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Expert system for adopting wireless identification technologies (WIT) in healthcare; fundamentals and applications

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ABSTRACT

The wireless identification technologies or WIT are all the technologies and applications for contact-less automatic identification. The term WIT implies that no visual or mechanical contact is necessary to transfer information about the identification of a device, product or process. WIT is a fertile and relevant field of study in healthcare. Among the new generation of innovative technologies, WIT provides enabling devices that improve the machine perception and integration. However, for non-experts particularly in the healthcare areas, the decision to adopt wireless identification technologies is a relatively complex process due to the wide variety of available options and the limited time of certified experts. This article demonstrates that it is possible to bridge the gap between the functional and technical requirements of WIT in healthcare institutions. This is achieved by developing an expert system to provide unbiased information about the most suitable technology for specific applications in healthcare. This article proposes an expert system to provide the initial fundamental platform to facilitate and stimulate the adoption of WIT in the healthcare industry. The system is tested in a private hospital to make appropriate decisions in the adoption and use of WIT in the hospital environments. Results of tests performed with the expert system show dominance of the following technologies for healthcare facilities: UHF RFID active working both, at 915 MH and 433 MH, UHF RFID passive working at 915 MH, Ultrasound working from 20 to 60 MH, and uW Active RFID working at 2.45 GHz.

Key Words: WIT, wireless technologies, expert system, health care.

RESUMEN

Las tecnologías de identificación inalámbrica o WIT («Wireless Identification Technologies») por sus siglas en inglés, son todas las tecnologías y aplicaciones de identificación automática cuya transmisión de información es inalámbrica. El término WIT implica que no hay un contacto visual o mecánico para transferir información sobre la identificación de algún dispositivo, producto o proceso. Las tecnologías WIT es un campo fértil y relevante de estudio en el área del cuidado de la salud. Dentro de la nueva generación de tecnologías innovadoras, WIT aportan dispositivos facilitadores que mejoran la percepción e integración de las máquinas con los humanos. Para los desarrolladores no especialistas, particularmente en áreas como el cuidado de la salud, la decisión de adoptar tecnologías de identificación inalámbrica es un proceso relativamente complejo dada la gran variedad de opciones disponibles y la disponibilidad del tiempo de algunos expertos certificadores en el área. El siguiente artículo demuestra que es posible hacer la conexión entre los requerimientos funcionales y técnicos de tecnologías WIT requeridas por las instituciones de salud. Esto se logra a través de un sistema experto para generar información imparcial acerca de la tecnología más factible para aplicaciones específicas en el área del cuidado de la salud. Este artículo propone un sistema experto para generar una plataforma fundamental que facilite y estimule la adopción de tecnologías WIT en la industria del cuidado de la salud. El sistema es probado en un hospital privado para tomar las decisiones apropiadas en la adopción y uso de tecnologías WIT en ambientes hospitalarios. Resultados de las pruebas realizadas con el sistema experto muestran un dominio de las siguientes tecnologías para instituciones de salud: UHF RFID activa trabajando a 915 MH y 433 MH, UHF RFID pasiva trabajando a 915 MH, ultrasonido trabajando de 20 a 60 MH, y uW RFID activa trabajando a 2.45 GHz.

Palabras clave: WIT, tecnologías inalámbricas, sistema experto, cuidado de la salud.

INTRODUCTION

Wireless identification technologies (WIT) are being implemented to assist healthcare facilities in attending the increasing demand of patients and to reach health maintenance goals at many facilities throughout the world[1]. The main benefits that hospitals and other health care facilities are obtaining from WIT fall mostly in two overlapping main areas: financial savings and patient service improvements. In many situations some of the main expenses for hospitals lies in renting or buying equipment, particularly mobile medical equipment. Many hospitals over-procure these assets by as much as 20 to 30 percent, to make sure they are available when needed. RFID provides better ways to locate, track and manage these inventories, allowing hospitals to reduce them, and with that, the time their staff dedicates searching for these assets[2]. From the patient service and treatment perspective, healthcare facilities are also able to track and monitor their patients, and not only on their physical location, but sometimes even in their clinical measurements. Thus providing better follow up on health status, and making sure each patient is observed and assisted when required. Application examples are available within four categories: elderly care, newborn care, real time location tracking and remote sensing, tracking and monitoring. We discuss some of the premier applications as follows[3-6]. The objective of this research is to propose a fundamental platform to develop an expert system such that a non specialist could make appropriate decision in terms of use, adoption and guideline selection for WIT technologies in healthcare facilities.

NEWBORN CARE

The main WIT application in newborn care at hospitals are identification and location tracking. Several institutions are using solutions such as RF Technologies SafePlace system, which enables the hospital to locate each newborn or child admitted to the facilities through a dual transmitter that sends signals to each of their installed antennas and readers. This systems allows hospital staff to monitor the location of any child at any given time. These tags are worn on the child's ankles or wrists and provide graphical information on the hospital computers as to their identity and whereabouts. This helps prevent child misplacing, removal or even kidnapping, plus history on where he or she has been.

Preventing newborn kidnapping with WIT. Safety for kids is one the main driver for hospitals to implement WIT in newborn care units. Back in 1998, a newborn infant was kidnapped from a hospital in Missouri, and fortunately recovered one week later. This inspired the Kansas' Shawnee Mission Medical Center to deploy a system that would allow the hospital to locate and track each child within their facilities. RF Technologies system uses active tags operating at 262 kHz (Tx) and 318 MHz (Rx). Their antennas, installed at points such as doorways, exits, staircases and elevators, read these signals and send their information to the main database[7].

