A Healthcare Application Based on Passive UHF RFID Technology

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***Abstract*— This paper presents the design, implementation, and evaluation of a passive UHF radio frequency identification system that was recently installed at a hospital in Cyprus. The three main pillars of this pilot project was patient identification, real-time location service of medical assets, and drug inventory control and monitoring. In this paper, we present the main steps followed during the design and implementation phases, some of the main features of the system application, and major finding drawn after the evaluation and testing of the system in a realistic environment.**

I. INTRODUCTION

Radio Frequency Identification (RFID) is a rapidly growing technology that finds a plethora of applications in many sectors of today's society. This paper emphasizes on the design, implementation, and evaluation of an RFID system which was recently installed at the Bank of Cyprus Oncology Center (BOCOC) in Cyprus. This is a pilot research project that combines a passive RFID technology in the UHF band (865-868 MHz) with current, state-of-the-art Information and Communication Technology (ICT) devices (e.g., lightweight medical tablet PCs, wireless access points, databases, etc.). The system has been carefully designed and optimized using computer simulations and laboratory measurements, and it is now under stringent evaluation and testing by the technical research team and the medical personnel of the hospital.

The primary objective of the project is threefold: a) Automatic and error-free identification of in-hospital patients through the use of passive RFID tags in the form of wristbands or plastic cards; b) Real-time drug inventory control and monitoring of the pharmacy; c). Real-Time Location Service (RTLS) of tag-equipped devices and assets (e.g., wheelchairs, walkers, infusion pumps, patient files, etc.).

The proposed passive RFID system aims to improve traditional practices that take place on a daily basis in a hospital environment. For example, routine medical tasks such as drug prescription or drug administration are based on paper-bound processes that are prone to human errors due to possible misreading of the handwritten notes or even misidentifying the patient. The US Institute of Medicine estimates that more than 44,000 deaths occur every year in the United States alone due to in-hospital medication errors [1]. The US Food and Drug Administration (FDA) estimates that medical errors approach 40% in paper-based environments. History has shown that traditional paper-bound practices in hospitals may result in patient mix-up errors which often create serious health problems for the hospitalized people. With the launch of the proposed passive RFID system, in-hospital patients will be given a unique identification code, in the form of an RFID wristband or an RFID card, which will be automatically identified by a handheld UHF RFID reader attached to a light-weight medical tablet PC in the hands of a medical doctor or nurse. Once the patient is uniquely identified, the tablet will be authorized to upload from the central database the patient's medical profile and other relevant information. This is the first major part of the project.

The second part of the project is real-time monitoring of the drug inventory room located in the hospital ward. Drugs stored in the inventory room are difficult to monitor on a daily basis. It is highly probable that drugs are removed from the inventory room without proper authorization. It is estimated that 10% of drugs in a hospital environment are lost every year due to possible thefts [2]. It is also possible that drugs expire without noticing, something which may put patients' lives into a real danger. Running out of a particular drug during an emergency call is also highly probable using traditional practices. Such an unpleasant situation can be effectively avoided if a real-time monitoring system is in place inside the drug inventory room. Knowing precisely the current stock – in terms of quantity, type of drug, and expiration date – may certainly improve quality of healthcare and patient safety.

The third part of the project is locating and tracking medical assets, patient files, and high-value medical equipment in the premises of the hospital ward. It is often the case that medical equipment, wheelchairs, infusion pumps, or even patient files are forgotten in different rooms and, when needed, nursing/medical staff is searching for them all over the place wasting valuable amount of time. Almost one third of the employee's working time is wasted daily on searching for equipment and assets throughout the hospital [2]. This translates to lowering productivity and efficiency at workplace; this, of course, has financial implications on the running cost of the hospital. This problem can be mitigated by tagging equipment and patient files with passive RFID tags which can be effectively tracked throughout the hospital ward using a network of antennas and stationary RFID readers. This network of antennas covering a great portion of the hospital's ward was carefully designed in order to provide adequate coverage and long-range readability. Optimization of the precise position of the antennas within the hospital ward – in such a way as to provide maximum coverage in the presence of walls, patient beds, and other obstacles – was achieved using effective ray-tracing models [3] and real measurements. Of course, there were many other issues involved in the design such as the physical size and type of the antennas used, electromagnetic interference with other medical electronic devices, the topology of the hospital ward, and recommendations and restrictions set by the medical personnel of the hospital; all these factors/issues had to be carefully considered by the research team during the design and implementation phase.

