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Applying autonomous sensor systems in logistics—Combining sensor networks, RFIDs and software agents

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Abstract

New sensor, communication and software technologies are used to broaden the facilities of tracing and tracing systems for food transports. An embedded assessing unit detects from sensor data collected by a wireless network potential risks for the freight quality. The estimation of the current maturing state of agricultural products will be supported by measurements of the gaseous hormone ethylene as an indicator for the ripening processes. A miniaturized high-resolution gas chromatography is under construction. The system autonomously configures itself to a product specific supervision task based on data scanned by an RFID reader during freight loading. Mobile software agents accompany the freight along the supply chain. They pre-process the vast sensor data and submit only substantial changes to the freight owner.

Keywords: Wireless sensor networks; Autonomous agents; Logistical applications; Ethylene sensors

1. Introduction

The transportation of perishable goods and foodstuffs has become a very important branch of logistics. More than 50,000 reefer trailers are registered only in Germany [1]. This line of business is a vast application field for sensor systems. Since the end of 2004 monitoring of transport parameters is legally required by EU regulations. The technical progress of data loggers strides through three generations. The first generation devices allow the recipient only to read a measurement protocol after end of transport. But these standard devices do not comply with the requirements of "just in time" processes. Damaged goods are only discovered at their final destination, when it might be too late for an appropriate reaction. The next generation of radio data loggers, allowing "on-the-road" access to sensor data, brings an improvement. But they can either only perform a very simple task or the amount of sensor data and configuration effort increases in a way that it cannot be handled by manual work.

In this work we present our concept and our first prototype for a third generation sensor system, characterized by: (a) autonomous configuration, (b) on-the-road sensor access and (c) autonomous assessing and decision-making. To get best performance we combine technologies from the fields of RFIDs,[1] wireless sensor networks and software agents.[2]

Ultra low power sensor nodes were developed for wireless communication with prolonged service intervals. Our miniaturized gas chromatography system [2] for detection of volatile aromatic components[3] will be optimized for high-resolution measurements of the ripening indicator ethylene.

2. Fruit logistics as example application

Fruit logistics was chosen as an example because of its market importance. The predicted total sum of maritime transport of refrigerated products for 2005 is about 57.1 million tonnes [3]. More than the half of it (56%) is allotted to fruit transports. Furthermore fruits and vegetables are an outstanding example for quality changes during transport. Unlike meat products fruits

[1] Radio frequency identification, an electronic "Barcode" with contact less interface.
[2] A form of artificial intelligence algorithms.
[3] The GC was developed under the CLEANAIR-Project as cooperation between IMSAS and CNR-IMM Sezione di Bologna, Italy.

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still live after harvest. Parts of the maturing processes take place during transport. Changes in quality and degree of ripeness along the supply chain are the normal case, not an exception. Enabling permanent supervision of these changes leads to an improved control of the transport chain.

During transport fresh agricultural products are chilled to a temperature between 0 and 15 °C. Deep freezing is seldom applied because of major quality reductions. Time pressure is given by the fruits themselves. Bananas have to arrive at the costumer within 3 weeks. Strawberries have to be delivered in less than 3 days. By controlled temperature and atmospheric conditions these time windows can be stretched.

Commonly used quality indicators such as firmness, starch and sugar content, taste and colour are not suitable for automated supervision, because they need unpacking and manual handling of the fruits or they even use destructive methods. Our aim is to derive a quality index from values that could be permanently measured inside a packed transport. These are the environmental conditions like temperature and humidity and gaseous metabolism products like carbon dioxide and ethylene.

3. System overview

The project is part of a new collaborative research centre[4] in Bremen, Germany. About 40 scientists are working in the field of adapting autonomous cooperating processes in logistics [4]. The sensor system will be integrated in a self-controlled transport supervision that goes beyond today's tracking and tracing systems. The demonstrator will be completed at the end of the first phase of the collaborative project in 2007.

The scope for automated decisions ranges from sending a message to the freight owner over changing the route planning up to ordering a replacement delivery. Our autonomous monitoring system for means of transport (MOT) consists of three layers: the sensor nodes, an internal wireless network and the assessing unit. The assessing unit operates at one hand as a gateway to the external logistical network, but its main task is to deduce changes of good quality from measurement values.

4. Sensor nodes and network

To handle the necessary protocols the sensors were equipped with a low power MSP430 microcontroller. The new designed sensor boards provide build-in self-test facilities.

For a detailed assessment of stress exposed to the good, the environmental parameters cannot be regarded as position independent. Especially the temperature may vary for a critical value. Locally freezing of the freight can cause major quality losses. This can happen due to improper adjustment of the freezer aggregate or blocking of the cooling air stream due to wrong packing. In extension to American regulations with four required temperature sensors, we implement a wireless sensor network (WSN) to monitor the gradient of different environmental parameters.

Besides secure communication the reduction of energy consumption is the most appealing challenge in designing wireless sensor networks. The service intervals for the battery powered sensor nodes should extend over several months. Measurement of slow changing parameters like temperature, humidity and illumination is not critical. These parameters can be monitored with an energy consumption of less than 1 mAh per month by interval measurements [5]. For the microcontroller that remains most of the time in power down mode about one additional mAh has to be added. Rapid changing parameters like acceleration/shock require constant measurement. For acceleration we have chosen the Star ACB302 sensor [http://www.starmicronics.com] with 72 mAh per month.

In order to reduce the power consumption of the wireless network we make use of the new IEEE standard 802.15.4, which is the base for the ZigBee protocol. But even with this ultra-low-power standard the communication is more expensive than taking a measurement. The communication rate has to be reduced to less than one message per minute on average.

The rate is adaptively controlled by the actual measurement value and the specific requirements of the monitored goods. In close proximity to critical values the sensor node reports even small deviations. In save regions only major changes are communicated. With the Chipcon CC2420 RF Transceiver the power consumption is about 2.5 mAh per month for an average rate of one message per minute. The owner has at any time access to each good and its state by a mobile connection.

5. Gas sensor for ethylene

For agricultural products the gaseous hormone ethylene is the most convincing indicator for stress exposed to the crop. Gäbler [6] found a distinct relationship between time dependency of the gas concentration and remaining quality at examinations of lettuce and other fruits.

During the maturing process nearly all plants exhale ethylene. Neighbour plants react to this gas by initiating ripening and ethylene production themselves. This can lead to a chain reaction where one overripe fruit can spoil hundreds of tonnes if they are connected to the same closed loop air stream. Especially

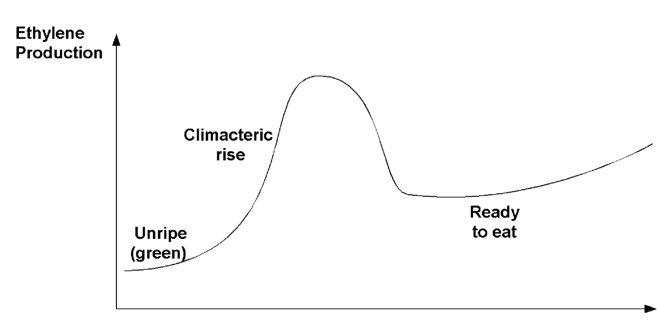

Fig. 1. Schematic course of the ethylene production over time for climacteric fruits.

[4] Collaborative Research Area Autonomous Cooperating Logistic Processes: http://www.sfb637.uni-bremen.de/.