Preventing false alarms when using WIT. Hospitals have been using RFID for years, but recent technological developments are pushing them to upgrade their systems. St. John's Children's Hospital in Springfield, IL, had a serious interference issue with their security system that would trigger up to 200 false alarms a day[8]. The Waukesha Memorial Hospital in Wisconsin, had a system in place that would notify each tag's location, but would not identify who was the child whose tag was activated[7]. Also, the tags would not trigger the alarm if removed from the child. Issues like these were solved for both locations by fine tuning the systems and, in some cases, upgrading hardware or software. To avoid similar situations in the future, it is advisable to perform electromagnetic compatibility studies before implemented any form of wireless identification technology that uses radio waves to convey information[9].

EQUIPMENT TRACKING

Treating more patients with less equipment using WIT. The Jackson Memorial Hospital in Miami has installed over 6,500 active RFID tags on their assets, from infusion pumps to ultra sound machines. Thanks to this tracking system, they have been able to treat up to eight critical patients simultaneously with less equipment, locating the unit needed in real time and having it ready when all the patients, injured in a cruise, came in. The tags attached to the equipment have an ID number that provides the visibility needed to locate it within the building. The tags send their ID information to small receivers, or sensors, that pass data between each other, forming and ad-hoc network until it reaches a main access point. From here, based on signal strength and ID number, a central server locates each asset on a map of the facility, accessible from any computer within the network, and with an accuracy of 1 to 3 meters. Since the hospital began using this technology, they have discovered it will be useful in additional situations other than tracking equipment, such as monitoring commonly stolen items, or even monitoring temperature in refrigerators used to store pharmaceuticals[10].

Saving money, providing faster service and improving room turnover using WIT. Yet another similar system is being used at the University of California San Diego (UCSD) Medical Center. The hospital estimates savings of $70,000 annually only by reducing the need for renting additional IV pumps. This system uses active RFID tags that transmit their unique ID and information to the central database, and their locations are displayed on a facility map. They currently have tagged about 700 items, which used to be inventoried with pen and paper. Now, they can locate each item within their building when needed, with an easy to use interface and more accuracy than before. Employees used to stash items often, so they would have them available when needed. With this system, a nurse can click on a device they need from the available list and view a map where all these devices are located. They are identified by red dots, which if clicked, show additional information about that specific item. This information allows the staff to reduce the time to find the required item, which in turn reduces the time it takes to start a procedure. Thus improving overall room turnover, one of the key performance indicators at the facility[11].

Using RF and infrared technologies to accurately locate assets using WIT. The Anne Arundel Medical Center in Annapolis, MD installed a hybrid RF/IR (Radio Frequency/Infrared) system for real time location. The system reduces the time staff dedicate to search for equipment, patients and personnel, and uses the collected data to manage medical records and billing. The system uses both technologies (RF and IR) to increase location accuracy, because infrared signals do not pass trough wall, thus exhibiting room level accuracy, whereas RF signals have greater location accuracy, but signals can leak through walls, sometimes making difficult to locate tags across multiple floors or rooms. The combination of both systems allows the facility to locate medical devices, and is now being contemplated to track items for housekeeping and kitchen staff as well, such as vacuum cleaners and food carts.

SUPPLIES AND SURGICAL INSTRUMENTS TRACKING

Tracking cardiac devices using WIT. Florida Hospital, in Orlando, used two technology vendors to integrate and create an RFID solution for their tracking needs: an RFID tracking solution provider, as well as a software developer. The goal was to obtain inventory accuracy in their medical devices, such as catheters, defibrillators and others. The implementation so successful that both companies began marketing their solution to other hospitals. At the conclusion of the trial, the Florida Hospital showed yearly savings for $65,000 by reducing their inventories and $85,000 by purchasing some devices in bulk[12]. Now, when a new device enters the hospital, an RFID tag is placed on them, and its unique code is logged into the database. The item is then stored in an RFID-enabled cabinet, keeping it inventoried on an on-demand basis. The system uses passive 13.56 MHz tags. Tracking Hernia Meshes Using WIT. Integris Health implemented RFID technology to track hernia meshes, stored in various models, sizes and styles, and having expiration dates that need to be tracked, as well as the complete inventory. This healthcare facility, the largest in Oklahoma, implemented a four month pilot program, which produced savings for nearly USD $1 million so far. The pilot consisted in the use of low frequency (LF) passive RFID tags to track the usage of hernia meshes and capture data about supplies, recording removal and return of each tagged item. The system helped the facility in reducing inventories, monitoring stock and ordering information in real time, whenever an item was used. Moreover, if the staff needs to know on which patient a specific mesh was used-when there are recalls for defective meshes from the supplier, for example - this WIT solution will make it easier to track down patient interaction records, making them available at this level of detail[13].

