature variation. For example, raising the temperature will darken the alert color.

These devices are a simple and affordable way of specifying when the product was exposed to an unsuitable environment and thus helping to optimize transportation, being one of the requirements of the current smart packaging.

4. WIRELESS SENSOR NETWORK (WSN)

Wireless Sensor Networks are the most used systems for monitoring and traceability, with a market share of 78% (Kassal *et al.*, 2018). Despite their great market representation, they show a disadvantage related to the impossibility of ensuring continuous monitoring of the distribution chain and, consequently, of estimating the remaining validity of the products. Figure 3 shows the evolution of scientific publications related to the different communication protocols with application in traceability systems from 2007 to 2016.

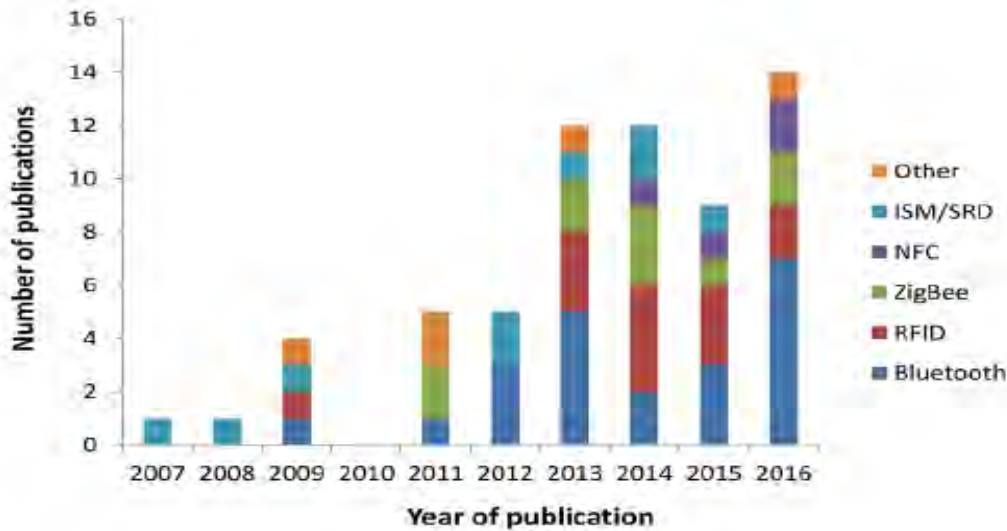


Figure 3: Incidence of different communication protocols presented in scientific publications between 2007 and 2016 (Kassal *et al.*, 2018).

Another disadvantage of WSN is the waveband used. Microwave, 2.4GHz, which is used for communication, is interfered by the resonant frequency of water. Communication flaws can occur since monitoring is required in refrigerated products, where the surrounding environment has a high-water content, i.e., relative humidity (Badia-Melis *et al.*, 2018). Monitoring during maritime transport is also affected by this phenomenon, with the crash of ships' hulls on the waves. There are several WSN systems for food monitoring. Examples are those presented by Xiangsheng, 2014; Wang *et al.*, 2015) and Maigler *et al.* (2013), who use communication protocols such as Bluetooth, ZigBee, LORA and NFC for the development of systems capable of monitoring the environment in which products are found. Fig. 4 summarize the most relevant protocols within WSN systems currently. Their characteristics are presented in Table 2.

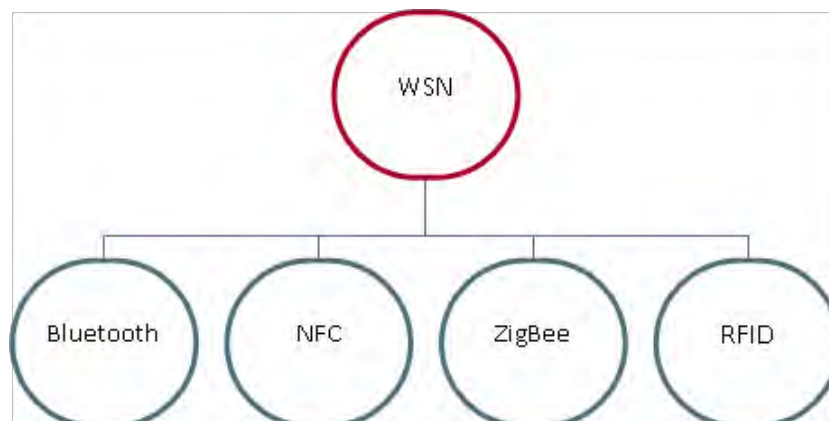


Figure 4: The most used communications protocols in WSN systems.

