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Two Application Examples of RFID Sensor Systems – Identification and Diagnosis of Concrete Components and Monitoring of Dangerous Goods Transports

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Abstract**-**The combination of radio-frequency identification (RFID) tags with different types of sensors offers excellent potential for applications with regard to identification, diagnosis, and monitoring. This should be demonstrated by means of two examples of actual developments carried out by the Federal Institute for Materials Research and Testing (BAM). The Identification and diagnosis of concrete components is a major task in the maintenance of critical infrastructure, for instance concrete bridges with heavy traffic volume. A feasibility study investigates the application of RFID sensor systems for this task. The second example reviews the transportation of dangerous goods. Using modern technologies enables promising possibilities to reduce accidents and to avoid non-conformity with transportation regulations. Project results demonstrate an innovative technical solution for monitoring of dangerous goods transports with RFID sensor systems.

I. Identification and Diagnosis of Concrete Components

Infrastructure is subject to continuous ageing. This has given life cycle management of infrastructure an important role. Therefore, an increasing demand for reliable inspection and monitoring tools is noticeable. The prediction of the service life of a new structure at the design stage or the diagnosis and the evaluation of the residual service life of existing structures is a key aspect of concrete structure management. A reliable prognosis of the condition and behavior of a structure is an important basis for an effective service life management. In order to determine the most economical point in time for repair measures in the lifetime of a structure, the knowledge about the deterioration process at exposed regions as well as a detailed knowledge about the current condition of the whole structure is essential [1].

Embedded Sensors are meeting the demands for gathering more information from the inside of a structure. Wired Sensors are meanwhile well established but may have disadvantages in case of a subsequent installation in existing structures. Wireless sensors which can be embedded in concrete provide an attractive alternative solution. This study summarizes the activities of a research project which dealt with the suitability of RFID sensor tags for concrete bridge structures.

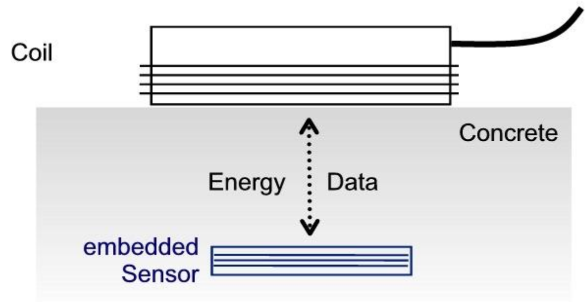

Figure 1. Scheme of the interaction between reader coil and embedded sensor in concrete

RFID is the wireless non-contact use of radio-frequency electromagnetic fields to transfer data (Figure 1) for automatically identifying and tracking tags attached to objects and is well developed and known in commercial use. Upcoming developments in sensor based tags for monitoring purposes in logistic and transport can be modified and used in civil engineering. This technology is by all means promising to be used within a monitoring system enabling a condition assessment for concrete bridge structures. The aim of the presented project, which was funded by the German Federal Highway Research Institute (BASt), was to investigate modular RFID sensor systems with respect to their basic suitability for the use in concrete (bridge) structures. The selected RFID tags have a sensor interface to be connected to sensors with low power consumption. The measured values of the embedded sensors can then be read wirelessly.

After a literature and product research, the project focused on basic investigations, such as:

- selection of suitable sensors for humidity, temperature and corrosion activity [2, 3]
- application of the sensors to reinforced concrete structures
- determination of the maximum distance (cover), at which an RFID sensor tag can still be discovered and delivers correct data
- comparison between high frequency (HF) and ultra-high frequency (UHF) radio communication
- investigation in laboratory and real world application

For this purpose, prototypes or RFID sensor tags where developed (Figure 2), assembled, encapsulated and embedded in concrete specimen with size of about 30 x 20 x 5 cm^3 (Figure 3). Measurements in climate chambers were carried out and showed useful results.

Figure 2. Encapsulated RFID sensor tag with reinforcement

Figure 3. Preparation of concrete specimen with embedded RFID sensor tag

Figure 4 shows the results of humidity measurements in a climate chamber comparing the encapsulated and in concrete embedded RFID sensor tag (red) with a not embedded tag (black). Relative humidity was applied between 10 and 90 % in steps of 20 %. While the signal sequence of the not embedded tag follows immediately the applied humidity settings, the sequence of the embedded tag is delayed caused by the transport processes through the concrete. The delay increases with increasing humidity indicating slower transport characteristics, presumably due to approximating saturation. However, measurements were successfully performed with the embedded specimen, with coherent results over the full measurement range.