Tracking surgical instruments using WIT. At the Advocate Good Samaritan Hospital in Downers Grove, IL, surgical instruments that have been prepared for a surgical procedure are tracked in real time using active RFID tags. The tags used in this application can be sterilized, withstanding steam autoclave cycles at temperatures of up to 135 degrees Celsius, as well as other liquid sterilizing methods. The facility uses about 150 tags to track metal surgery trays, and 40 more for assets such as pumps, cameras and scope warmers. Trays can even be associated with patients, surgeons, or specific surgeries, making it easier for them to locate the requested equipment. The system allows the hospital to ensure the trays and instruments are ready when surgeons need them, allowing the nurses to track tray locations within eight feet accuracy[14].

REMOTE SENSING, TRACKING AND MONITORING

There are many applications of wireless identification technologies throughout the world, particularly real time sensing, tracking and monitoring. Those applications are some the most popular WIT applications in healthcare, and are being exploited by many facilities in different countries. Both regional and global healthcare companies are adopting new developments in Auto-ID, bringing wireless identification technologies to different corners of the world. The following subsections include examples from different parts of the world.

Belgium. Hospitals in Belgium, such as St. Trudo and Jan Yperman are currently using RFID technology to track assets and patients, and even for IT infrastructure monitoring. Using 2.45 GHz active RFID tags and Wi-Fi based communications, the hospital staff is able to track hospital equipment, from wheelchairs to specialty air-filled anti-decubitus mattresses. Thus generating savings in leasing expenses for additional equipment, simply by having updated information about their current asset availability. Using special tags with embedded sensors, the temperature of different areas, from data center rooms to blood bags and lab specimens' refrigerators (both crucial for daily hospitals processes) can also be monitored in real time[15].

United States. Mary Washington Hospital, in Fredericksburg, Va., also use RFID tags for equipment tracking and temperature monitoring. In this case, the temperature of interest is that of the refrigerators used for medicine and vaccine storage. In contrast to the previous example from Belgian hospital, Mary Washington Hospital tags are RTLS active tags that do not use existing Wi-Fi infrastructure to convey information, but their own 915 MHz transmitters and receivers. This is done to prevent additional traffic on their already busy network, currently used for communication via PCs and handheld devices. Another innovative use of WIT Application is the application of wireless cardiac telemetry units. These allow the hospital to monitor patients' heart rate without having them hooked to a bed or other stationary device. These RFID tags are especially developed for and are designed to work with cardiac telemetry units from different manufacturers[16].

Spain. In Spain, healthcare facilities like Cabueñes Hospital in Asturias, are using passive 868 MHz EPC Gen 2 RFID tags on patient wristbands. They are used so patients can be tracked throughout the building, providing up-to-date information about their locations, their undergone treatments, analytics and X-rays results. This significantly decreases the length of patient hospital stays. They plan to expand tracking information to assist on medication control for patients, as well as laundry control[17].

Singapore. Singapore arguably has gone a bit ahead from other locations, using active ultra high frequency (UHF) tags to monitor individual's body temperature to detect serious infections without using other intrusive means. The Tan Tock Seng Hospital uses real-time patient tracking through RFID tags to increase efficiency in bed allocation and nursing services, as well as reducing patient waiting times. Wireless temperature sensing and paperless vital signs monitoring allows nurses and doctors to have clinical charts updated automatically. This gives them a better way to share patients' information among staff, and reduces their workload[18].

FACILITY-SPECIFIC APPLICATIONS

Lahey Clinic Medical Center. http://www.lahey.org/, Burlington, MA, RFID Journal Article 2265, April 17, 2006. Using active RFID tags and interrogators (readers) installed in a portion the facility, the Lahey Clinic Medical Center, in Burlington MA., ran a pilot program to decide upon implementing a system that would help track their mobile assets. Using the software provided by the vendor, they were able to track the location of about 500 assets in real time. The main objective was to reduce the time nurses spent looking for equipment, and having that time available to invest on caring for patients instead. The pilot served its purposes, the staff was able to detect how to improve the implementation of the system, working on reducing tags size to increase the number of assets they could identify. The smaller the tags, the easier it was to work with them without having an impact on the equipment functionality. They even increased to 1,000 the number of tagged assets throughout the facility. Also, the identification capabilities of the tags were improved, associating the unique serial number of each tag to the specific equipment it was attached to. Interrogator antennas were better distributed and increased in number, so that the system provided more accurate data as to where an item was located within the building. The asset tracking system can even be linked to a new maintenance system that will allow the staff to know when an asset requires maintenance or cleaning. With the tangible benefits obtained, the clinic management team will soon be deploying the tracking system in the rest of the building, as well as on a sister facility located in Peabody, MA. For this full implementation, they expect to use even smaller tags thus increasing the number of tagged assets. This will also allow the staff to have complete confidence in the system and will bring more benefits that will translate in better care for their patients.

About Lahey Clinic. When Frank Lahey, MD, founded a group practice in 1923, his vision was unique: Every component of a patient's health care would be coordinated under one roof. Today, Lahey Clinic still offers a distinctive patient experience. Retrieved from Lahey Clinic's Website at http://www.lahey.org/About/ on April 30, 2009.

