A Low Cost Internet of Things Solution for Traceability and Monitoring Food Safety During Transportation

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Abstract. In the last decade, we are faced with a dozen food crisis, which have impact on human health. EU as response to food contamination applies a set of laws and standards for food traceability through all stages of production, processing and distribution, forcing that all food and feed operators implement special traceability systems. One of the main and a crucial element of this system is food transport from manufacturer to consumer, and possibility for monitoring food quality through the transportation process. Applying new technologies, like Internet of Things (IoT), nowadays it is possible to connect food producers, transportation and hospitality/retail companies. A low cost solution based on IoT for real-time food tracebility and monitoring in food transportation process is presented in this paper.

Keywords: Food monitoring, Transportation, Internet of Things, Raspberry Pi

1 Introduction

Food safety today is defined as a public health priority and has been a growing concern among EU citizens over the last decades ("Food Traceability," 2007). It represents a scientific discipline which includes a number of routines and inspections between industry and the market and between the market and the consumer that should be followed to avoid potentially severe health hazards. Public concern about food quality has intensified in recent years and key global food safety concerns include: spread of microbiological hazards; chemical food contaminants; assessments of new food technologies (such as genetically modified food); and strong food safety systems (to ensure a safe global food-chain). Specific standards, such as ISO 22000, ISO 22005 and SQF for food traceability have been mandated internationally; by law in the European Union (EU), Japan, and more recently the United States; and by private firms and associations (Karippacheril et al., 2011). These standards ensure the ability to follow a food related material or product through all stages of the supply and distribution chain as a vital element for consumer safety (Kozlowski, 2012). According to EU law, this ability is called "traceability" and means the ability to

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track any food, feed, food-producing animal or substance that will be used for consumption, through all stages of production, processing and distribution ("Food Traceability," 2007).

The food safety system, based on defined standards, includes food production, processing, packing, distribution/transportation, storage and preparation. The research challenges connected to food safety can be summarized in (Vermesan and Friess, 2013):

- Design of secure, tamper-proof and cost-efficient mechanisms for tracking food contamination from production to consumers, enabling immediate notification of actors in case of harmful food and communication of trusted information.
- Secure way of monitoring production processes, providing sufficient information and confidence to consumers.
- Ensure trust and secure exchange of data among applications and infrastructures (farm, packing industry, retailers) to prevent the introduction of false or misleading data, which can affect the health of the citizens or create economic damage to the stakeholders.

A technology like mobile phones, radio frequency identification (RFID) systems, wireless sensor networks, global positioning systems - GPS (Karippacheril et al., 2011), and Internet of Things (IoT), as an important part of the new generation information technology, are applied in order to ensure efficient delivery and food safety, which are compliant with food safety and traceability standards. IoT is an emerging paradigm and a cutting edge technology which goal is to enable things/objects to be connected anytime, anyplace, with anything and anyone ideally using any path/network. The IoT applications are numerous and cover “smart” environments/spaces in domains such as: transportation, building, city, lifestyle, retail, agriculture, factory, supply chain, emergency, health care, user interaction, culture and tourism, environment and energy (Fig. 1) (Vermesan and Friess, 2013; Bassi et al. 2013). IoT nowadays makes possible a new cooperative between food producers, transportation and hospitality/retail companies.

Fig. 1. The Internet of Things applications (Ake, 2014).

Food contaminants can enter the food supply at any point from farm to table. With the help of IoT-connected testing equipment, food quality can be monitored as food leaves the factory or warehouse. In this way food companies across the supply chain gain the real-time visibility and enable the automated, intelligent actions needed to ensure high food quality, delivery on time and food preparation in optimal settings

(Jones, 2014). In this paper is presented a low cost solution based on IoT for real-time foodstuffs traceability and monitoring in transportation process. A low cost computer board (Raspberry Pi platform) is utilized as a central processing unit which provides a set of services for accessing sensor data, and communicates with end users, while different types of sensors (depending of target parameters) can constitute the detection module.

The rest of this paper is organized as follows. The state of the art is presented in Section 2. Section 3 presents requirements and challenges in food products transportation processes. A proposition of low cost IoT solution for food safety monitoring during transportation is given in Section 4. Finally, Section 5, based on the performed research and obtained results, provides conclusion remarks and outlines directions for future work.