A software platform was developed that runs on light-weight medical tablet PCs and provides a user-friendly graphical interface to the RFID hardware. The software platform was carefully developed in order to provide the necessary functionality requested by the medical and nursing staff of the hospital in a user-friendly and simple-to-use environment. The following two subsections briefly describe the hardware design of the system and the graphical user interface between medical personnel and RFID hardware. The last subsection describes system evaluation and testing.

II. Hardware System Design

Fig. 1 illustrates a block diagram of the RFID system installed in the hospital ward of the BOCOC. Valuable information related to in-hospital patients, drugs, and medical assets are securely stored on a server connected to the LAN. Information stored on the database can be securely accessed by medical tablets using encrypted communication and data exchange through wireless access points. Due to the sensitivity of the information stored in the database, it was deemed essential that data security principles were applied as sensitive information is communicated via a wireless network. On the other hand, data accessibility and system functionality must be ensured at all times.

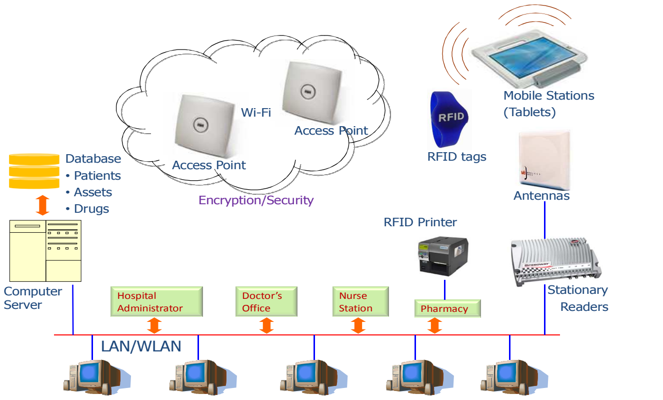


Fig. 1 Block diagram of the RFID system design

Using a medical tablet PC, someone may activate a group of networked stationary RFID reader(s) feeding a number of directive antennas attached to the corresponding RF ports via coaxial cables. Two 7dBi, circularly polarized antennas with sufficiently large beamwidth, in both elevation and azimuth planes, are connected via extremely low-loss cables (<1.3dB/10m) to each of the 4 monostatic ports of the reader. A low-insertion loss bi-directional power splitter is used for this purpose. Two antennas were installed in each of the patient rooms. Optimization of antenna position and tilt angle in the presence of lossy walls, floor/ceiling, and patient beds was carried out using an in-house developed ray-tracing code [4], which takes into account antenna pattern and polarization, radiated power, multiple reflections, edge diffraction, etc. From simulations, which were verified afterwards by a series of laboratory measurements, it was shown that by judiciously choosing the lateral position of the pair of antennas in each of the patient rooms, as well as the antenna height and relative tilt angles, the percent electromagnetic (EM) coverage is higher for the two-antenna configurations using a splitter than for a single antenna configuration. Even though using a power splitter the input power in each of the two antennas is divided in half, the interaction of the two antennas – provided their position, height, and relative tilt angles are carefully optimized – provides an improved percent coverage. Fig. 2 shows the total field distribution inside a typical patient's room when using a pair of antennas whose position was optimized in order to provide maximum EM coverage. As seen in the figure, the two antennas were placed at a close proximity to each other with a certain elevation/azimuth tilt. Using this configuration and assuming tag sensitivity of -14dBm and 3dB power reduction due to the bi-directional power splitter/combiner, we can achieve 93% EM coverage inside the room. This may be further improved by using RFID chips with higher sensitivity. Chips with -18dBm [5] sensitivity are now available in the market. In addition to using higher sensitivity tags, readability and asset identification can also be improved by using tag diversity. This translates to using more than one tag per object or drug with the tags oriented along orthogonal directions and spaced apart from each other. Readability is guaranteed if one tag is identified. Fig. 3 illustrates the percent EM coverage when using three orthogonally placed tags at each location in the room. For simplicity, a single-antenna configuration was implemented, whereas the RFID tag used had a sensitivity of -14dBm. As shown in the figure, item identification was improved to 89% when using tag diversity, e.g., three orthogonal tags per object. Readability for a z-directed tag corresponds to 79% which corresponds to a 10% lower coverage compared to the case of using tag diversity. Even better performance is sought when using higher tag sensitivity. Note that for the above simulation, the antenna was placed 2m above the room floor with a tilt angle of 20^o from zenith. The room was (4×3) m and the antenna was installed on the wall with the smallest dimension.