St. Vincent Hospital. http://www.stv.org, Birmingham, AL, RFID Journal Article 2549, August 28, 2006. St. Vincent Hospital, located in Birmingham, AL., was interested in implementing RFID to prevent the loss of potential patients due the lack of real time information on bed availability. It was estimated that the hospital was losing almost USD$20 million in net revenue due to patient diversion (sending patients to others facilities). Using an active RFID system operating at 433.9 MHz, and programming the tags to beacon at 10 seconds intervals, it was possible to track patient location within the facility. Instead of asking the patients to wear a bracelet with an active tag, the staff decided to track patients' charts, which accompany them wherever they go in the hospital. Interrogators are wired to the hospital Ethernet network, and any location changes are logged automatically to the centralized database. The information is then displayed in real time on the screens installed throughout the facility, showing patient location and color-coded status. The pilot started with 140 interrogators and slightly fewer than 500 tags. After 6 months on the pilot, the system was expanded to the rest of the hospital, including the maternity ward team that had been skeptic since the beginning. The benefits were clearly visible, as the hospital saw an increase of 19% in admissions during the pilot, and a reduction of time in discharging patients from the system. Originally, it would take up to six hours to log discharged patients out of the hospital's computer system. With the data provided by the system during the pilot program, it took only about six minutes to have that information readily available for the staff (a drop of 98.3% in the time to reflect discharged patients from the system). This allowed the hospital to take in more patients and increase its revenues. Also, the system would optimize nurses' time invested in looking for information about their patients' location or lab results, having real time information displayed on the screens. Even outpatients are now being tracked when visiting the diagnostics center. The St. Vincent Hospital staff is now considering expanding the system to other hospitals within the group, and implementing a wireless asset-tracking project using WiFi instead of RFID, to determine which technology best suits each of the different applications. What the staff learned during the pilot is that technology has the ability to transform unstructured, chaotic business processes, but technology alone will not improve the hospital's bottom line. Processes must be improved in order to gain most from technology implementation.

About St. Vincent Hospital. St. Vincent's is part of Ascension Health Corp., US largest Catholic and largest nonprofit health system, serving patients through a network of 67 acute-care hospitals and related health facilities providing acute care services, long-term care, community health services, psychiatric, rehabilitation and residential care in 20 states. Sponsored by four provinces of the Daughters of Charity, the Congregation of St. Joseph and the Sisters of St. Joseph of Carondelet, Ascension Health is committed to caring for those who are most in need in the communities we serve. Retrieved from Ascension Health website at http://www.ascensionhealth.org/ on April 30, 2009.

Jacobi Medical Center. http://www.nyc.gov/html/hhc/jacobi/, New York City, NY, Gartner Article G00127318, June 6, 2005. Jacobi Medical Center proved that bar code and RFID technologies can work together and bring more benefits to healthcare facilities. The staff had been using a bar code system to supply medication to their patients, but were still investing too much time verifying the patient identity. Providing nurses with tablet PCs equipped with RFID capabilities and wireless access to hospital's computer systems, they were able to maximize the efficiency of the original bar code system. Patients were outfitted with RFID bracelets that also had a printed barcode for backward compatibility with other systems. Using the provided tablet PCs, nurses can now provide the right medication and the appropriate dosage based on the information displayed on the tablet by the hospital's computer system. After the pilot program of the RFID system, the IT management support for the wireless network was improved and more RFID tags were purchased. The pilot was extended from two to three nursing units, and was well received by the staff. The results showed proven time reduction in time spend during medication administration to patients, as well as additional benefits both for the nurse and patient. One of these benefits was making it easier to identify medication each patient needed without having to disturb them. If sleeping or has an IV line on that wrist, RFID can avoid the inconvenience movement would bring. What the Jacobi Medical Center staff learned during this implementation was that robust wireless network and good support are critical for RFID and bar-code implementations. Also, that short-term and inexpensive installation of RFID technology can deliver significant value patients and staff throughout the facility. In some cases, the synergy between RFID and bar-code technology can bring better results than the usage of both technologies separately, because of the compatibility with existing systems and human-readable information. From the staff's point of view, as RFID technology continues to mature, it will most certainly become an essential tool to decrease errors in processes and reduce costs, while increasing staff efficiency and patient satisfaction.

About Jacobi Medical Center. Located in the Bronx, Jacobi Medical Center provides quality health care for some 1.2 million Bronx and New York area residents. Founded in 1955, Jacobi was named in honor of Dr. Abraham Jacobi, known as the father of American pediatrics. Jacobi Medical Center is a member of the New York City Health and Hospitals Corporation, and a partner in the North Bronx Healthcare Network.

DISCUSSION

The application examples illustrate the benefits that WIT brings to many healthcare facilities, from monitoring their equipment to assisting patients, caring for newborns and even evaluating clinical measurements. The facilities using WIT obtained many benefits from every implementation and the more the decision makers understand the system capabilities, the more successful the results will be. Return of investment will probably become more evident when improving the quality of patient care and operational efficiency, but WIT can also help to improve room turnaround, to remind employees to make sure patients are being looked after and thus even making patients feel a little bit better by making sure their needs are fulfilled. Moreover, a higher return on investment can be obtained by healthcare organizations when finding innovative ways to use WIT to solve day to day challenges. Nowadays, WIT may be seen as an option that brings competitive advantages, but later on, it might become an expected service, such as electronic health records or portable ECG devices. Healthcare facilities will greatly benefit from early implementations and experiences today, and in time, improve applications and increase their competitive advantage tomorrow[19,20].