2 State of the Art

Every stage of the food chain (food production and preparation processes, including packaging, distribution, etc.) should be carried out and monitored scrupulously to enhance food safety. Hazard Analysis and Critical Control Points (HACCP) is a scientific and systematic preventive approach to food safety, from biological, chemical and physical hazards in production processes that can cause the finished product to be unsafe, and designs measurements to scale down these risks to a safe point. HACCP is used in all stages of a food production and usually is referred as the prevention of hazards rather than relying on end-product testing ("Seven Principles," 2007; "Food Safety Management System," 2014). The seven principles of a HACCP system are ("Seven Principles," 2007): identifying any biological, chemical, or physical hazards, identifying the critical control points, establishing critical limits, monitoring critical control points, establishing corrective actions, verification and record keeping. Based on the before mentioned, a Food Safety Management System (FSMS) can be defined as a network of interrelated elements (programs, plans, policies, procedures, practices, processes, goals, objectives, methods, controls, roles, responsibilities, relationships, documents, records, and resources) that combine to avoid potentially dangerous health hazards.

To ensure that food reaches its destination in a safe condition without compromising quality, it is necessary to provide an environment that reduces the risk of contamination and protects food from various hazards. Also, there is a need to develop comprehensive and well-designed food contaminants monitoring systems. Food traceability system (production, inspection, supervision and consumption) didn't remain immune to continuous upgrading in IT sector. Bakucs et al. (2008) using a key technology survey investigated the likely future impacts of technology on food quality and health in six Central European countries. Falling cost of hardware and software accompanied with IoT paradigm affects the whole supply chain: starting with the production site, through transport and retail, up to the customer, and therefore can facilitate the whole process and improve the service (Bassi et al. 2013). Karippacheril et al. (2011) emphases in their work the significance of mobile devices, advances in communications, and greater affordability of nanotechnology in traceability systems. The existing approaches in food traceability are summarized into: structured database solutions, RFID based solutions, barcode technologies, nanosolutions, DNA techniques and nuclear techniques. Commercially available hardware and software as well as solutions providers offer a variety of solutions for recording, storing and retrieving data. IoT based approaches for monitoring food safety in various stages of the food chain with the help of RFID and wireless networking can be found in (Aggarwal, 2013; " Elektron launches wireless food safety monitoring system," 2013; Hopper et al., 2008; Zeidler, 2010, Xu et al., 2013). Authors of (Martins et al., 2012; Hopper et al., 2008; Hsu and Shangguang, 2014; Ramesh and Das, 2012; Zhang et al., 2012) focused their research on monitoring food safety during transportation. The idea of Internet of Vehicle (IoV) is implemented in these works where the advantage of connected vehicles is highlighted. Accessibility of information nearly in real-time and the creation of a sensing network with a massive reach, amplified by the inherent mobility of vehicles are the main characteristic of proposed approaches. Solutions presented above are mostly low cost wireless remote systems with continuous and automated monitoring features and fast response. These systems are regularly accompanied with appropriate software. Keeping in mind that data is the backbone of any quality system, a data collection, analysis and reporting system must be established. In other words, proposed solutions collect process and store data, send alerts and warnings when specifications are not met and create reports. Therefore an automated data collection, along with the necessary analytical software is required in order to keep data collection costs low (Ryan, 2014).

A forementioned presented survey shows that the traceability information can be accessed through the Internet, and thus it can be concluded that IoT technologies provide efficient tools for data gathering, communication and sharing from different resources automatically. In other words, the IoT, accompanied with RFID, sensor technology, wireless communication and data mining techniques, provides unprecedented opportunities for product tracking. In such way, a food traceability system can make consumers understand the production and circulation process, and increase consumers' faith in the food itself.

3 Transporting Food Products

It is evident that there are so many types of foods with so many containers, temperature and handling requirements and so many modes of transportation available to the modern food company. Independently of the mode of transportation, foods and food ingredients are susceptible to abuse and/or contamination during transportation and storage. There are a number of interesting standards, compliance recommendations and laws that point to the development of a set of management, HACCP, sanitation, monitoring, transportation, and training standards. Preventive controls for food transportation safety hazards are identified by the expert panel and presented in detail in (Ackerley, et al. 2010). Ryan (2014) by reviewing documents published by the United States, Canada, Australia, Europe, China and Australia, creates a general picture which can serve to guide the standardization of in-transit food safety systems.

One of the main documents which propose the hygiene rules in food total food chain for Europe is Regulation of European Commission EC No 852//2004 On the hygiene of foodstuffs ("Guidance document," 2012). It is mainly directed at food businesses and competent authorities, and aims to give guidance on the implementation of the new food hygiene requirements and on related subjects. It covers all food chain, from production to human consumption.

The regulation covers primary production. At the level of primary production, primary products have to be subject of following operations so as to ensure a better presentation, such as:

- Packaging without further treatment;
- Washing of vegetables, removing leaves from vegetables, the sorting of fruit etc;
- The drying of cereals;
- The slaughter, bleeding, gutting, removing fins, refrigeration and wrapping of fis;
- Centrifugation of honey to remove honeycombs.

