APPLYING AUTONOMOUS SENSOR SYSTEMS IN LOGISTICS

Combining Sensor Networks, RFIDs and Software Agents

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Abstract: In this work we present an integration of a wireless sensor network into a logistical system. Based on data scanned by an RFID[1] Reader during freight loading the sensor network is configured to perform a specific monitoring task. Autonomous software agents assess whether goods are in danger due to wrong environmental conditions. If necessary the agent triggers an appropriate reaction.

Keywords: Wireless Sensor Networks, Autonomous Agents, Logistical Applications

Three generations of Sensor Systems

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 [6]. This line of business is a vast application field for sensor systems.

Since end of 2004 monitoring of transport parameters is legally required by EU regulations. First generation data loggers allow the recipient to read a measurement protocol. But these standard devices don't comply with the requirements of „just in time“ processes. Damaged goods are only discovered at their final destination, when it might be to 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 can't be handled by manual work.

In this work we present 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].

System Overview

The project is part of a new collaborative research center in Bremen, Germany. About 40 scientists are working in the field of adapting autonomous cooperating processes in logistics [8,10] . The Sensor system will be integrated in a self-controlled transport supervision that goes beyond today's tracking and tracing systems.

The scope for automated decisions ranges from sending a message to the freight owner over changing the route planning 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.

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 can't be regarded as position independent. Especially the temperature may vary for a critical value. Locally freezing of the fright 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 save 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 [2]. 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 [www.starmicronics.com] with 72 mAh per month.

To reduce the consumption of the wireless network we make use of the new IEEE standard 802.15.4, which is the base for the ZigBee protocol.

1 Radio Frequency identification, an electronic „Barcode“ with contact less interface

2 A form of artificial intelligence algorithms

But even with this ultra-low-power standard communication is more expensive than measurement. The communication rate has to be reduced to less than one message per minute in 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.

Gas Sensor for Ethylene

For agricultural products the gaseous hormone ethylene is the most convincing indicator for stress exposed to the crop. The remaining quality can be deduced from the time dependency of the gas concentration [5]. Ethylene is equally an indicator and an accelerator for maturing processes.

Available devices [http://www.icastorage.com/ica56.htm] allow measuring gas concentrations above the limit where ethylene acts as external influence that promotes decay. For most crops this limit is above 1000 ppb (parts per billion). To use the ethylene emission as an indicator for an early maturing state a much higher resolution is necessary. First surveys [5] showed that typical concentrations rage from 20 to 100 ppb. A resolution of 1 ppb or better is needed to record the concentration over time function.

Due to its small molecule size ethylene (C_2H_4) is hard to detect by gas chromatography. Near Infrared Spectroscopy (NIR), Thin Film Resistive Sensors and photo-acoustic (PA) methods can be applied for detection. These methods suffer from cross sensitivities to CO (e.g. exhaust fumes), $C0_2$ (crop metabolism) and H_2O (humidity). Available sensor elements achieve resolutions in the region of 100 ppm. Only PA-methods are suitable for high-resolution detection. With appropriate technical expenditure ethylene can be measured in concentrations of 0.1 ppb [4].

We work on a micro technology based solution that is small and cost effective enough for permanent monitoring of containers and transport vehicles.

Assessing Unit

The freight owner is rather interested in statements about freight conditions than in detailed sensor information. Dynamic transport and route planning needs assessments of the following factors:

- **Current quality state** of the good
- **Remaining logistical time window** to decide whether it is still possible to deliver the good in perfect condition
- **Acceleration factor for maturing processes** to indicate the stress caused by deviations of the environmental parameters or contamination by micro organisms.

Our partner institute FriLLog has introduced a general model for the dynamics of quality loss [7]. Assessing schemes for specific products are under development.

The vast information requires automated processing. The communication with the container might break down during transport. Costs of mobile or satellite communication have also to be considered. For these reasons the preprocessing of the sensor values is done locally by an embedded system mounted inside the means of transport as assessing unit. Only major changes of the freight condition are reported to the outside.

Autonomous Configuration

The demands on the sensor system change at each new transport. First the number of available sensors may change with the loaded freight. The list of possible radio connections between the sensor nodes is dependent of the packing and may also vary during transport. The network tree structure has to be updated automatically. For the distribution of the measurement task over the sensor network battery state, tolerances, position and reliability have to be considered. Sensor tolerances and faults should be compensated automatically. The network should be configured in a way to get all necessary data with the least possible energy consumption.