EXPERT SYSTEM DEVELOPMENT

An expert system (ES) is a computer system that uses human knowledge about a specific subject to provide advice that would ordinarily require an expert in the field. It is considered a decision-making tool that can reach a performance level similar to that of a human expert in a narrow expertise area. Expertise is considered an extensive knowledge possessed by experts, and it is acquired from explicit sources, such as reading material and training, or from implicit sources, like experience and practice. Expert knowledge acquisition is fundamental in the development of expert systems, and it is defined as the «accumulation, transfer and transformation of problem-solving expertise from experts or documented knowledge sources to a computer program for constructing or expanding the knowledge base»[22]. Potential sources of knowledge include human experts, textbooks, multimedia documents, databases, special research reports and information available on the Web. The process of knowledge transfer and transformation from different sources are needed to: Design an application and technology structure for classification and user interaction purposes Establish the set of applications and technologies available for the user Define evaluation scheme for each application and each of the available technology solutions using semi-automatic methods Evaluate every technology for each application based on the collected knowledge and the previously defined evaluation criteria.

Define a fuzzy logic membership function to map the evaluation of each technology with the feedback to be provided to the user.

The results of the knowledge transfer and transformation presented will be tested using a prototype of the expert system that was reported in[21].

Structure and set of WIT applications. As defined earlier in this thesis, the goal of the «WIT for healthcare» expert system is to provide fundamental and unbiased information about different technology options for a given application. It is therefore important to define two elements up front: first, an accurate and standard application description, and second, the set of different technology options available to the user for the prototype development. A clear definition of these two elements may enhance the expert system effectiveness and ease of use for the user, as well as a simplified updating process for the administrator, expert or knowledge engineer updating the system. The use of a simple and practical definition for WIT applications is important in allowing the user to express the functionality he or she expects. An application may be defined generically, for example as a «Real-time locating system» or as a «Wireless sensor network», but these terms, while technically accurate, render little or no information to the user if he or she is not familiarized with the terminology. Sometimes certain applications can be classified using more specific terms, such as Patient Tracking System or Indoor Positioning System, but still the potential user might not know what is exactly the name of the solution required.

A simple description pattern was identified by examining different WIT applications in healthcare and exploring the basic structure of their definition by non-experts. Most applications can be described by specifying an object, a variable

Table 1. Evaluation criteria for each technology and a specific application[21].

Criterion	3	2	1	0
Technical feasibility	High. It has been proven/ tested/designed for this purpose and there are even out-of-the-box/tumkey solutions	Likely. It is technically possible. Fine tuning of the system may be required to achieve desired results	Low. Theoretically possible, currently experimental or not yet demonstrated, but this might change in the future	Practically impossible
Commercial availability	High. Standards-based technology exists, as well as many vendors and satisfied customer in the market	Limited. There are fully functional solutions, but mostly based on proprietary technologies	Low or nonexistent, but a custom-made or experimental approach may be possible	Unknown to this date
Estimated cost (Buy or Develop)	Affordable in most cases	Affordable in some cases. Proceed with caution	Usually high. Users are mostly sophisticated early adopters and/or aggressive investors	Too high for practical purposes
Documented/ proven cases	-	-	Yes	No

and an action (Table 1). For example, if the need of a group of users is «we need a solution to track the location of biomedical equipment», this need can be translated to a more fundamental object-variable-action structure. This translation would be «equipment location tracking». Another example may be: «we need a solution that allows wireless monitoring of the temperature of all of our critical patients». This application will simply be specified as «patient temperature monitoring». This application structure has two main advantages. First, it provides enough information to expert system to identify the functionality the user is seeking to achieve, and thus allows for a simple three variable classification of applications. Second, it enables experts, administrators or knowledge engineers to easily add new applications and update and enhance the existing catalog. Table 2 enlists ten WIT applications that will be used to test the expert system. The number of applications is limited to ten to allow for fast application prototyping and testing.

The technology options considered in the development of the expert system are seventeen. These are: five active RFID technologies, five passive technologies, two semi-passive technologies, ultrasound identification technology, ultra wide band technology, Wi-Fi identification, hybrid RFID/infrared technology and near field communication (NFC) technology (Table 3). Each of these technologies were described in[21]. The structure to define each option is by frequency band, power source, and technology, followed by the specific frequency between parentheses. For example: «UHF Active RFID (915 MHz)» or «HF Passive RFID (13.56 MHz)». However, certain technologies have a default power sources and operating frequency bands, such as NFC and Wi-Fi Identification. In this case only the technology name is required.

Evaluating each WIT technology for every application. After defining the structure and set of applications and technologies for the development of the expert system, it is time to define an evaluation scheme for the each technology in every application. There are manual, semiautomatic and automatic methods to collect the knowledge required to do this. Manual methods include structured and unstructured interviews, case analysis and discussions with users. Semi automatic methods provide an environment to capture knowledge in an iterative process, and automatic methods use computers to extract knowledge from vast amounts of datta[22]. Manual methods were used sparingly for this chapter and automatic methods were not used at all. The evaluation scheme presented in this section was developed using mostly the semiautomatic method of Repertory Grid Analysis.

Repertory grid analysis (RGA). Repertory Grid is an evaluation technique developed by George Kelly. This technique analyzes different factors to determine the knowledge and perceptions that enable a person to act in a particular way. This approach can also be used to capture the knowledge and perceptions of experts that enables them to provide particular advise in a narrow knowledge area [23], Hart 1992. Repertory Grid Analysis has four basic stages. First, identifying important objects in the domain of expertise. Second, defining the most relevant factors considered to make decisions in the field of expertise. Third, defining the evaluation scale for each attribute. Finally, the fourth stage is the evaluation of each object using the factors and scale defined in the previous three stages.