Such operations must be considered as normal routine operations at the level of primary production. On the other hand, certain operations carried out on the farm can lead to the contamination of products e.g. the peeling of potatoes, the slicing of carrots, the bagging of salads with the application of packaging gases or the removal of gases. These operations cannot be considered as normal routine operations at the level of primary production nor as operations associated with primary production. The Regulation creates the need for food companies to establish, under the HACCP-based procedures, documentation commensurate with the nature and the size of the business. Together, this documentation will constitute operational procedures that are an important element in ensuring food safety.

The main focus of the Regulative ("Guidance document," 2012) is on the food transportation. As related to the transport, the Regulative emphasizes on:

- The transport, storage and handling of primary products at the place of production, provided that this does not substantially alter their nature;
- The transport of live animals;
- In the case of products of plant origin and fishery products: transport operations to deliver primary products, the nature of which has not been substantially altered, from the place of production to an establishment.

It is common for all primary products that conveyances and/or containers used for transporting foodstuffs should be kept clean and maintained in good repair and condition. Furthermore, to protect foodstuffs from contamination vehicles and/or containers should not to be used for transporting anything other than foodstuffs ("Guidance document," 2012).

Ryan (2014) states 15 food main risk problem areas during transportation: refrigeration and temperature control, transportation unit management (prevention, sanitation, etc.), packing, loading and unloading, security, pest control, container design, preventive maintenance, employee hygiene, policies, handling of rejected loads, holding and traceability. Therefore, no matter what kind of food commodities and products are transmitted, they all require common multiple steps in their transportation between point of origin and point of use in order to ensure safe food products transportation and to avoid any contamination (Keener, 2003).

Recent trends in food safety are focused on miniaturization of analytical procedures through application of sensors, biosensors, microchips lab-on-a-chip, or micro total analysis systems (Mirasoli et al., 2014). This will allow fast detection of possible contamination especially during transportation. Different parameters as indicators of contamination of foodstuff could be measured by miniaturized devices. These parameters could be temperature, humidity, chemical contaminants, microbial contaminants etc. Increasing of temperature and humidity cannot give information about the type of contamination which will occur but it is a sign of contamination in many types of food stuff (milk, meat, plants etc.). Thus, temperature and humidity can be taken as parameters to follow in sensor design in order to have universal sensors for many different foodstuffs.

4 A Proposition of Low Cost IoT Based Solution

Sensors are a key enabler in the realization of an IoT and many of the objects associated with the IoT are sensor-based systems. With the help of sensors in food safety system, temperature, humidity, carbon dioxide, heavy metals and other environmental conditions in fields, as well as perishable items during transport can be monitored. In this paper the creation of an economical, sensor based remote monitoring system using cost-saving technology based on cheap computer board and wireless communication modules is proposed.

The presented solution is based on two elements: a traceability (which provide information about a product which is tracked and monitored) and monitoring (which provide a state of the product and its environment). The main function of food traceability and safety monitoring system is to provide information and record keeping procedures that indicate the path of a product unit, a group of products or ingredients from a supplier, through all intermediate steps along the food chain to the final consumer (Zhang et al., 2011; Ene, 2013). For the fulfillment of the set functionalities, together with rapid technology advancements, a several key requirements which depend on global principles can be defined (Zhang et al., 2011; Ene, 2013):

- Wireless, light weight, small size, low cost solution equipped with accurate and stable sensors for an essential variable;
- Ruggedness and transportability;
- Non- or minimally-invasive;
- Compatibility and standardized information;
- Defining the resources and identification of lots of products;
- Continuous monitoring functions and real time food safety data gathering at each decision point;
- Recording information on the production process and establishing links between information;

- Sending the result to the cloud automatically so that can be viewed online in a presentation form that is easily understood;
- Food safety emergency response system: immediate recall and preventive elimination of potential hazards.

Aforementioned requirements represent a main guideline for building a custom monitoring system which can be applied on global scale issue.

To ensure traceability, a system must implement a set of GS1 standards which is de facto default way for communication of customers, suppliers and partners. GS1 provides a concept and technology for efficient way of accessing information about items in their supply chains, and share this information with trading partners. All organizations must be a member of GS1, and they obtain a GS1 company prefix which forms the basis of ID keys, unique identifiers for products, documents, physical locations and more. A technology which GS1 provides for identification of products is 1D and 2D barcodes, and lately commonly used a RFID tag which will be used in our case. For monitoring, sensor unit represents a main building element which can be combined based on user needs and monitor different elements and parameters of products and its environment.

