Mohamed Bourouah*, Vadim Goridko, Dietmar Schumacher, Hermann Scheithauer, Stephan Knappmann, and Peter Nommensen

Identification of surgical instruments using UHF-RFID technology

Abstract: The paper presents research, development and advantage of Radio Frequency IDentification (RFID) technology based system for medical instrument management and safe usage. The system is developed for two scenarios. In the first scenario, a Ultra High Frequency (UHF) is used and the UHF–interrogator system with UHF-antennas is constructed to work as conveyor-belt and instruments are placed between two antennas. Second scenario, suitable for the operating rooms, includes four antennas, placed under the table with instruments, system's phase shifter, inserted between the antenna and reader in order to reduce the effect of dead spots, caused by the electromagnetic reflections. High reliable identification rate is achieved by synchronizing phase shifters with particular interrogator. The system is software calibrated and can be re-calibrated at run-time to achieve high efficiency of power transmission to the antenna and in order to enable the receiver to decode the tag signals. With currently on the market available RFID tags and previously mentioned technology approaches, detection rate of 87.5% can be achieved.

Keywords: Signal processing; RFID application in healthcare; Phase shifter; Impedance matching

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1 Introduction

The healthcare systems in Europe and in the USA are confronted with immense challenges. It is well known that the demographic change in Europe and in particular in Germany affects the social insurance system. As a consequence, taking in account other factors, the total health expenditures in Germany have increased by 70% since 1995 [1]. Dealing with high expenses requires cutting expenses without reducing the quality of work and services in public and private hospitals.

RFID technology is frequently used in many fields, such as transport automation processes and object identification. The success of RFID-technology in the industry inspired the healthcare sector to introduce it for added value such as management of pharmaceuticals, increasing the patient's safety and realizing efficient working processes in hospitals. Both previously mentioned scenarios deal with medical instruments. Among others, the following technologies and methods can be used to optimize and secure some ongoing processes in the healthcare: Introduction of Information and Communication Technology (ICT) to healthcare sectors [2], sophisticated management of electronic patients records and networking systems inside and between hospitals. Further, information technology is very useful for drug management and assignment [3]. One of such optimization benefits is the cost reduction.

RFID based approach is one of the technology which can be integrated in already existing ICT, due to existing experiences in other fields and reasonable implementation costs. Although there are many different RFID system structures, a well-known system structure is preferred (Figure 1) for such particular study. This RFID system consists of four main components:

1. A tag, attached to the target object. A passive tag harvests the energy from the radiated electromagnetic field. If the magnetic field is strong enough to charge and activate the tags, the RFID tag goes into ready mode and starts to listen for interrogator commands.
2. The RFID reader or interrogator is responsible for powering the tag, writing to or reading from the it by sending radio waves. The approach using passive tags requires an appropriate antenna, where the size of the antenna depends on the used frequency band, tag size and the desired reading range.
3. The RFID-Middleware layer is the interface between the RFID-reader and the Enterprise- Resource-Planning) (ERP) system. The middleware layer filters, formats and synchronizes the data from different reader systems, also allowing high system scalability. In the majority of cases the middleware is included in

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the ERP system and is implemented as software layer [4].

4. The ERP-system allows integration of collected data from middleware with ongoing processes such as inventory management and resource planning.