First RGA Stage: Identifying important objects in the domain of expertise. The first stage was already done when the set of applications and technolo-

Table 2. List of WIT applications[21].

Application (Automatically concatenated)	Object (Required)	Variable (Optional)	Action (Required)
Newborn location monitoring	Newborn	Location	Monitoring
Equipment location tracking	Equipment	Location	Tracking
Cabinet inventory monitoring	Cabinet	Inventory	Monitoring
Garment owner identification	Garment	Owner	Identification
Patient assistance request	Patient	Assistance	Request
Patient movement monitoring	Patient	Movement	Monitoring
Patient proximity monitoring	Patient	Proximity	Monitoring
Patient temperature monitoring	Patient	Temperature	Monitoring
Refrigerator temperature monitoring	Refrigerator	Temperature	Monitoring
Room temperature monitoring	Room	Temperature	Monitoring

Table 3. Structure and set of WIT technologies for the development of the expert system[21].

Technology	Frequency band	Power source	Technology (required)	Specific frequency
1 LF active RFID (125 kHz)	LF	Active	RFID	125 kHz
2 HF active RFID (13.56 MHz)	HF	Active	RFID	13.56 MHz
3 UHF active RFID (433 MHz)	UHF	Active	RFID	433 MHz
4 UHF active RFID (915 MHz)	UHF	Active	RFID	915 MHz
5 uW active RFID (2.45 GHz)	uW	Active	RFID	2.45 GHz
6 LF passive RFID (125 kHz)	LF	Passive	RFID	125 kHz
7 HF passive RFID (13.56 MHz)	HF	Passive	RFID	13.56 MHz
8 UHF passive RFID (433 MHz)	UHF	Passive	RFID	433 MHz
9 UHF passive RFID (915 MHz)	UHF	Passive	RFID	915 MHz
10 uW passive RFID (2.45 GHz)	uW	Passive	RFID	2.45 GHz
11 UHF BAP RFID (433 MHz)	UHF	BAP	RFID	433 MHz
12 UHF BAP RFID (915 MHz)	UHF	BAP	RFID	915 MHz
13 Ultrasound (20-60 MHz)	Default	Default	Ultrasound	20-60 MHz
14 UWB RFID (60 GHz)	Default	Default	UWB RFID	60 GHz
15 Wi-Fi ID (2.45 GHz)	Default	Default	Wi-Fi ID	2.45 GHz
16 Hybrid IR-RF (UHF/IR)	Default	Default	Hybrid IR-RF	UHF/IR
17 NFC (13.56 MHz)	Default	Default	NFC	13.56 MHz

Acronym	Definition	Acronym	Definition
RF	Radio frequency	LF	Low frequency
RFID	Radio frequency identification	HF	High frequency
BAP	Battery assisted passive (semi-passive)	UHF	Ultra high frequency
NFC	Near Field Communication	uW	Micro wave
IR	Infrared	UWB	Ultra wide band

gies were defined. The remaining three stages are defined below.

Second RGA Stagge: Defining the factors to make decisions in thee field of expertise. Thee most relevant factors when evaluating different WIT technologies for a particular application are four: First, technical feasibility, second, commercial availability, third, estimated cost to buy or develop a solution using a specific technology, and fourth, whether or not similar implementations have been documented to date. These were selected because of their clarity and relevance in the evaluation process. Clarity in order to avoid uncertainty and confuse either the user, the expert or the knowledge engineer consulting or updating the expert system. Relevance because it is important to identify and evaluate the most important characteristics that matter for potential adopters. A recent study on WIT adoption factors include at least 21 characteristics that are important for decision makers. From 133 RFID Journal readers surveyed, almost 60% have not yet implemented WIT, and among them some of the most important decision factors mentioned were data accuracy, inventory management capabilities, track and trace capabilities, ongoing costs, acquisition costs and replacement costs [24],Fosso-Wamba, 2009. The factors related to cost where combined in a single attribute name «Estimated Cost (Buy or Develop)». Then the three factors related to capabilities and accuracy where split in two separate attributes, «Technical Feasibility» and «Commercial Availability». This was done because it is equally important to consider the theoretical potential of a technology, as well as the availability of reliable vendors in the market. According to experts in the field, such as John Bacon, an RTLS specialist from WhereNet Corp., the data accuracy of a location system depends upon many aspects, some of them are the technical capabilities of the technology used, the expertise of the systems integrator and the granularity and redundancy of the location grid. Third RGA stage: Specifying an evaluation scale for each attribute. Three degrees of truth were specified for the first three attributes. The fourth is binary.

The specific guidelines to assign each of the degrees of truth available for each attribute are depicted in Table 4. Each attribute is listed in the left column and the next three columns display the bipolar scale used. Table 1 shows a description of the meaning for each value.