Hardware implementation of proposed system is based on Raspberry Pi (RPi): a credit card sized, powerful and lightweight ARM based computer board which has support for a large number of input and output peripherals, and network communication what makes it the perfect platform for interfacing with many different devices and enables an almost limitless choice of its uses. RPi is running on Linux (version A, A+, B, B+, B2) or Windows 10 (version B2) operating systems, and the whole unit is powered with 5V and 200-800mA current, what implies a low-level consumption of 1-4W (depends on version). Internet connectivity may be via an Ethernet/LAN cable or via an USB WiFi, WiFi Shields, Bluetooth, WiFi/Bluetooth USB Combos, RF Add-ons and cellular solutions (3G/4G USB modem or GSM/GPRS shields). RPi usage as a hardware for building an IoT solution with in detail presented analysis of its performance and constraints is given in (Vujović and Maksimović, 2014). A complete solution of RPi utilization in home automation is presented in (Vujović and Maksimović, 2015), while proposition of communication over GSM/GPRS is given in (Vujović et al. 2015).

Relaying on presented knowledge, defined requirements and conclusions from Section 3, a proposition of custom solution is built and it is shown on infrastructure diagram in Fig. 2. In order to create as much as possible universal solution for monitoring many different foodstuffs during transportation, the cargo area (container, trailer) is equipped with Raspberry Pi unit (as a central processing unit) and sensors for measuring temperature and humidity (digital or analog temperature sensors). The advantage of the proposed system is the fact that additional sensors, depending on special food product monitoring requirements, can be easily added. Beside of that, a whole system is connected to devices for scanning and reading a cargo items (box, pallets, barrels, etc.), usually RFID but also a Near Field Communication (NFC) or Bluetooth devices can be used. In this solution, RPi behaves as a Web service (RESTful Web service) with unique address and provide worldwide access over the Internet (for sending measurement data) which is done over Wireless 802.11 or GSM/GPRS module. After the cargo is being loaded on transportation vehicle, an

RPi make a scan with middle range RFID and detects all items. When items' detection is completed, a list of cargo items can be read from Central Monitoring System (CMS) or accessed through unique Uniform Resource Identifier (URI) address, depending on further analysis. CMS detects and links items to GS1 database, recognizing the essential parameters for monitoring (in our case temperature and humidity) during the transportation process, and implements a simple (reading values from sensors and alerting when monitored parameters are disturbed) or complex (a fuzzy logic or neural network based systems for decision-making) monitoring system.

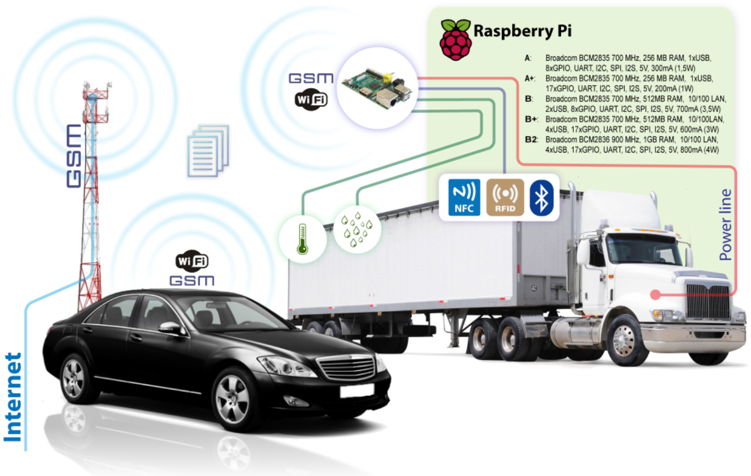

Fig. 2. Monitoring food safety during transportation.

Monitoring parameters of interest, this solution can provide an instant real-time view into food safety and trigger alerts if problems occur so they can be caught before real damage is done. The whole system can be powered from a vehicle or autonomous battery power supply. Optionally, the proposed solution can be used in the creation of sensor networks in connected vehicular environments.

5 Conclusion

Food safety is a main concern nowadays, and therefore it is crucial to have a system which enables foodstuffs traceability and monitoring during the whole food chain process. This paper, beside presented food safety requirements and existing systems, proposes a low cost solution based on IoT. The advantages of presented system for foodstuffs monitoring during transportation are: low cost, small size, flexibility, rapid system expansion, real time access and automatic cargo identification. Future research will be focused on interconnecting vehicles, sensors, and mobile devices into a global IoV network, what should enable various services to be delivered to vehicular and transportation systems, and to people within and around vehicles.

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