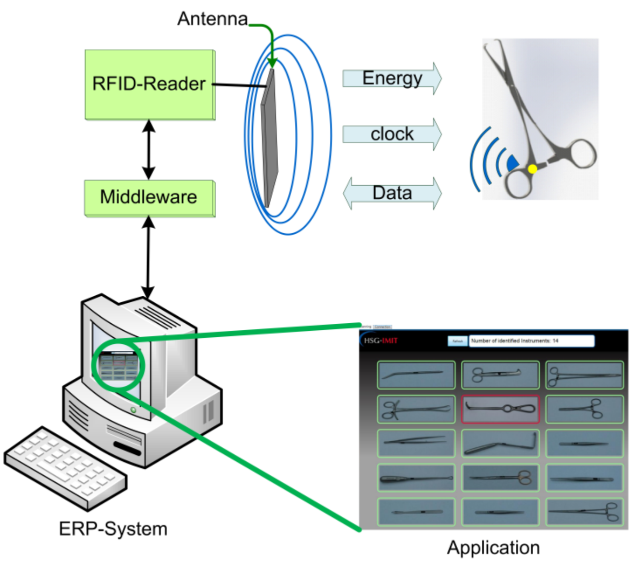

Figure 1: Components of the RFID system

The RFID technology covers many frequency bands, where low and high frequency bands (125 *kHz*, 13,56 *MHz*) use load modulation for transmitting data. The Transmission of energy and data strongly depends on the coupling factor between antennas of a tag and a reader. Thus, the reading distance of a desired small size tag is only few millimeters. However b scatter technique in the UHF band (868 *MHz*) allows to receive data from a small size tag with significantly longer distance between the antenna and the tag. In our application we assume random orientation of surgical instruments inside the identification range, thus a reading distance of 15 centimeters is required. As explained above, the low and high frequencies are not appropriate for this challenging task. Furthermore the UHF band proved on the basis of state-of-the-art as a proper technology for this application.

2 Methods

The development of RFID reader system requires hardware and software components including the development of a UHF interrogator and the add-on modules for signal processing. The UHF interrogator consists of a UHF Analog Front End (AFE) for data modulation, demodulation, coding and decoding. The differential output of the AFE is very small, in the range of 0 *dBm*. Additionally the output power is reduced by additional signal losses caused by signal filtering, directional coupling element, circuit matching and reflection effects on signal paths between the AFE and antenna load (Figure 2), thus while impelementing the system, the Printed Circuit Board (PCB) was developed and designed for minimum losses. In order to amplify the signal to the desired level, the gain factor is controlled by an analog signal from a Digital-to-Analog Converter (DAC) and the output power is then tuned in the range from 0 *dBm* to 20 *dBm*.

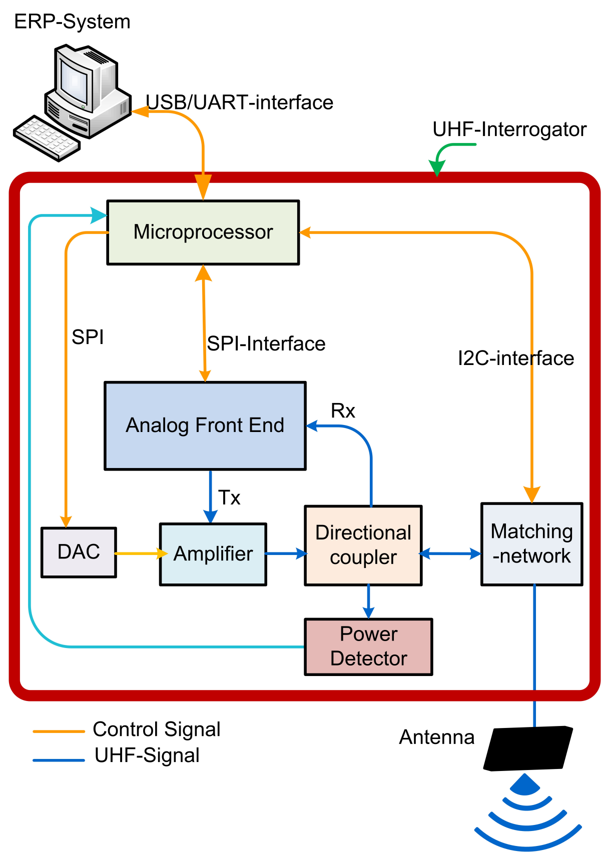

Figure 2: Structure of the UHF-Interrogator

The systems is designed to have six controlling units, based on MSP430 microprocessors, where one acts as a master, controls and communicates with all the rest, four control and communicate with AFE and last one controls the DAC. The AFE is configured and read out through Serial Peripehral I (SPI) interface. AFE registers include configuration of data rates, data encoding type, frequency of data transfer from the tag to the reader as well as selection of frequency communication channel.

The radiated power of RFID system, while being used in healthcare, is limited to not to interfere with work of life support equipment and any other electronic system, located in range of RFID-identification system. The interrogator is equipped with a power detector, indicating the power level of the received signal from the transponder, in order to find the optimal power level to detect the instruments and not exceed the limitations.