An RFID networked printer was also used in the design in order to read/identify unassigned tags from the reel and associate the specific EPC code to a new drug, asset, or patient. The RFID printer is located at the pharmacy of the hospital where tags are assigned to drugs that are checked out for the in-hospital patients. The pharmacist is also responsible for assigning tags to medical assets monitored by the real-time RTLS system.

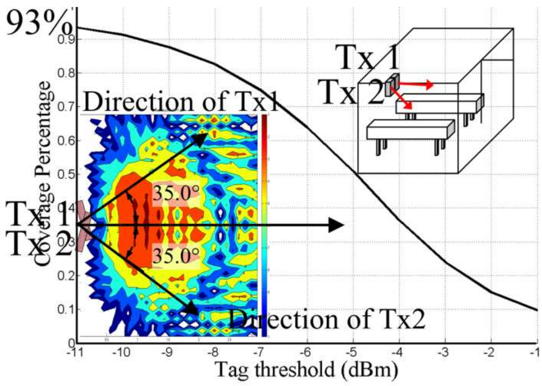


Fig. 2 Total field distribution at a constant z-cut using an optimized two-antenna configuration

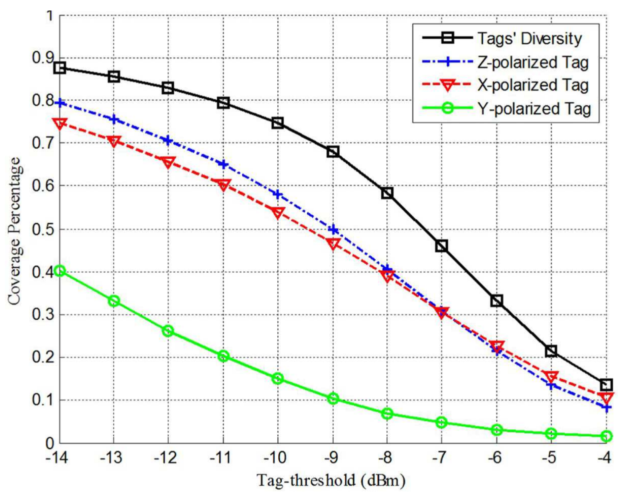
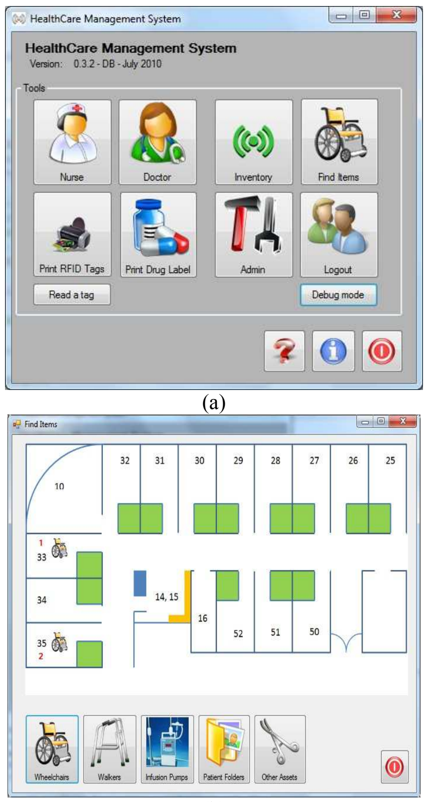


Fig. 3 Percent coverage for a single antenna configuration using tag diversity

III. SOFTWARE PLATFORM

Fig. 4(a) illustrates the login screen of the software application. There are three types of user accounts: administrator, doctor, and nurse. Each of these accounts has distinct privileges and functionalities. There is also the inventory control and monitoring account which can be accessed only by the pharmacist of the hospital. The RTLS account can be accessed by all medical staff. There is also the 'Print RFID Tag' icon – for assigning a tag to medical assets – and the 'Print Drug Label' – for assigning a tag to drugs. These two icons can be activated by either the administrator or the pharmacist. Fig. 4(b) depicts the RTLS screen with the top view of the hospital ward. As shown, the system identified 1 wheelchair in Room 33 and 2 wheelchairs in Room 35. Other types of objects can be identified.

