Smart Sensors for the Intelligent Container

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***Abstract*—Food losses along the cold chain can be reduced by accurate monitoring of the transport conditions. After 10 years of research on the 'Intelligent Container' we summarize our results in regard to the following questions: a) What are the challenges in establishing a wireless communication systems that links sensors inside food packing with global networks? b) Which sensors are most useful to detect deviations of food quality? c) Which improvements in the food chain are possible if detailed data about temperature and quality deviations are provided? d) What level of intelligence or smartness can be implemented on sensor or container level?**

Keywords—food logistics; cold chain; temperature monitoring; shelf life; first-expired first-out; food losses.

I. Introduction

One third of the world's food production is never eaten [1]. Large shares of these losses are related to the logistic cold-chain of food products. The shelf life gives the number of days until the products quality drops below an acceptance threshold. Losses in shelf life are often not visible from the outside. A 'red' tomato can have a shelf life of 2 weeks or only 2 days due to temperature mismanagement during transportation.

In order to detect such hidden shelf life losses we developed the idea of the 'Intelligent Container'. A wireless sensor network inside the container measures temperature and other relevant parameters. A so called Freight Supervision Unit (FSU) collects the data from the sensor network and operates as a gateway to global networks such as GSM/UMTS or the Iridium satellite system.

II. Communication challanges

In order to estimate shelf life losses it is necessary to measure the temperature directly in the center of the food packing. Unfortunately, the propagation of radio waves is hindered by the high signal attenuation of water containing products. Communication is only possible if messages are forwarded inside the network by means of multi-hop protocols. By a physical model [2] we could show that most problems can be overcome by reducing the operating frequency to a range below 1 GHz (Fig. 1).

In a global network, data has to be exchanged between the system of different companies and players in the cold chain. Hardware platforms of different manufactures have to be supported. A high level of standardization can be achieved if the data transmission is organized in accordance to standard Internet protocols: The IPv6 over Low power Wireless Personal Area Networks (6LoWPAN) protocol enables wireless sensor nodes to be addressed as any other Internet device. The Constrained Application Protocol (CoAP) is specially adapted to the requirements of Machine-to-Machine (M2M) communication (Fig. 2). CoAP is designed for easy interfacing with HTTP, but provides a reduced message length [2].

III. Sensors for food quality

Temperature has the most influence on food quality. Except for vacuum packed products, the air humidity should also be monitored. Low values lead to higher evaporation and weight loss; values above 80% increase the risk for mold infections. Especially the gas ethylene is an indicator for the start of unwanted ripening processes of most fruits. A new miniaturized gas chronograph makes it possible to measure ethylene directly in the container without the need for large and expensive laboratory equipment [3]. A further approach to translate the manual handling of culture mediums for mold detection into mobile and fully automatized system is currently under development [4].

IV. Improvements in the food chain

The flow of the cooling air is often blocked by inadequate packing or stowage of pallets inside the container. During our test transports, the efficient heat removal from the boxes was less than 10% of the nominal cooling capacity of the reefer unit. A thermal model [5] calculated the balance between heat removal and heat generation by biological processes in the food product (Fig. 3). The model enables to analyze the effect of improvements on the packing and detect critical situations in which the temperature runs out of control in an early state. However, proper control of the thermal balance it is even possible to ripen bananas inside the container as three field tests with our prototype have shown.

If the remaining shelf life is known for each pallet, this information can be used for intelligent stock rotation to reduce food losses. According to the first-expired first-out (FEFO) strategy products with low shelf life shall be send to close-by stores for immediate sale, whereas products with high shelf life can be hold back for intermediate storage or longer transport routes.

V. Embedded Decision Systems

For various reasons it is beneficial to evaluate the sensor data directly inside the container: a) Communication costs can be reduced if only warning messages are transmitted when a hazard is detected. b) External communication can fail; an autonomous system can react to critical situations e.g. by lowering the set point. c) A human operator is not able to handle full temperature records of various pallets in hundreds of containers.

The FSU or even the sensor nodes in the wireless network inside the container can be made smart by implementing a local decision system. A biological model, adapted to the special properties of the transported food product [5], was implemented on the sensor node level.