Table 2: Different communication protocols and their principal characteristics.

Protocol	Radio Band	Data rate	Range	Features
Bluetooth	2.4 GHz	1 Mbps	10 – 100 m	Good for real time data transfer, Smartphone compatible, Good indoor range
NFC	13.56 MHz	<424 kbps	< 5 cm	Ultra-low power, good for secure file swaps, contactless only
RFID	128-135 kHz, 13.56MHz, 860 – 960 MHz	<100 kbps	<15 m (frequency dependent)	Ultra-low power, short range or contactless, very low data rate, good for e labels and small file transfers
Wi-Fi (802.11)	2.4, 3.6, 5 GHz 60 GHz	6-780 Mbps 6.75 Gbps at 60 GHz	100 m (range can be affected by building materials)	Has a standardized protocol for all countries, devices can be added without any cost, Standards development is continuous, with incremental improvements

2.1. Bluetooth

Bluetooth is a short-range, low-power wireless communication protocol proposed in 1994 (Chadha *et al.*, 2013). Operating in the range 2400-2483.5 GHz in the ISM standard, it allows different devices to connect. With the emergence of IoT, Bluetooth was one of the existing options able to meet the communication needs due to popularity and simplicity. But with these factors, an issue arises, the security. As an open system, one of the current concerns is data loss and intrusion prevention in networks, with the level of security being defined by hardware and software manufacturers. The way a Bluetooth connection works is relatively simple. Initially, when feeding the device, it starts searching for the Master, if it is not already paired. When the Master device responds to the Slave's request, a connection is established if the Slave continues to listen on the network. After the formalities, it is performed the synchronization between devices (Master and Slave), using FHSS (Frequency hopping spread spectrum) to data is sent. One of the communication topologies used is Piconet allowing at most 8 devices to connect (1 Master, 7 Slaves), resembling an adhoc network. Because communication is never done simultaneously, signal interference is not a problem. Although Bluetooth communication only allows 8 devices to communicate simultaneously, the maximum number of connections is 255, that is, it allows 255 devices to pair in the network. There are several predefined connection topologies, each with a different combination of error protection mechanisms.

- **Point-to-point**

It is aimed at the interaction between 2 devices, namely for streaming music, also working with loudspeakers, hands free and headsets. It can also be used for file transfer, using the Bluetooth mode Low energy.

- **Broadcast**

This typology allows establishing the connection between several devices (one-to-many). It is optimized for location sharing, traceability and point-to-interest. This typology is present in devices such as beacons, which consists in the diffusion of data to the network actors.

- **Mesh**

With a typology like Broadcast, it allows the connection between several devices (many-to-many). This variant allows, for example, to establish a network of sensors in a limited environment.

2.2. RFID

The appearance of the RFID technology occurred during World War II (1939-1945) for the identification of military aircraft Friend or Foe (IFF), based on wireless communication between a tag and a reader with radio frequency. RFID was then seen as one of the most promising technologies for identifying products compared to other technologies already in use, such as bar codes. Due to the possibilities offered by this technology, there was a growing interest among several economic sectors, such as logistics, identification, tolls and traceability of products, pallets and animals, where more than 3000 applications are known (Bibi *et al.*, 2017). To add value to this technology, several

sensors have been developed to be implemented in tags for the monitoring of various environmental parameters in the transportation of perishable products. This combination of systems offers the possibility of creating a database accessible to traders and consumers through the unique identification code. Several sensors have been developed, such as, for example, gas (Vergara *et al.*, 2007; Steinberg & Steinberg, 2009; Bhadra *et al.*, 2011; Potyrailo & Surman, 2013; Steinberg *et al.*, 2014), moisture (Abad *et al.*, 2009; Martinez-Olmos *et al.*, 2013) to be implemented in smart packaging. For the correct functioning, several components are needed, such as an RFID antenna for communication, a chip for identification and storage of data, a reader and a computer. Tags can also be divided into three groups, depending on your power source:

- **Passive RFID tags:** They do not have battery, being fed by the reader. The different mechanisms allow the exchange of energy and data. The energy rate that is transferred varies between 10 μ W and 1 mW.
- **Semi-Passive RFID tags:** They incorporate a battery to keep the memory in the tag or to feed the different electronic devices that make it possible to modulate the electromagnetic waves emitted by the reader.
- **Active RFID tags:** They are powered by an internal battery that is used to run the circuit of the microchip, thus being more expensive than passive tags.