Fourth RGA stage: Evaluation of each object using the factors and scale defined in the previous three stages. The evaluation of WIT technologies for one application is depicted in Table 5 as an example. Each of the first three attributes evaluates one technology in comparison to the other seventeen technologies. The first attribute is evaluated using the acquired knowledge summarized in[21]. The second attribute deals with the number of vendors and standards available in the market. These were accounted for from visits to trade show floors, conferences, vendor web sites and consulting buying guides, such as the Buyers' Guide to RFID resources from RFID Journal, arguably «The World's RFID Authority», as stated by the slogan of the site. The third attribute, estimated cost, is evaluated comparing the quoted prices of similar configurations from different vendors at trade shows, consulting firms and web searches. Finally, a fourth attribute links some of the information from[21] with each application, this is done to evaluate wether or not vendors or users of the specific technology have publicly available documented experience in the particular application.

Table 4. Evaluation criteria and degrees of truth each one[21].

Attribute	Degrees of Truth	(+)	(-)
Technical feasibility	3	High	Practically impossible
Commercial availability	3	High	Low or nonexistent
Estimated cost	3	Affordable	Too high
Documented cases	1	Yes	No

PROVIDING FEEDBACK BASED ON EVALUATION RESULTS

Expert advise and final alternative discrimination is provided depending upon the total score (integration of all criteria) of each technology for a specific application. The objective is to provide the user with the most suitable technology for his or her application, but in many cases more than one technology will exhibit an identical evaluation. Moreover, sometimes is impossible to completely rule out a single technology. In other

Table 5. Evaluation example for the newborn location monitoring application.

Technology	Technical feasibility	Commercial availability	Estimated cost (buy of develop)	Documented/ proven cases	Total
LF active RFID (125 kHz)	1	1	0	0	2
HF active RFID (13.56 MHz)	2	1	1	0	4
UHF active RFID (433 MHz)	3	2	2	1	8
UHF active RFID (915 MHz)	3	2	2	1	8
uW active RFID (2.45 GHz)	3	3	2	1	9
LF passive RFID (125 kHz)	1	0	0	0	1
HF passive RFID (13.56 MHz)	1	0	0	0	1
UHF passive RFID (433 MHz)	1	0	0	0	1
UHF passive RFID (915 MHz)	1	0	0	1	2
uW passive RFID (2.45 GHz)	1	3	1	0	5
UHF BAP RFID (433 MHz)	1	1	1	0	3
UHF BAP RFID (915 MHz)	1	2	1	0	4
Ultrasound (20-60 MHz)	3	2	2	1	8
UWB RFID (60 GHz)	3	2	2	1	8
Wi-Fi ID (2.45 GHz)	3	2	2	1	8
Hybrid IR-RF (UHF/IR)	3	2	2	1	8
NFC (13.56 MHz)	1	0	1	0	2

words, the expert system should simply provide different technology options to the user. Different approaches where considered to define the advise to be provided.

A rule-based approach using boolean logic was discarded, because it would render only two possible recommendations, such as «this is recommended» or «not recommended». A decision tree approach was also discarded because of the complexity to set it up and to update it. Instead, a fuzzy logic§ approach using membership functions was selected to provide differentiated feedback. Five membership functions were defined to define the advice to be provided about each technology for every application, depending upon its evaluation. These functions were named «impractical», «unconventional», «uncertain», «feasible» and «recommended». This was done by analyzing all the attribute evaluations that added up to each number between 0 and 10 (the minimum a maximum evaluation values, respectively). Many unlikely combinations of attribute evaluations where ruled out to define the membership functions, for example «Technical Feasibility = 0 ('impossible') and Commercial Availability = 3 ('high')». After discarding this and other unlikely combinations, a total of 42 combinations were considered to define the membership sets. It was found that technologies with an evaluation of two or less were highly impractical and with four or less were rarely used (unconventional). In contrast, any technology with an evaluation of six or higher was feasible and above eight it represented a highly recommended approach. The degrees of membership for each evaluation value were refined until a satisfactory interpretation was achieved.

Figure 1 depicts the membership functions used by the expert system to provide feedback on WIT technologies for each application. The membership functions are obtained by using the expert advice of electronic engineers and by reviewing commercial specifications of given technologies. After refining the membership values, the domain space is efficiently used, the membership functions are symmetrical and the names of the membership functions are more accurate. The interpretation for

§ "Fuzzy logic (fuzzy sets) is a technique for processing linguistic terms. It extends the notion of logic beyond a simple true/false to allow for partial (or even continuous) truths. Inexact knowledge and imprecise reasoning are important aspects of expertise in applying commonsense to decision making situations. In fuzzy logic, the value of true or false is replace by a degree of set membership. For example, in the traditional Boolean logic, a person's credit record is either good or bad. In fuzzy logic, the credit record may be assessed as both, good and bad, but each to a different degree»[22].

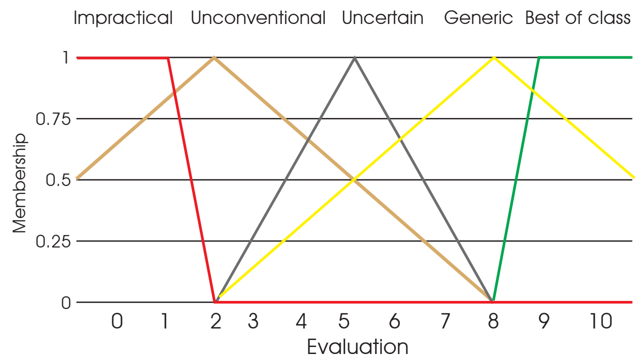

Figure 1. Membership functions to perform the Fuzzy construction for the expert system.

each evaluation value based on the membership functions illustrated in Figure 1 is given in Table 6. This will be the general feedback provided to the user.

