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Linking RFIDs and Sensors for Logistical Applications

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Abstract

RFID and sensor technologies will have a great impact on supply chain logistics in the next years. Linking these technologies is an essential factor for cost reduction. Besides the direct hardware link we present a solution that allows Online-Access to the sensory environment of each transport item and enables automated supervision of surrounding parameters. The control system adapts to the individual parameters of each merchandise stored on an RFID-Label. Compared to a data logger solution our approach offers more flexibility. A possible technical realisation of the novel solution is presented by our prototype.

Three new trends in Logistics

Modern supply chain management will be an important market for sensor systems. To understand how future sensor applications could look like, it is helpful to examine the three main areas where new solutions are needed.

Supply chain control by RFID

The control of the supply chain will become more and more automated. RFIDs[1] offer a higher performance as optical codes like the well-known barcode. RFID-Transponders or -Tags store a unique number to identify the merchandise. They can be read by an electromagnetic field up to distances of a few meters. The transponder chips obtain their energy from the magnetic field. Their lifetime is not limited by batteries. After activation by the field the tag sends his number by shortcutting his antenna[2].

Great retailers like Metro[3] (Germany) and Wal-mart (USA) force their suppliers to equip each palette or covering box with RFID-Tags. The Tags are scanned at each reloading. Combined with a GPS System at the means of transport it is possible to trace each palette: Where is its actual position and is it in the right transport?

By now there exists a vast number of proprietary solutions in industry and logistics. There is a huge demand for a global standard like EPC[4] [EPC].

Monitoring of merchandise state by Sensors

The amount of perishable goods needing sensor monitoring is increasing. The monitoring of transport parameters is required by international regulations and by insurance companies. The traceability of foodstuffs must be assured by end of 2004 [EU02] and the temperature must be comprehensively recorded during cold transport.

There is also a need for locally detailed sensor information. The temperature within a freezer-container may vary by a critical value due to wrong packing. The heat of decay processes[5] may cause local maxima, which won't be detected if only the air temperature of the freezing aggregate is monitored. American regulations force four distributed temperature sensors in freezer-containers.

By now most systems are restricted to data loggers recording the temperature. These data loggers are used to prove product quality. In case of damaged goods they might be used to clear responsibilities.

Sensors for humidity and vibrations will give valuable additional information. Low cost sensors for special parameters like the detection of decay gas are still on the wish list.

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1 Radio Frequency Identification
2 This effect is called „Load modulation“, at higher frequencies data are send by wave reflection / backscatter modulation
3 22 Top suppliers by November 2004, 70% of all goods will be tagged end of 2005
4 Electronic Product Code a 128 bit code containing manufactory, kind of good and serial number.
5 This problem occurs e.g. on Transports of Pollack from Alaska to the EU.

Online access to transport goods

The trend to „Just-in-time“ logistics forces fast reactions. It is necessary intervene before the merchandise arrives at the wrong receiver or in a damaged state. Problems like loading mistakes or a quality loss of the product should be reported immediately. Loading mistakes can be recognised by RFID-Readers installed at each place of transhipment. But a quality loss due to inappropriate environmental conditions can happen at anytime during transport. The means of transport must be equipped with sensors, reporting errors by wireless network to the carrier.

How to link RFIDs and sensors

RFID and sensor technologies take the crucial part in fulfilling these needs. At the moment the marked is crowded with a lot of proprietary solutions. RFIDs and data loggers are implemented as separate systems. For RFID a powerful network is developing allowing access to product data at every transportation node. Our aim is to enable access to RFID and sensor data by the same network. The question is how to link RFIDs and sensors.

Two different approaches

For the linked system we have to distinguish two contrary approaches. The crucial point is the importance of Online-Access to the merchandise. If you can do it without accessibility at any time, then a combined RFID-Sensor-Label might be the best starting point. But if all three needs of modern logistics should be fulfilled, we have to discuss a more complex solution.

Combined RFID-Sensor-Labels: The Data Logger Solution

RFIDs with combined sensors have been used for many years [Fink02]. There are already technical solutions in the market place that can be used in logistics. Sensor and RFID are combined in a micro system on hardware level [Figure 1]. Because the sensor should collect data even in the absence of an RFID-Reader, he can't be powered by the magnetic field. The chip card sized TempSens-Labels obtain their energy from a paper-thin battery [KSW]. They perform as a data logger that can be traced by RFID-Readers when the merchandise is reloaded. They conform to the first two needs of modern logistics. On arrival the receiver can control maximum temperature values by a special RFID-Reader. Product information can be stored on the label as well.