Fig. 5(a) shows a patient identification screen with all possible task icons. At the bottom of the screen, the nurse can find all scheduled tasks for the day; e.g., drug administration, radiotherapy, etc. In this screen, the nurse may choose to also view the patient's profile and the doctor in charge. Fig. 5(b) illustrates the screen for drug inventory control and monitoring. With the activation of the 'scan' icon, the application lists all drugs found in the inventory room and gives the user the ability to classify them according to type, date of expiration, name, etc. By double clicking on a specific drug, one may view additional detailed information regarding the drug.

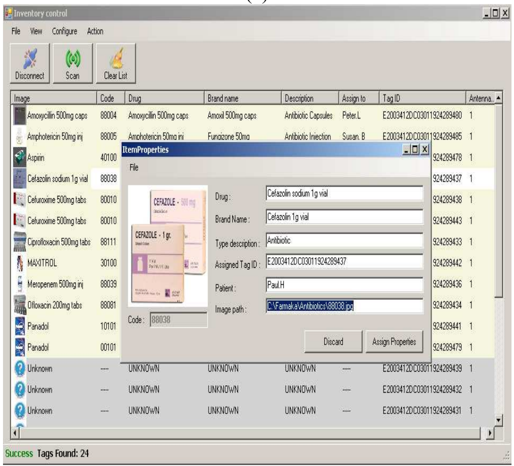


(a)

(b)

Fig. 4 (a) Login screen of the graphical user interface; (b) RTLS view with the top view of the hospital ward

(a)



(b)

Fig. 5 (a) Patient identification view; (b) Inventory control view

IV. System Evaluation

The RFID system, which was designed according to the three main pillars of the project, namely, patient identification, inventory control, and RTLS, was installed at the Bank of Cyprus Oncology Center in Nicosia. As this was a pilot research project, the system was installed in three patient rooms only, each one having dimensions (6×3) m. Two antennas (see Fig. 6) were installed in each of the rooms via a bi-directional splitter fed by one of the four monostatic RF ports of the UHF/RFID scanner. The group of antennas is radiating for a very short period of time (~5sec) once the 'scan' button of the RTLS software application is activated thereby asking the system to search the space for possible tagged medical assets, e.g., wheelchairs, infusion pumps, etc. Measurements were performed in order to determine the percent EM coverage in the three patient rooms. In each of these rooms, there were two patient beds (dimensions are shown in Fig. 7), chairs, and medical equipment (e.g., computer monitors). The measurements were performed in the presence of the two in-hospital patients, two close relatives of them, and two members of the research team performing these measurements. It is also important to emphasize here that the precise position and orientation of the two antennas in the rooms did not fully agree with the initial design proposed by the research team mainly due to restrictions imposed by the hospital administrators during the installation of the system. Nevertheless, we proceeded with the installation and testing of the system despite of these modifications. Of great importance was the fact that measurements of EM coverage were performed in a realistic hospital environment as opposed to a laboratory. EM coverage measurements in one of the three patient rooms are shown in Fig. 7 for the case of having 20 RFID tags placed on a cardboard box oriented either vertically or horizontally. In other words, the tags are all co-aligned either vertically or horizontally. Due to the position and orientation of the antennas, we did not expect to obtain readability when the tags were located close to the entrance of the room, which was indeed the case. Mounting the antennas on the opposite wall would have been a better choice, however, that was not feasible. As seen from Fig. 7, the maximum readability observed corresponds to reading 20 tags (100%), and the lowest readability observed corresponds to reading only 11 tags (55%). The number of tags read is shown in red, whereas the height of the cardboard box from the ground is shown in black. On the average, for vertically oriented tags, readability was found to be 85%, and for horizontally oriented tags, readability was found to be 79%. The sensitivity of the chip was -17dBm. As mentioned before, readability of an object can be further improved by using tag diversity or tags with higher sensitivity.