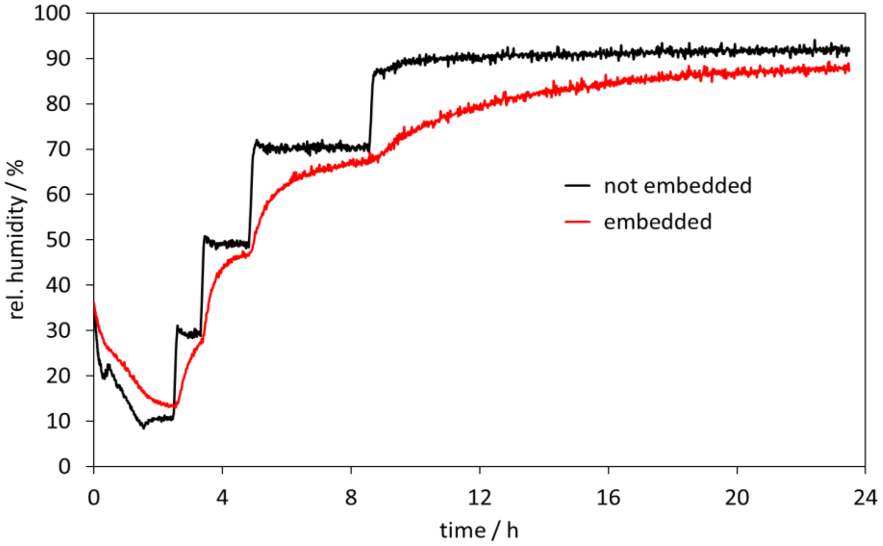

Figure 4. Humidity measurements, comparison between embedded and not embedded RFID sensor tags

Range measurements were carried out to determine the maximum distance of RFID data communication through concrete. The results show that an effective range of up to 170 mm is reachable with the developed RFID UHF system in the undisturbed case. In addition, the developed RFID sensors were successfully embedded in a reinforced concrete slab with properties of a typical bridge superstructure. The laboratory experiments have confirmed the basic functional efficiency and reliability of the developed sensor system. Further investigations will be carried out on bridge components under real application conditions.

The demand for embedded sensors in civil engineering is increasing. For further developments, other measuring principles as a supplement to or a combination with the developed system are being investigated.

II. Monitoring of Dangerous Goods Transports

The project "Sensor-enabled RFID tags for safeguard of dangerous goods" with acronym SIGRID investigates and evaluates possibilities to improve safety and security of dangerous goods transports through the use of the latest RFID technology [4]. This technology can be used to greatly enhance the transparency of the supply chain and aid logistics companies in complying with regulations. In the context of SIGRID custom RFID sensor tags (Figure 5) were developed to monitor dangerous goods during transport and help to prevent hazards by allowing timely countermeasures. This requires the combination of communication technology and sensor functionality with low power consumption and small design.

To achieve long battery-life, the use of very energy efficient sensors is mandatory. Other desirable properties of the sensors include high accuracy, long lifetime, and short response time. For gas sensors a high selectivity is also very important. Currently four types of sensors are integrated in the RFID tag, which are a combined humidity and temperature sensor, gas sensors for carbon monoxide (CO) and oxygen (O^2), and a tilt sensor. Other interesting sensor options that might be tested in future include sensors for detecting the filling level and sensors for monitoring the operation of equipment that is built into the container like a stirring unit.

Figure 5. Prototype of the sensor enabled RFID tag

The integrated sensors enable the system for recognizing and evaluating of different scenarios. Adequate gas sensors indicate an emission from the containments via measured concentrations. If a possible gas release from the transported substance cannot be detected because of lacking the proper sensor, the O^2-sensor can indicate a leakage through decreasing oxygen values. For numerous dangerous goods a maximal transport temperature is defined to prevent any chemical reaction. Temperatures can be measured and compared periodically to substance specific values. If that value or a tolerance is exceeded an alarm or countermeasure can be activated. The tilt sensor can be triggered on heavy vibrations or tilting of the containment. In case of a dangerous good accident the available information about the type, amount, and condition of the dangerous goods can be used to accurately inform the relief forces. Unavailable or inaccurate information represents a significant problem. This often leads to a delay of the rescue operation, because relief forces must be aware of the involved substances and their condition to effectively protect themselves against them.