Data acquisition from metallic surgical instruments in the near field and up to few centimeters from the antenna significantly changes the antenna properties, in particularly antenna input impedance. A variation from the given reference impedance (50 Ω) causes reflection effects appearing between the interrogator and the antenna. Reducing the undesirable effects at run time require a matching network, such as e.g. a Pi-band-pass-filter, which includes digital controllable capacities. Microprocessor controlling the AFE measures in real-time at the moment reflected signals and rapidly digitally adjusts the capacitances to the optimal values.

Simultaneously with AFE sending a few microseconds carrier-wave without modulated data, the reflected signal is tapped by a directional coupler, passed through the power detector and sampled with a ADC inside the of one of the four AFE controlling microprocessors. The measurement procedure is repeated several times with different capacitance combination until the reflected signal is minimized. The automatic impedance matching is done periodically to insure maximal signal transmission and avoiding standing waves on the transmission path.

Due to the used frequency band and the metallic barriers (surgical instruments, metallic box), the electromagnetic waves are reflected causing dead zones, where the signals interfere destructively. Minimizing or avoiding this fundamental problem requires a dynamic phase shifting at run-time. Hence, the majority of hidden transponder in dead zones are then made accessible for the RFID reader. The phase shifting bank is inserted between the UHF-Interrogators and antennas. As mentioned previously, one of the microprocessors is controlling the phase shifter hardware with an analog voltage signal, generated with DAC.

3 Results

The system's hardware was designed, implemented and tested using commercial antennas (linear- and circular polarized). Since the system consists of multiple antennas, used in different constellations, it is necessary to consider a synchronization process and "listen before talk" technique for preventing the collision effects between the interrogators.

In the first scenario, with a linear polarized antenna, providing wide direction in plane, the tag's signal quality has still strong signal quality dependency from it's orientation according to the field generated by the antenna. In some constellations the signal quality drops in the proximity of the tag and is not sufficient for activating it, what leads to reading failures or missing tag in the ERP system. With this kind of antennas at least 30 from 40 instruments are identified.

In the second scenario, circular polarized type antenna is used. 4 near field antennas are placed on top of the table (see Figure 3) where the electromagnetic wave is divided in 90°shifted components. With a reduced reading range, an identification yield of 35 from 40 instruments has been achieved. A system structure is shown in Figures 3, where as real-life implementation is shown in Figure 4. In the third implementation, tunnel RFID reader

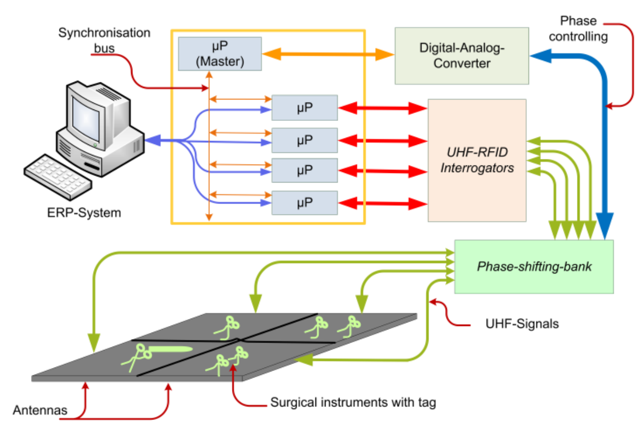

Figure 3: RFID system structure for identifying instruments on a table

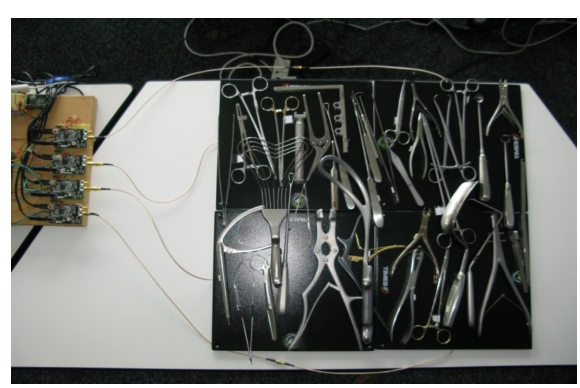

Figure 4: Part of the implemented RFID system

was build. The main difference to the previous demonstrator is the software and the synchronization procedure (Figure 5). While measuring, the system showed the same performance as in the second scenario.