Despite the many possibilities that RFID presents in food monitoring, there are still some disadvantages that systems such as Bluetooth can easily overcome, such as reading distance. To read a tag, the reference distance is 10 cm. For readings at higher distances, an antenna with higher power is required, which consequently causes the system to use more power. RFID is a promising technology with high development in the last years, since it allows the encoding of several types of radio frequencies and sensors in the tags, making this system have a high potential (Bibi *et al.*, 2017).

5. SENSORS

For monitoring purposes it is necessary to convert an environmental parameter into an understandable signal, thereby using a sensor. In addition to monitoring air temperature and air humidity, there are other parameters that must be monitored to ensure the quality of the food product, such as ethylene or oxygen/carbon dioxide gases. In fruit and vegetables, the ethylene release rate is related to the maturational state. In an advanced state, the ethylene release is substantially higher. In the meat industry, it's the development of microorganisms. It is in this field that electrochemical sensors, biosensors and gas sensors can convert a stimulus into an interpretable signal. The difference between an electrochemical sensor and a biosensor is in the recognition layer, i.e. in a chemical sensor, the receptor is a chemical component whereas in a biosensor, the layer is composed of biological materials such as enzymes and antibodies (Ghaani *et al.*, 2016). In recent years, different types of electrochemical sensors have been developed for the food industry. Examples are shown by Gao *et al.* (2015); Goulart *et al.* (2016); Liu *et al.* (2015); Nasirizadeh *et al.* (2015) and Pacheco *et al.* (2015). An ideal sensor, according to Hanrahan *et al.* (2004), should have the following characteristics: specificity for each product, sensitivity to changes of concentrations in the product, rapid response time to variation, durability and reduced dimensions, with possibility of low production cost.

6. FUTURE TRENDS

Perishable product monitoring is a sensitive area and as such, the systems to be implemented need to comply with hygiene and safety standards so as not to compromise the assets to be monitored. In addition, they must ensure continuous monitoring with real-time data transmission in a secure manner. WSN simplified the development of sensor-based applications to monitor hazardous environments or remote areas, resulting in a reduction in the complexity and cost of maintenance (Wang *et al.*, 2006). IoT-related technologies can be applied to food transport and conservation, with a variety of objectives, such as optimization of post-harvest processes, monitoring of conservation conditions, conservation treatments and data for decision-making; as well such as the optimization of the distribution chain, the development of autonomous lorries and boats or swarms of drones for delivery (Tzounis *et al.*, 2017). The technologies described in this paper present themselves as systems capable of being implemented in the distribution chains for traceability, demonstrating that they can enhance the food industry. However, they have disadvantages that do not go unnoticed, such as the high cost of implementation (Badia-Melis *et al.*, 2018). With monitoring systems, the

concepts of smart and/or active packaging emerge. Smart packaging is called when there are sensors that evaluate the environment, able to send the data through a communication protocol, and this information is accessible at any time. An active packaging incorporates materials in its construction that allow the maintenance and prolongation of the shelf life of the product it transports (Mane *et al.*, 2016).

7. CONCLUSIONS

Despite the diversity of existing solutions in the market, there is no one that can meet all the requirements demanded by the industry, making it more complicated to implement them. But the optimization of distribution chains with emphasis on reducing food waste also involves a change in the mentality of FIFO (First in First Out) for FEFO (First expires- First out). It is expected that with the development of these technologies, the gaps will be corrected making these systems more feasible and reliable to implement. Using traceability systems goes in line with three main objectives: improve supply management; facilitate traceback for food safety and quality; and differentiate and market foods with subtle or undetectable quality attributes. In relation to packaging, a global goal is the elimination of plastics, therefore it is necessary to develop a packaging that is recyclable and non-polluting, capable of interacts with the product, which will drive the implementation of a monitoring system in response to demand (Han *et al.*, 2018).

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