TESTING AND RESULTS

The expert system was tested for different RFID technologies and the following applications were considered in a typical healthcare facility:

1. Newborn location monitoring,
2. Equipment location tracking,
3. Cabinet inventory monitoring,
4. Garement owner identification,
5. Patient assistance request,
6. Patient movement monitoring,
7. Patient proximity monitoring,
8. Patient temperature monitoring,
9. Refrigeration facility monitoring,
10. Room temperature monitoring

The Table 7 shows the preliminary results from the Fuzzy Logic expert system evaluation.

Table 7 illustrates a dominant technology as the UHF Active at 915 MH for most of the applications. Also, Ultrasound is a very attractive alternative for new born location, equipment location, patience assistance and patient movement. RFID passive technology is very adequate and feasible for cabinet inventory, garement owner ID, and patient proximity. Other important competing solutions are UHF active RFID working at 433 MHz and uW active RFID working at 2.45 GH. Those are contendents in applications such as: new born location, equipment location, patient assistance request, patient movement, patient temperature, refrigeration facility and room temperature monitoring.

Table 6. Fuzzy construction using membership functions shown in the Figure 1.

Evaluation	Interpretation
0	This approach is impractical and unconventional. Not recommended
1	This approach is moderately impractical and unconventional. Not recommended
2	This approach is completely unconventional. Not recommended
3	This approach is unconventional. Very slightly feasible and somewhat uncertain. Not recommended
4	This approach is unconventional and uncertain. Not recommended, but slightly feasible
5	This approach is uncertain. Might work under specific circumstances. Not recommended
6	This approach moderately uncertain and slightly unconventional. Not particularly recommended, but very feasible
7	This approach is highly feasible and generic. Under certain circumstances it might be slightly unconventional. Somewhat recommended, but proceed with caution
8	This is a generic approach that works under many circumstances. Proceed with caution
9	Among best of class. Highly recommended. Compare with generic approaches and take a decision based in organizational goals, interoperability and vendor reputation and resiliency
10	Best of class. Look no further. This is the most appropriate technology for your application

Table 7. Results of best alternative technologies for the given application.

Application	Best technologies for the application (Evaluation > 7)		
New born location	UHF active RFID (915 MH)	Ultrasound (20-60 MHz)	UHF active RFID (433 MHz)
Equipement location	UHF active RFID (915 MHz)	Ultrasound (20-60 MHz)	UHF active RFID (433 MHz)
Cabinet inventory	HF passive RFID (13.56 MHz)	Other alternatives < 6	Other alternatives < 6
Garement Owner ID	UHF passive RFID (915 MHz)	HF passive RFID (13.56 MHz)	Other alternatives < 6
Patient assistance request	UHF active RFID (915 MHz)	Ultrasound (20-60 MHz)	UHF active RFID (433 MHz)
Patient movement	UHF active RFID (915 MHz)	Ultrasound (20-60 MHz)	UHF active RFID (433 MHz)
Patient proximity	UHF passive RFID (915 MHz)	HF passive RFID (13.56 MHz)	Other alternatives < 7
Patient temperature	UHF active RFID (915 MHz)	UHF active RFID (433 MHz)	uW active RFID (2.45 GHz)
Refrigeration facility	UHF active RFID (915 MHz)	UHF active RFID (433 MHz)	uW active RFID (2.45 GHz)
Room temperature	UHF active RFID (915 MH)	UHF active RFID (433 MHz)	uW active RFID (2.45 GHz)

CONCLUSIONS

Wireless identification technologies (WIT) are a relevant and fertile field of study and application in the biomedical equipment and health care facilities. The new generation of innovation in information technologies, WIT consolidates a set of fundamental enabling technologies to improve machine perception and interaction. However, for non experts, the decision to adopt WIT devices, strategies or methodologies is not necessarily a simple task, given the wide diversity of options available and a quite few certified experts in the field who could have the time to provide the required advice. Healthcare facilities could greatly benefit from WIT applications, from tracking valuable medical equipment to reduce spending on new or leased equipment, to monitoring newborns or elderly patients, enabling health administration professionals to provide the best possible management service.

This article demonstrates that it is possible to bridge the gap between the functional and technical requirements for WIT in healthcare facilities. This is achieved by posing the basis for an expert system to provide an unbiased information about the most suitable technology for the narrowly defined applications. The background and expert system platform was refined using fuzzy logic membership functions to evaluate the solutions according to degree of: impractical, unconventional, uncertain, generic and best of its class. To follow the sequence of this research, a web application of this expert system will be implemented to achieve a complete user friendly tool to provide expert advice to health administration professionals.

Results show that the UHF Active RFID technology working at 915 MH is a dominant scheme for the following applications: now born location, equipment location, patient assistance request, patient movement, patient temperature, refrigeration facility and room temperature. UHF Passive RFID technology working at 915 MH is dominant for cabinet inventory, garement owner ID and patient proximity. Ultrasound at 20 to 60 MH is very competitive for applications such as new born location, equipment location, patient assistance request and patient movement. Finally, uW Active RFID working at 2.45 GHz show potential for applications such as patient temperature, facility refrigeration and room temperature.

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