The thermal balance model required the product's and the air supply's temperatures as input parameters. It was therefore implemented on the FSU were both data sources are available.

The use of the JAVA programming language enables to update software bundles without stopping the system, the 'Intelligent Container' can therefore be easily adapted to the requirements of new types of products. Tests with the inversion of a 20 by 20 matrix showed that the FSU is even capable to execute complex algorithms, e.g. for spatial interpolation [6].

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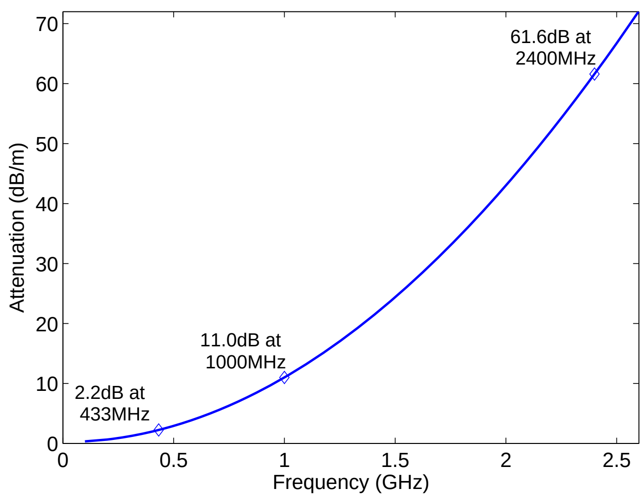

Fig. 1. Signal attenuation per meter as function of frequency for bananas inside a reefer container.

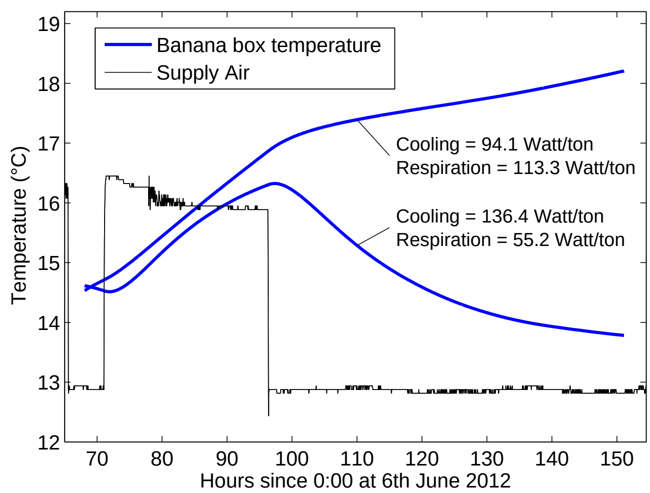

Fig. 3. Measured temperature curves for two boxes with good/deficient cooling and calculation of thermal balance.

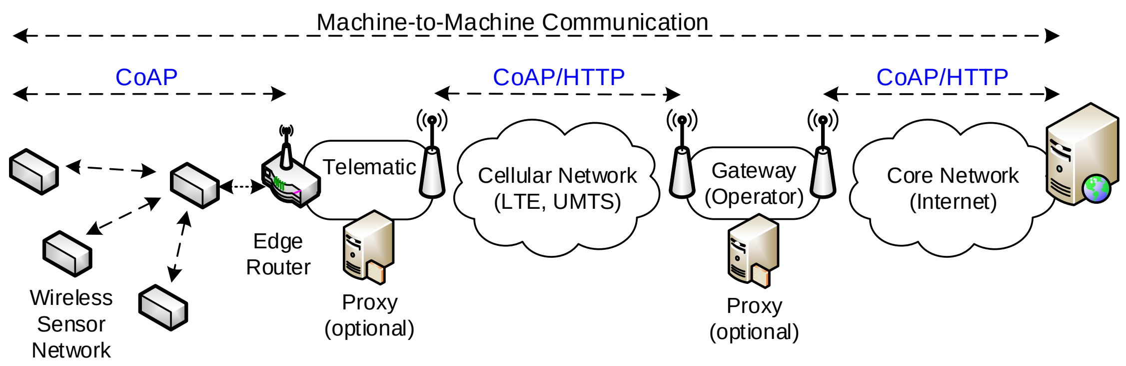

Fig. 2. Communication system of the 'Intelligent Container'.