Within the scope of the project, an RFID tag was developed, that allows connecting with different types of sensors. This RFID tag combines the advantages of semi active (only sensors are battery supplied) and active tags (sensors and radio communication are battery supplied). On one side this tag is compatible to the ISO 18000 respectively EPC-Gen2 standards, on the other side this tag has also the ability to communicate via the widely adopted wireless LAN standard Wi-Fi. Because the tag is woken up the same way as battery-less passive tags and for that reason does not need to power-up a receiver-module, battery-lifetimes of more than half a year are possible - just as with semi active tags. After the tag is woken up, the WLAN module is activated and allows very fast data transmission, that otherwise would only be achievable with active tags. This greater transmission speed makes the tag suitable as storage device for much larger amounts of data, than the ones that are normally possible with RFID tags. The possibility to store great amounts of data in combination with a very long battery lifetime makes this tag ideal for use as a data logger. Logging intervals can be configured individually for every sensor. The tag has also an open interface which allows an easy integration of different kinds of sensors.

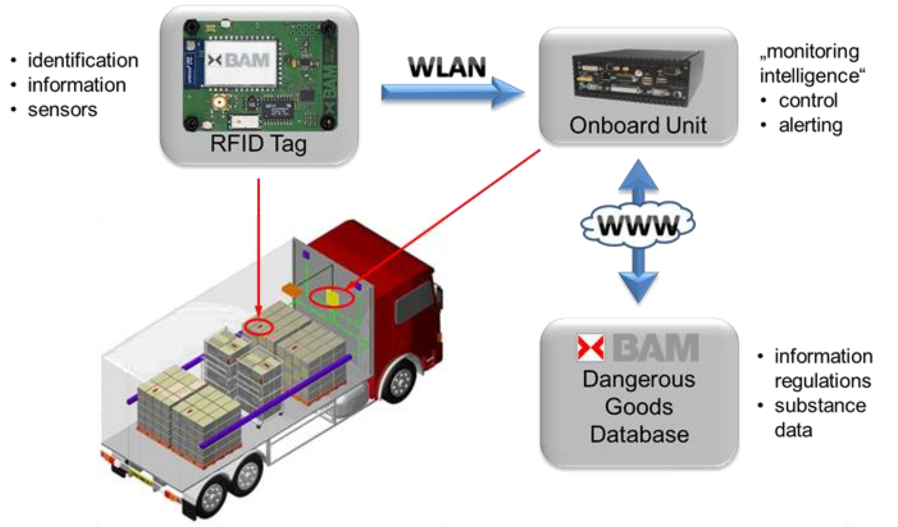

Figure 6. Interaction between the main system components during transport

Sensor-Tags, data communication, and software are combined to an interactive solution, which can tackle various scenarios during dangerous goods transports. The underlying information is provided by a data base with expert knowledge, in this case the BAM dangerous goods database "GEFAHRGUT" [5]. Figure 6 displays the interaction between the main system components during transport. The focal point of the vehicle equipment is the onboard unit (OBU), which consists of a ruggedized industry PC that is specially designed for use in a truck. The main functions of the OBU include acquisition of position data via GPS, routing, generation of transport documents, data communication via the mobile phone network, monitoring of the load with sensors and surveillance cameras as well as WLAN connectivity. It is either possible to read the sensors of the semi-active transponders or sensors that are permanently installed in the loading area. The OBU constantly monitors the measurements to ensure, that they are in the allowable range. If that is not the case, an alarm is automatically triggered. Current status messages are transmitted to the centralized database, that has also the cargo manifest stored. In case of need, the OBU should supply the relief forces with all required information via WLAN. But if the OBU gets destroyed during an accident, all information is still available through the centralized database.

III. Conclusions

Several applications require identification, diagnosis, or monitoring or a combination of them. Often, general conditions, like mobility or embedding, favor wireless solutions. The presented examples demonstrate, that radio based communication and small-sized, low-energy demanding sensor technologies offer the basis for innovative solutions in this regards. Subsequent tasks like sensor data fusion and automated analysis and evaluation processes offer additional benefits.

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