REVIEW ARTICLE

The Potential Implementation of Radio-Frequency Identification Technology for Personal Health Examination and Monitoring

Andrew Nguyen*

ABSTRACT: This paper presents several possible applications of the radio-frequency identification (RFID) technology for personal health examination and monitoring. One application involves using RFID sensors external to the human body, while another one uses both internal and external RFID sensors. Another application involves simultaneous assessment and monitoring of many patients in a hospital setting using networks of RFID sensors. All the assessment and monitoring are done wirelessly, either continuously or periodically in any interval, in which the sensors collect information on human parts such as the lungs or heart and transmit this information to a router, PC or PDA device connected to the internet, from which patient's condition can be diagnosed and viewed by authorized medical professionals in remote locations. Instantaneous information allows medical professionals to intervene properly and in a timely fashion to prevent possible catastrophic effects to patients. The continuously assessed and monitored information provides medical professionals with more complete and long-term studies of patients. The proposed ideas promise to result in not only enhancement of the health treatment quality but also in significant reduction of medical expenditure.

KEYWORDS: Medical sensors, medical technologies, health examination and monitoring, health care, health treatment.

INTRODUCTION

Medical costs in the United States have risen rapidly and substantially, making health care expenditure one of the most troubling economic and social problems for the U.S.A. government, private companies, and individuals. The local, state and federal governments as well as citizens are generally aware of the magnitude and seriousness of the problems of health care costs to individuals and their families, to communities, and to the nation. According to the National Coalition on Health care (1), the U.S.A. has the highest health care expenditures compared to other industrialized nations. In fact, the U.S.A. annual health care expenditures constitute a significant portion of the U.S. Gross Domestic Product (GDP). For instance, health care expenditures in the U.S.A. reached $2 trillion in 2005 and are projected to reach $4 trillion or 20% of the GDP by 2015 (1). This problem is not in the U.S.A. alone – it is seen worldwide in both developed and developing countries. In addition to this health-care cost problem, the numbers of elderly adults and population are growing along with increased longevity and more demands for different health care services resulting from changes in lifestyles. According to the U.S.A. Census Bureau (2), 35.9 million people were aged 65 and older as of July 2003 and this number is expected to double within the next 25 years. By 2030, almost 1-out-of-5 Americans, about 72 million people, will be 65 years or older. Worldwide, the number of adults older than 65 years is also expected to increase from 420 million in 2000 to 974 million by 2030. Apparently, there are two severe problems facing the U.S.A. health care system (and perhaps those of other developed countries): enormous health care expenditures and the large growing number of elderly adults who need frequent and more health examinations and monitoring, which in turn drive up the health care cost further.

While the sky-rocketing health care expenditures are the result of various issues such as increased and

*To whom correspondence should be addressed:
Andrew Nguyen
Department of Biological Sciences
University of California, Irvine
Irvine, California 92697

uncontrollable charges from health care providers and increased cost of medicine, it is believed that implementing advanced technologies for medical practices and health treatments not only will help reduce medical costs, but will also improve the treatment for patients from medical professionals. For instance, the use of advanced robotic, wireless and information technologies can assist surgeons to perform remote surgeries quickly, accurately and safely on individuals located far away from the surgeons (3). Therefore, it is crucial that not only advanced health care techniques and devices are developed and deployed, but also that technologies potentially leading to improvement in health care are introduced to the health-care professionals and organizations.

Technologies, in general, and sensing, imaging, and wireless communications, in particular, have advanced considerably in the past decade which in turn can affect not only health care costs, but can also influence health examinations and monitoring. For instance, advances in sensing, imaging, and wireless communications have opened the door for possible wireless, fast, accurate and remote monitoring, examination and diagnosis of the inside of the human body. These advances have led to the development of advanced medical techniques and equipment such as Magnetic Resonance Imaging (MRI) (4) and endoscopic ultrasound (5). In order to push forward medical technologies, improvement in health care techniques needs to be continuously developed. To that end, it is imperative that advances in technologies be utilized wisely and properly for medical applications.

One of the most significantly advanced technologies in the past decade is radio-frequency identification (RFID), which has profound impact on various applications – from consumer to military applications. RFID technology dates back to the 1940s as a military technology for identifying aircraft in World War II (6). The recently declining cost along with improved sensitivity and durability of RFID systems has made these systems increasingly interesting for the distribution and retail industry. In fact, RFID has been identified as potential technology to replace the currently dominant UPC bar-code system (7). RFID is very attractive for medical applications and if properly utilized can potentially lead to breakthroughs in the way medical examinations and monitoring of patients are conducted.