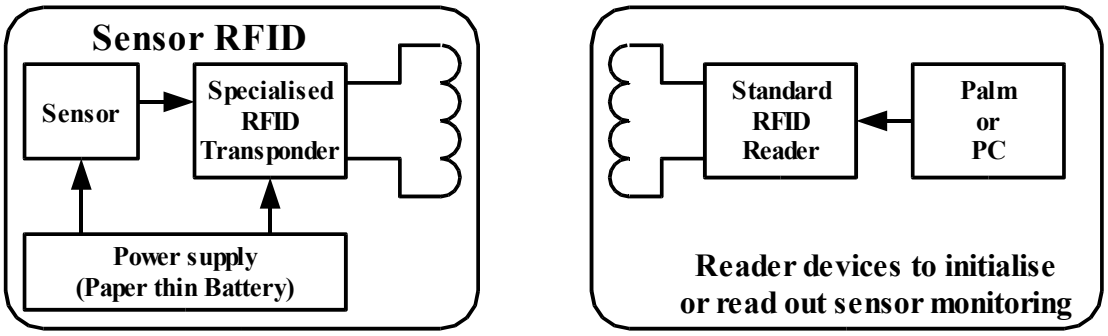

Figure 1: Block Diagram of combined RFID-Sensor-Label with Reader

Restrictions by the Range of RFID-Readers

UHF-Readers can read Labels from a distance up to 3 meters. Metals or liquids considerably reduce the reader range. Therefore it isn't possible to scan the content of a packed container. RFID-Labels can only be accessed during loading or unloading.

The third need of modern logistics can't be meet by these systems. An Online-Access to sensors during transport can't be achieved by passive RFID communication. An active wireless communication is needed.

Combining RFID and Sensors by Software: The Novel Solution

For economical reasons it isn't feasible to combine RFID-Sensor-Labels and wireless communication in the same micro system. RFID-Sensor-Labels already extend the costs of a standard RFID-Tag by the factor of ten. By adding wireless communication the factor will increase to about one hundred. The answer to the three needs must be rather a network solution than a single micro system.

To allow Online-Access to the environmental conditions of each merchandise at reasonable costs we developed or novel solution. It is characterised by separate hardware for RFID and sensor. The link is performed by the software of a special board computer. The System consists of the following elements:

- **RFID-Labels:** Standard RFID-Tags are used. Beside the identification number information about the kind of good and the specific limits for environmental conditions are stored. These Tags are available for much less than one Euro.
- **RFID-Reader:** The door of the means of transport is equipped with a long range RFID-Reader. Alternatively Dock-Door-Readers can be installed at the loading platforms.
- **Wireless Sensors:** It is not necessary to equip each transport unit with a set of sensors. A distributed sensor network is required to get reliable data for each good, but the number of sensors will be much lower than the number of goods inside the means of transport. Wireless sensor nodes with battery powered active communication allow access even in a packed container.
- **Board Computer:** A software agent running on the master node or board computer performs the link between RFID and sensors. The agent is initialised with monitoring parameters that are detected during the loading of the RFID-Tags. Sensor values are demanded from the wireless network and logged during transport. During transport no access to the RFID-Tag is necessary. The sensor protocol or a special mark if boundary conditions were overstepped is written only at unloading of the good.
- **External Network:** The board computer mediates between the inside low power / short range and an outside global communication. In our prototype the environmental conditions of each merchandise can be accessed by a web interface.

Use of the novel system

The novel system can of cause be used as a data logger. The sender attaches a cheap RFID label on the merchandise and writes the product data and boundary values on it. The receiver controls with an RFID-Reader if the parameters during transport complied with the given boundaries. If not, a time stamp is written on the label.

But it is not enough to know, when the good are finally damaged. To be able to intervene in time the system also reports critical states as soon as a lower threshold is exceeded.

During transport the state of each merchandise can be controlled by the web interface [Figure 2].