And secondly the assessing unit has to adapt to the special fright requirements at each transshipment. The unit doesn't know in advance how a certain good has to be supervised. The freight owner might even give the good an individual transport instruction on its way.

In the further course of the project the task of the assessing unit will be extended to plan appropriate reactions to endangerment of the freight.

RFID and Parallel Information Stream

Fright items are identified by a unique number (UID) stored on an RFID label. On one hand it is desirable to save all freight information and the complete sensor protocol on the label. But in practice a lot of restrictions have to be considered. RFID systems still don't comply with the wishes of transport companies. UHF Readers are able to detect a label in a distance up to 3 meters but they can't penetrate materials containing metals or moisture.

Tags can only be accessed during loading and unloading. New UHF technologies loosen the limits for storage size and transfer rate, but the risk that changed data get lost during rewriting at unloading is still present. All critical data have to be transmitted over a reliable network. Besides the UID number the tag contains only selected duplicate information for quick access. If this information gets lost, a backup can be retrieved from the network. The freight state, the assessing function and reaction schemes are transmitted in a parallel information stream. This electronic consignment note accompanies the real object.

Technical Implementation

In our prototype we make use of a 13.56 MHz reader from Feig Electronic [www.feig.de]. The effective data rate of the ISO 15693 protocol including overheads is less than 1 kbit per second. To avoid prolonged access times we restricted the amount of data stored on the tag to 64 Bytes. Experiments resulted in 200 ms for data reading at the loading process and 400 ms for rewriting changes at unloading. To extend the reading range and speed up the data transfer we will switch over to UHF readers that are now available for the European market.

The hard- and software for the assessing unit was chosen to comply the following needs:

- Sufficient calculation capacity for preprocessing and network configuration
- Ability for dynamically loading of assessing functions
- Integration into the means of transport. Limits in costs, size and power consumption have to be considered.

The ARM7 family provides a good relation between speed and power consumption. In our prototype we used Intel's StrongARM consuming 1 W at a clock rate of 200 MHz. Two further ARM9 derivates are under test: Intel's XScale and NetSilicon's NS9750.

Software

The selection of the programming language was driven by the need to execute platform independent dynamic code for the transport instructions. JAVA supports this feature but has hardly been used on embedded Systems. The new Jamaica environment allows even real time applications under JAVA without stalls by garbage collection [9]. With JAVA it is possible to download and execute the code of the assessing function. This process resembles the loading of applets from Internet pages.

In our solution we implemented a concept that goes beyond downloading dynamic code. Programs that are already in the state of execution have to be transferred. The used mobile software agents are a special software construct that perform a defined task: for example the freight supervision on behalf of the owner. Several hosts unite to form an agent platform. Within this platform agents communicate independent of their current location. A simple command transfers an agent with its program code and current state to another processor. The new location could be the assessing unit of the next means of transport or a warehouse.

This JADE [1] framework was developed in a former EU-Project. We adapted this platform to a JAVA environment that supports processors from the ARM family.

Tests with our system prototype demonstrate that it's feasible to apply even a “luxury” framework like JADE to embedded systems. Only JADEs mobility mechanisms have to be downsized. The current method causes delays by transferring the complete class graph with more than 20 subclasses. By taking the advantages of object orientated programming only changes toward a library of predefined parent functions have to be transmitted.

The monitoring process

The producer or manufacturer of the good starts the supervision agent and defines how sensitive the agent reacts to sensor deviations. The agent connects himself with the sensors of the warehouse to start the monitoring. The processes that take place when the good is loaded into a means of transport with autonomous monitoring are summarized in **Figure 1.** New fright items are detected by an RFID reader mounted at the vehicle door or at the loading platform. The UID, the kind of good and the address of the last known agent location are picked form the tag. With this information the embedded assessing unit requests the corresponding fright agent. The agent with the assessing function continues his work on the local processor. Based on values retrieved from the wireless sensor network he estimates the current stress for the fright item.