In this paper, we present several ideas of using RFID technology for personal health examination and monitoring. Our main objective is not to present specific RFID systems for these medical practices, which are outside the scope of our research and requires significant collaborated efforts between different disciplines, but to give ideas that can possibly lead to significant improvements in medical examinations and monitoring of patients. It is hoped that this paper will provide medical professionals and students some overview of what RFID technology can potentially do for medical applications, effectively motivating and facilitating them to utilize this valuable technology not only for the improvement of patient treatments, but also to possibly develop particular RFID devices, in collaboration with other disciplines such as biomedical and electrical engineering, for specific medical needs.

FUNDAMENTALS OF RFID

Understanding the basics of RFID helps medical professionals, such as medical doctors, not only to properly utilize the technology for medical practices, but also to possibly improve it for specific medical needs. Fig. 1 shows a general RFID system consisting of a tag (or transponder derived from Transmitter/responder) and a reader (or interrogator). The basic objectives of a RFID system are to acquire, store, process, and report specific data or information about objects at an appropriate time and location, determined by users or operators, via wireless means. Detailed information on RFID as described in this section can be found in the RFID Handbook by Klaus Finkenzeller (8).

In operation, the tag is attached to the object to be sensed, monitored, imaged, or identified. For instance, tags about the size of a large grain of rice are implanted under the skin of a dog, cat, or other animal for identification purposes (9). Implantable tags of about 11 millimeters long and 1 millimeter in diameter can also be placed under the skin of hands and arms in humans for identification, physiological characteristics, health, nationality, etc. (10,11). Particularly, as noted in (8), Alzheimer's patients, mentally ill patients and people with communication difficulties could benefit from implanted RFID chips for identification purposes. Data can be pre-programmed or written (during operation by the reader) into the tag to provide instructions for the tag to perform certain functions or

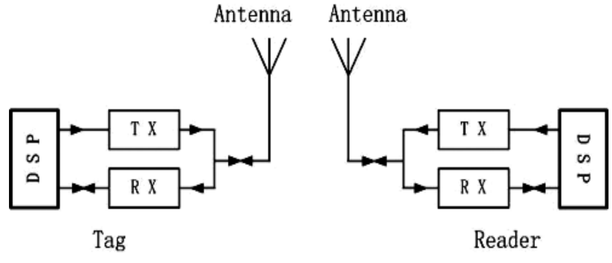

Figure 1: A general RFID system consisting of tag and reader – each is a microchip containing a transmitter (TX), receiver (RX), digital signal processor (DSP) and antenna. The tag and reader communicate with each other wirelessly via their antennas.

identification of the object. This data can be rewritten and/or modified to accommodate different applications. The tag acquires and stores certain data from the object for various functions such as monitoring the object's activities. The tag is typically programmed so that it automatically activates when it is within the interrogation zone of readers. However, the tag can also be activated at any time by the user or operator. The transmitter is used to transmit collected data to the reader. The receiver includes circuits used for specific functions, such as collecting temperature of the object, and is used to receive, store and possibly process specific information of an object onto which the tag is attached (with help of DSP) as well as receive information sent by the reader. The DSP controls the tag and processes and stores its information. Not all tags require transmitter, receiver, antenna or DSP, nor do they conduct the same functions; depending on the applications, some of the components or functions are not needed. For instance, in applications where only data reading is needed, such as object identification, a receiver is not contained in the tag.

A reader may include a communication device to enable the transmission of retrieved data to other systems, such as a PC and/or other portable devices like PDA for storing, processing and display or further communication with other media such as the internet, from which the information can be retrieved by remote offices. The DSP controls the reader, processes and stores retrieved information, and provides interface with other possible communication devices for transmission or reception of information.

All RFID functions are carried by radio waves at various frequencies[1] depending on the application. These include low frequency band from 100-500 KHz, intermediate frequency band from 10-15 MHz, and high frequency bands from 850-950 MHz and 2.45-5.8 GHz (8). Each frequency band has it own characteristics suitable for different applications. Higher frequency provides a broader choice of different types of antenna (13), which is the main component influencing the overall size of the RFID system. Higher frequency also results in smaller antennas and hence smaller systems (8). In applications involving media with substantial losses, such as the inside of the human body, lower frequency bands may be needed to facilitate the transmission and reception of signals. Typical RFID systems have practical read distances ranging from about 5 cm up to a few meters depending on the chosen frequency and antenna (8).