Transport Monitoring

Consignment			Sensor state			
Type	Container		**Type**	**Current**	**Max**	
Destination	Hamburg		Temperature	3	8	° Celsius
Number	123456		Humidity	45	48	% Relative

Content (Packages)

ID	Product	Destination	Temperature		Humidity		State
			Critical	Max	Critical	Max	
E0A8B9C1	Books	Hamburg	70	80	50	60	**Ok**
E0123456	Fish	Kiel	-2	5	90	100	**Exceeded**
D1654321	Coffee	Bremen	30	40	40	50	**Critical**
C00456A9	Fruits	Bremen	5	10	90	100	**(Critical)**

Figure 2: Example view of the web interface

Automated decision making by Software Agents

The vast of information can't be handled by human resources alone. The Online-Access to all sensor values of each item creates a fourth need in modern logistics. Decisions or at least recommendations should be made automatically.[6] To be independent from communication problems the intelligence has to be distributed in the logistical system. Our project is part of a new collaborative research centre in Bremen, Germany. About 40 scientists are working in the field of adapting autonomous cooperating processes in logistics [SFB04].

A software agent representing the transport-units is either stored on the RFID-Tag or in a database. His abilities go far beyond monitoring maximum values. He decides himself whether it is necessary to take action. If the good is in danger he contacts other agents to initiate a replacement delivery or to organize selling ahead of schedule. The board computer as part of an intelligent container hosts the agents.

Technical Implementation

Our first desktop size prototype demonstrates the application of the system. A transport situation with various goods and different environmental limits can be watched by a web browser. The definition of the merchandise is scanned by an RFID-Reader [Figure 3].

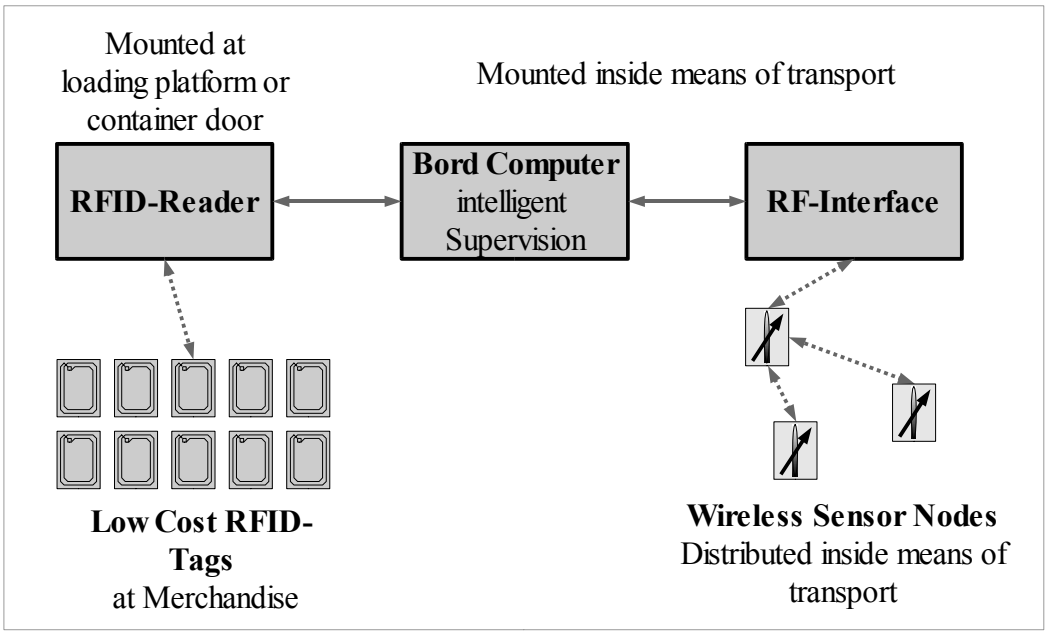

Figure 3: Block Diagram of our novel system

Board Computer

The Heart of the system is the board computer. It consists of an ARM-Processor and various interfaces for sensors and the RFID-Reader. The system is connected to the outside world by a WLAN-Bridge. For later experiments the WLAN interface will be replaced by an UMTS modem.

We are evolving to different implementations of ARM Processors: The DilNetPC with Intel's Strong-Arm or Xscale from SSV-Embedded[7] and NetSilicons NS9750 Teaser Board[8]. They provide clock rates of 200 or 400 MHz at a power consumption of 1 Watt. This is not critical because the board computer can share the power supply of the means of transport, e.g. the cooling unit of a container.