Warnings and recommendations are sent through the external network. This could be as in our prototype the WLAN of a transshipment point or a cargo ship. If the vehicle leaves the range of the local network satellite or mobile communication has to be used. At unloading the location address and changes of the freight state are written back to the tag. The receiver could easily scan the product quality with a handheld reader. The owner can watch all freight messages concerning his consignments by a graphical interface **(Figure 2)**. He can also send requests to the means of transport for the current fright state and sensor conditions.

Conclusions

Autonomous decisions enable fast reactions times to violation of specified sensor limits without human delays. The separation of sensors and identification tags allows full room monitoring without the need to apply expensive sensor notes to each transport item. The System can be easily expanded to special sensor requirements.

In a few years time the use of RFID-Tags on transport items will be a standard in logistics. It is a logic step to use these available tags for sensor configuration. There is a great challenge in modern logistic to broaden tracking and tracing by extensive sensor facilities.

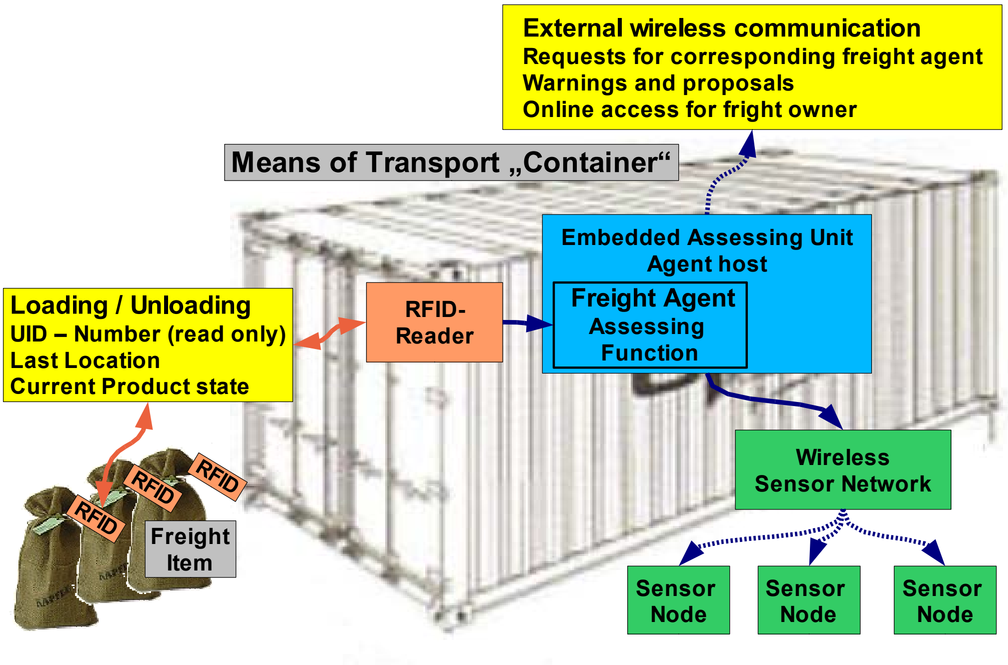

Figure 1: Monitoring Process

Monitoring

Freight Messages | Error Messages | Freight List | Sensor Values

Time	Location	Message	UID	Product	Priority	Astress	Cstress
15:15:04	Vehicle IP-99	Quality loss, take immidiate action!	e004010000586cf6	Tomatos	yellow	50,0	0,5
15:13:22	Vehicle IP-99	Freight is losing quality	e004010000586cf6	Tomatos	normal	25,0	0,5
15:13:06	Vehicle IP-99	Freight moved to new transport	e004010000586cf6	Tomatos	normal	21,0	0,5
15:12:50	Vehicle IP-99	Freight moved to new transport	e004010000586b7e	Cucumber	normal	2,25	0,25
15:12:36	Warehouse-1	Freight item waiting for transport	e004010000586b7e	Cucumber	normal	0,25	0,25
15:12:12	Warehouse-1	Freight item waiting for transport	e004010000586bff	Lettuce	normal	0,2	0,2
15:11:54	Warehouse-1	Freight item waiting for transport	e004010000586cf6	Tomatos	normal	0,5	0,5

Freight: Tomatos @ Vehicle_IP-99 : Quality loss, take immidiate action!

Figure 2: Detail of the graphical interface for the owner (time-lapse mode)

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