PERSONAL HEALTH EXAMINATION AND MONITORING USING RFID TECHNIQUE

Personal health care and treatment for patients depends largely on the ability to assess their health condition. Accurate and reliable assessment of health condition is essential not only for personal health, but also for the planning of health maintenance, including treatment. It is, indeed, one of the most important tasks in health care and preventive medicine. Current personal health examination and monitoring typically involves data collection using devices and equipment connecting to the body via wires – an example is Holster monitors used for ECG and EEG monitoring. The collected data is retrieved and analyzed off-line by medical professionals. This kind of health examination and monitoring is normally carried out periodically in certain durations and thus may not represent an optimum or completely desirable solution for patients who are constantly in need of examination and monitoring, such as those having severe problems. As will be seen in the following, the use of RFID allows personal health examination and monitoring to be wirelessly conducted either periodically or continuously, which should benefit medicine significantly, not only in cost reduction but also in enhanced treatment of patients, as compared to what is available now.

Fig. 2 illustrates an idea of personal health examination and monitoring using the RFID technique. It shows tags attached to the body's skin and readers located externally to the body. Different tags may be used for different functions, such as reading the lung's temperature[2], measuring the blood flow, measuring the heart rate, *etc*.). The readers may be placed at various locations – for instance, at different places in the house of the person being monitored or in a medical facility. The tag performs specifically instructed functions and transmits the data collected to the readers. The tags can also receive instructions from the readers to perform additional functions or to modify some preprogrammed functions, such as changing the time or duration of the data collection period. The readers transfer the received data to a router, a PC or PDA which is connected to the internet. The PC or PDA is also used to store the data and can analyze and display them in a useful format,

[1] Frequency is associated with radio waves or signals. For instance, cellular phones can operate at a single frequency of either 800, 900, 1800 or 1900 MHz or at all these frequencies (12). That is, they transmit it and receive information such as data or voice using radio waves at these frequencies.

[2] From the fundamentals of physics, the lung, like any other object, continuously emits waves of thermal energy which depends on the lung's temperature. This phenomenon is known as the "black body radiation" (16). By wirelessly capturing this energy with a specially designed tag, the temperature can be extracted.

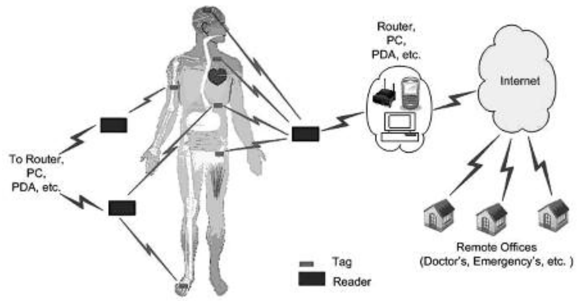

Figure 2: Illustration of a patient being examined and monitored by RFID sensors with tags attached to the body's skin and readers located externally to the body (*e.g*., in the patient's bedroom). The tags and readers are tiny microchips and their associated antennas are small, light printed circuits. The combined tag and antenna is very small, e.g., size comparable to a digital camera memory card, and is thus very convenient for body attachment. All communications between devices are carried out wirelessly.

such as heart-beat waveforms, for immediate use by someone such as an in-house care taker. The information transmitted to the internet can be viewed by different authorized remote offices such as a doctor's office, an emergency facility, *etc.* The reader can also be configured as a mobile handheld device to be operated by a medical professional, such as a nurse, to read the patient's tag data on his/her visit to the doctor's office. Information from this portable reader is transmitted wirelessly to a PC for data storage, processing, diagnosis and display. Additional functions such as data analysis and display can be built into this portable reader to provide patient's information directly to the medical professional without using a PC. It should be noted that medical professionals from remote offices can also control the readers to act upon the tags through commands transmitted to the readers via the internet, as needed for proper actions.