Software

Dynamic code is an intrinsic feature of the system. Goods can bring their own code defining measurement and reaction schemes. The host for agents has to be platform independent. During transport the agent code can travel from a high performance workstation to a reduced embedded system. These requirements are best fulfilled by JAVA as programming language, although it consumes more resources. But by using up to date tools there is no need to exclude embedded Systems from the JAVA world. A special high performance

[6] The carrier controls the grad of autonomy of the system. During Learning all decisions are counterchecked by humans.

[7] http://www.dilnetpc.com/, see DNP1110 or DNP2110

[8] http://www.netsilicon.de/products/netarmprocessors/ns9750.jsp

JAVA virtual machine allows execution without stalls by garbage collection [Sie02]. Most parts of the code, which are not dynamic, are precompiled to save processor time.

RFID-Reader

RFID-Readers work is different frequency ranges. The 13,56 MHz standard is gradually replaced by UHF-Readers working at 866 MHz[9]. We decided to use a 13,56 MHz system, because the standardisation process for UHF-Tags wasn't finished yet. But the 13,56 MHz high frequency range has some disadvantages: First the reading range is physically limited to 1.5 meter. With two antennas it is barely possible to supervise a container door. And secondly the transfer rate is limited to 1,65 kBit/s[10]. To transfer one kBit of product information will take about 1 second. End of 2005 we will switch over our prototype to UHF-Range.

Sensors

For the sensor nodes we aspire a battery lifetime of one year. The Sensors are mainly chosen by their power consumption. Another important factor is the relationship between measurement duration and interval. Temperature and humidity are for example slowly changing parameter. It is more than enough to monitor them in intervals of 100 seconds. The actual measurement is typically done in 0.1 seconds. Our example sensors Sensirion SHT75, Texas Instruments TMP121 and Galltec CalHT06 consume less than 1 mAh per month. Monitoring a container door with a hall switch is also possible at this value.

Acceleration and gas detection are much more power consuming. The shock after a fall is a very short event. The acceleration sensor has to be active 100% of time. The Star ACB302 three-axis sensor offers the lowest power consumption of 72 mAh per month.

For gas sensors two technologies are available: Resistive thin film and infrared sensors. Both have a high current consumption of about 100 mA either to heat the device or the power the infrared light source. The energy consumption is proportional to the time to reach a constant temperature. IR light sources have the advantage of a very fast reaction time. The Heimann EMIR source can be clocked at 30 Hz. Combined with a HTS Multichannel Sensor three gases can be detected simultaneously. For an active period of 1% the power consumption is about 100 mAh per month. But not all gases can be detected by infrared spectroscopy. Oxygen for example has no relevant absorption line.

For the wireless communication with the sensors we use the low power 802.15.4 standard. The network is organised in a hierarchical system, where the board computer acts as master node. The Sensorboards with wireless interface are under development. Prototypes will be finished this year. Security protocols for wireless sensor networks will be presented in the following session [Gor05].

Conclusions

Our demonstrator shows how future sensor monitoring of transport goods could look like. Considered for direct transport without reloading our solution shows the most advantages. Compared to stand-alone data loggers, the novel solution offers much more flexibility. New sensor types can be added easily if required.

The cost advantage increases by the number of single packages needing sensor tracing. One time investment enables a data logger function for less than one Euro per item. The RFID-Tags don't need to be collected and reused as more valuable stand-alone data loggers.

Two questions have to be considered to assess the usefulness of the novel solution in the context of a complex supply chain:

First the significance of Online-Access. Online-Access has always to be secured by encryption and authentication. If only an offline data logger function is needed to prove product quality and to settle insurance questions after end of transport, combined RFID-Sensor-Labels might be the best solution. They are easy to implement and don't require special equipped means of transport. A simple password protection might be satisfying for security. But if the permanent availability of sensor information is an important feature, a more complex solution than an integrated RFID-Sensor-Label is the answer.

And secondly the number of involved different means of transport. The complexity increases with each reloading. The novel solution will be first applied in short or circular supply chains with a limited fleet of means of transport. This is very comparable to today’s situation of commercial RFID implementations. But in the course of globalisation of RFID controlled supply chains the big carriers will be disposed to new investments and new standards. Now is the change to get wireless sensors into these standards.

[9] In America an other frequency range is used, readers have to switched to 930 MHz

[10] For the long distance mode of the ISO 15693 protocol, including address an redundancy bits

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