Commercial UHF-tags, used for identifying, are fixed with epoxy on the surface of the surgical instruments. Mechanical structure of some surgical instruments allowed to embed the tags into appropriate opening of the instrument, provided better identification rates and protection against mechanical shocks or damage from impact with other surgical instruments (Figure 6).

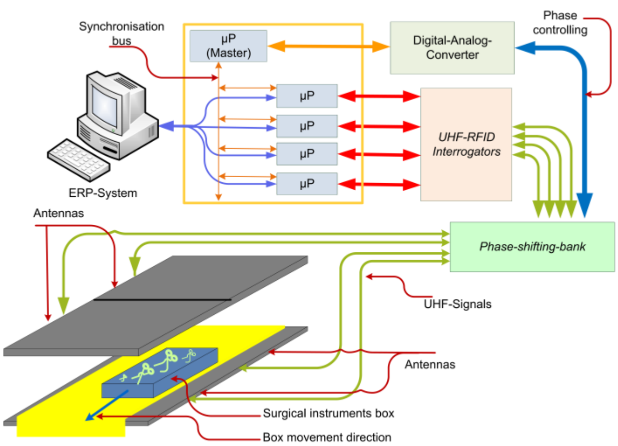

Figure 5: Tunnel RFID-System

Figure 6: RFID system structure for identifying instruments on a table

4 Conclusion and future work

Experiments showed, that The developed system and appropriate tags embedded on surgical instruments allow a detection rate of 87.5% in the worst case. The improvement of detections rates up to 100% require implementation of advanced signal processing methods, such like carrier leakage suppression [5, 6] for improving the separation between transmitter and receiver. Furthermore, new anti-collision algorithms can increase data processing speed and reliability of identification [7, 8]. Currently new antenna concepts, optimizing the electromagnetic interferences, are under development.

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Author's Statement

Conflict of interest: Authors state no conflict of interest. Material and Methods: Informed consent: Informed consent has been obtained from all individuals included in this study. Ethical approval: The research related to human use has been complied with all the relevant national regulations, institutional policies and in accordance the tenets of the Helsinki Declaration, and has been approved by the authors' institutional review board or equivalent committee.

References

[1] Susanne Erbe, "Gesundheitsausgaben: Kostenexplosion und Alterslasten?", Wirtschaftsdienst, pp.420-422, 2012.
[2] Fichman, R. G., Kohli, K., and Krishnan, R., Editorial Overview-The Role of Information Systems in Healthcare: Current Research and Future Trends. Information Systems Research, pp.419–428, 2011.
[3] Cresswell, K.M., and Sheikh, A., "Information technology-based approaches to reducing repeat drug exposure in patients with known drug allergies" Journal of Allergy and Clinical Immunology , pp.1112–1117, 2008.
[4] Floerkemeier, C. & Lampe, M.. RFID Middleware Design: Addressing Application Requirements and RFID Constraints, Smart Objects Conference, ISBN 1-59593-304-2, Grenoble, pp. 219-224, 2005.
[5] J.-W. Jung, H.-H. Roh, J.-C. Kim, H.-G. Kwak, M. S. Jeong, and J.-S. Park, "TX leakage cancellation via a micro controller and high TX-to-RX isolations covering an UHF RFID frequency band of 908–914 MHz," IEEE Microw. Wireless Compon. Lett., vol. 18, no.10, pp. 710–712, 2008.
[6] T.Xiong,X.Tan,J.Xi,andH.Min,"HighTX-to-RXisolationin UHF RFID using narrowband leaking carrier canceller" IEEE Microw.Wireless Compon. Lett., vol. 20, no. 2, pp. 124–127, Feb. 2010.
[7] S.-R. Lee, S.-D. Joo, and C.-W. Lee, "An enhanced dynamic framed slotted aloha algorithm for rfid tag identification" in MOBIQUITOUS'05, Washington, DC, pp. 166–174, 2005.
[8] W. Engels and E. Sarma, "The reader collision problem," in Proc. IEEE Int. Conf. Syst., Man Cybern., vol. 3, pp. 92–97, 2002.