Another idea for personal health examination and monitoring using the wireless RFID technique has tags implanted onto certain body's parts and readers attached to the body's skin. As described in the other idea illustrated in Fig. 3, the tags perform various functions on the human's parts and transmit the collected information to the readers, which are connected to the router, PC, or PDA wirelessly. This idea requires the use of implantable tags and is thus more difficult to be implemented. However, it is more effective for examination and monitoring because tags have direct contact with the parts to be monitored and can accommodate a wider range of monitoring than those used in Fig. 3. Direct contact with human parts facilitates more accurate measurements. Wider range of monitoring is possible since more implantable devices can be placed at different places in the body for monitoring while only a limited number of parts can be monitored using tags attached to the body's skin. A potential problem of this approach is the transmission of collected data from the implanted tags to the readers partly or completely across the body, whose media have very high loss (15) and hence attenuate substantially the transmitted signals that carry the collected data. These signals may thus be too weak to be detected by the readers. Another potential problem is the radiation exposure inside the human body which might cause other health issues. This potential health effect indeed needs extensive study before the deployment of implantable tags. This concern, however, is expected to be less than that with cell phones if the radio signal reaching the implantable tags is limited to much less than that currently used by cell phones, which is possible since the RFID range is only a fraction of what is used for cell phones. Implantable tags should not allow radiation exposure exceeding a safe level, nor put patients at further risk for other problems such as infections after they are approved by an authorized government health organization such as the Food and Drug Administration (FDA), which regulates medical devices in the U.S.A. In fact, in 2004, the FDA approved an RFID tag for implantation in humans as a means for accessing a person's health records (17). Implantable RFID chips designed for animal tagging are now being used in humans (10,11). Most importantly, this approach should be used only for those in dire conditions, such as patients in the situation that have no other choices for monitoring purposes, due to the need of patients' operation and implantation. Implantable tags require special materials and packaging for them not to cause detrimental effects to the body upon implantation. Development of such tags requires significant interdisciplinary collaboration between different disciplines such as electrical engineering, biomedical engineering, and medicine.

Fig. 4 shows an application of RFID in examining

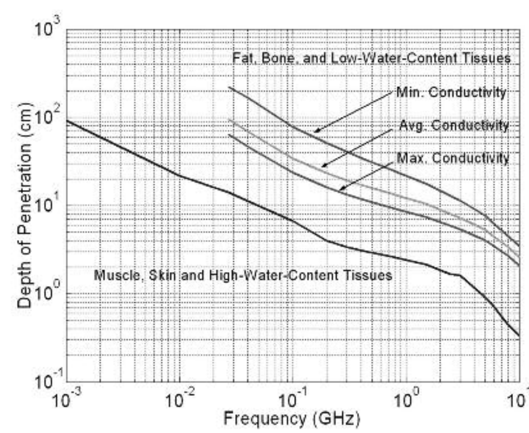

Figure 3: Depth of penetration in biological tissues. The three curves for the "fat, bone and tissues with low water content" correspond to the minimum, average and maximum values of the conductivity ranges listed in (15).

and monitoring many patients simultaneously in a medical facility. Each patient carries tags that are either attached externally to the body or implanted inside the body and can be identified with a unique ID preprogrammed into his/her tags. This arrangement not only improves the examination and monitoring of patients significantly but also substantially reduces the use of the financial and personal resources, thus offering a very efficient and cost-effective health assessment and monitoring system.

Although periodic personal health inspections and monitoring are important, there is a significant interest and need not only to examine but also to monitor health condition continuously. Continuous monitoring of the health of patients provides instantaneous information on the state of patients, effectively and significantly improving health care, especially for elderly patients or those experiencing deteriorating health. This can effectively help medical professionals to respond quickly and more efficiently in emergencies, helping prevent many potentially catastrophic events. Additionally, continuous monitoring supplies valuable, complete and accurate health condition of the patients. This information will allow medical professionals to conduct long-term studies of the patients' health condition and gain invaluable knowledge not only of the patients but also of particular illnesses. The information can also make feasible more accurate prediction of the patients' future health conditions – thus allowing optimum treatment plans to be made. Continuous monitoring of personal health conditions wirelessly from a remote location further offers more convenience, lower cost and facilitates improved care for patients, particularly out-patients or those living in rural areas that are inconvenient and difficult to access to health care facilities, or in emergency situations. It should be particularly noted that the constant monitoring of patient well-being does not take into account the non-measurable aspects such as pain, but the use of the proposed RFID techniques should not duplicate the function of a nurse working with the patient for pain.

Figure 4: Illustration of patients being examined and monitored by networks of RFID sensors in a medical facility. The tags are attached to the patients (as seen in Fig. 3) implanted inside the patients' bodies. The readers are located at various places (e.g., walls and ceilings). These sensors do not interfere with patients' normal activities.