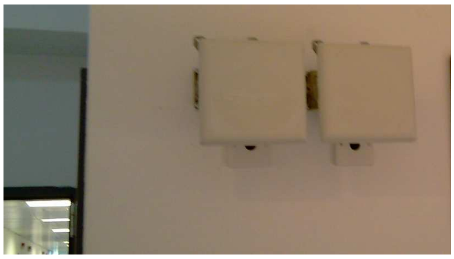


Fig. 6 Installation of the two side-by-side 7dBi, circularly-polarized antennas inside the patient's room

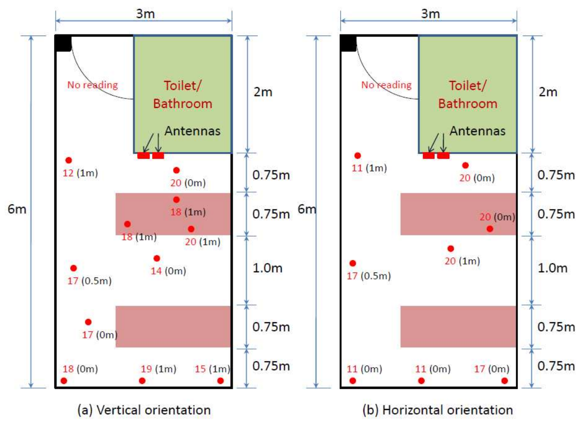


Fig. 7 Electromagnetic coverage inside the patient room for vertically and horizontally oriented tags

Besides EM coverage, measurements were performed in order to evaluate the readability of the system for a variety of drugs stored in the inventory cabinet shown in Fig. 8. The pair of antennas was pointed into the cabinet from the roof. For powder-based drugs, like the one shown in Fig. 9(a), there was absolutely no problem with readability and identification when the drug was placed anywhere inside the drug inventory even though the cabinet was full of bottles filled with liquid. The same drug was tested for readability when placed inside a patient room a certain distance away from the pair of antennas. Readability was possible even from a distance of 3m away. For these experiments, the tag was oriented in such a way as to ensure maximum link budget.

Fig. 8 Drug inventory cabinet with IV bottles

(a) (b) (c)

Fig. 9: (a) Powder-based drug; (b) Liquid-based drug (IV bottle) with tag on the side; (c) IV bottle with tag on the bottleneck

In the case of using an IV bottle (diameter is 7cm and height is 12cm) with an RFID tag as shown in Fig. 9(b), the observations were not the same as the observations recorded for the powder-based drugs. The tagged liquid bottle was placed inside the cabinet starting from the upper shelf all the way to the lower shelf. The bottle was standing upright, as shown in Fig. 9(b). Readability and identification of the liquid bottle was possible only for the cases where the bottle was sitting on the two upper shelves. The liquid affects the resonance of the attached tag antenna, and hence its impedance, deteriorating its performance. When placed on the lower shelf, the tag was not visible by the system, thereby concluding that a significant amount of radiated power is absorbed and dissipated by the lossy liquid. Readability was achieved for all the shelves only when the tag was placed on the bottleneck, as shown in Fig. 9(c). In this case, the liquid was not directly beneath the tag. As a result, the resonance of the tag antenna was not greatly affected. The same experiment was performed with an even larger IV bottle, and readability was achieved even when the bottle was placed on the lower shelf.

Patient identification was also evaluated using a medical tablet PC. The medical tablet is lightweight and equipped with a clip-on and a USB port. A USB stick housing a UHF RFID reader/writer is attached to the USB port. The software application is able to activate the USB stick once the doctor or nurse enters the platform of patient identification. We tested the system using a variety of wristbands available in the market but readability was very poor. Then, we used RFID tags in the form of inlays attached to the patient's plastic ID card and the results were excellent. The system was able to identify the patient from a distance of 80cm provided the stick is well-attached to the USB port. Readability was compromised in cases where the USB stick was loose at the port connection.

Experiments were also performed in order to test electromagnetic interference with other electronic devices that are used in the hospital ward, namely, infusion pumps and computer monitors. We activated the stationary RFID system (RTLS) multiple of times in the presence of these devices during normal operation. There was no interference of the RFID system with the normal operation of any of these devices.

V. Conclusions

A number of other experiments were performed in order to evaluate the RFID system in a realistic hospital environment. The overall results were not ideal but satisfactory to a large degree, given the fact that this is a growing technology that makes giant steps day after day. The feedback received from the medical personnel of the hospital was overly positive with a strong sense of support and encouragement. The system works very well in the hospital environment; however, there still exist problems that need further attention from the research community. Such problems include enhancing EM coverage in a typical patient room and improving readability of tags on liquid based drugs.

Acknowledgment

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