As with any technology and its intended applications, the cost of the proposed RFID systems can be approximately broken down into two categories: RFID system development cost and implementation cost. For system development cost, existing tags and readers developed for consumer applications can be used directly with modifications for personal health examination and monitoring. Consumer tags and readers are relatively inexpensive - a tag can cost as low as a few U.S. cents (18) and a reader can cost around 100 U.S. dollars (19). Some implantable tags have also been developed and cost around 2 U.S. dollars each (10). Specially designed implantable tags are needed in one of our proposed ideas and, for these tags, new research and development needs to be conducted. We expect that the cost of these implantable tags, once fully developed and mass produced, should be very similar to that of the existing tags. The primary cost of developing the proposed RFID systems lies in the integration and testing of the RFID systems for the particular application of personal health examination and monitoring. All these development costs, however, are born by biomedical-equipment development companies just as in the development of any other medical equipment. The implementation cost is the actual cost encountered by health care providers. This cost mainly consists of the cost for purchasing readers and tags, cost of maintenance and for the RFID sensor networks to be installed in medical facilities as proposed in Fig. 4, cost for installing the readers at various places. The prices of the readers and tags, as discussed earlier, are inexpensive. The RFID system is basically a wireless device and its maintenance is also relatively inexpensive. The installation cost for RFID sensors in a medical facility is very similar to the installation of other in-building wireless networks such as Wi-Fi hotspots for internet access (20). This cost, therefore, should not be significant. Nevertheless, presently, the actual cost for implementing the proposed RFID sensor network is not available, as this system is new and has not been implemented for medical practices.

A major concern with the use of RFID technology in the medical field is its ethical aspects. RFID uses wireless technologies whereby patients' information is transmitted wirelessly. It is therefore prone to security breaches. Privacy of patients is an important issue with RFID. For instance, it may be possible to gather sensitive data about a patient without consent through reading of the tags at a distance without his or her knowledge. Furthermore, tags can be used for non-consent surveillance of the patient or other purposes. Additionally, patient data transmitted through air or the internet can also possibly be stolen without consent.

These privacy issues, however, may be completely or partially resolved with proper encryption methods. In general, the ethical concerns can possibly be addressed with better and more secured technologies for RFID.

CONCLUSION

We have presented several ideas using RFID technology, one of the most significantly developed and advanced technologies in the past decade, for personal health examination and monitoring. These ideas demonstrate that health examination and monitoring of patients can be done wirelessly at any time and any place without interfering with the patients' normal activities and should therefore be attractive once developed and deployed for the medical field. It is believed that implementing the RFID technology would not only help reduce the enormous and significantly growing medical costs in the U.S.A., but also help improve the health treatment capability as well as enhance the understanding of long-term personal health and illness. It is hoped that these ideas will serve as a way to illustrate potential use and advantages of the RFID technology for medical applications. Potential applications and advantages of the RFID as well as other advanced electronic technologies for medicine are enormous and if properly developed and implemented, can have tremendous impacts on the medical field. In essence, they allow us to "see farther, wider and clearer" into patients' bodies, which is one of the ultimate objectives of medical professionals and most desirable capabilities in medical treatments. Applications of these technologies to medicine seem to be limited only by our imagination – with creativity, numerous applications of these technologies in the medical field can be derived.

ACKOWLEDGEMENTS

The author wishes to thank Dr. C.T. Hsieh for lectures on RF and valuable advice.

REFERENCES

1. http://www.nchc.org/facts/cost.shtml
2. http://www.census.gov/prod/2006pubs/p23-209.pdf
3. Rosen J. and Hannaford B., "Doc at a Distance," IEEE Spectrum, Vol. 43, No. 10, Oct. 2006, pp. 34-39
4. Westbrook. C., Handbook of MRI Technique, 2nd Edition, New York, New York: John Wiley & Sons, 1999.
5. http://www.nci.nih.gov/Templates/db_alpha. aspx?CdrID=46602.
6. Landt J.. "The History of RFID." IEEE Potentials, Vol. 24, No. 4, Oct.-Nov. 2005, pp.8-11.
7. Palmer R. C.. The Bar Code Book, 5th Edition, Oxford, England: Trafford Publishing, 2007.
8. Finkenzeller K., RFID Handbook, 2nd Edition, Translated by Waddington R., Chichester, West Sussex, England: John Wiley & Sons, 2003.
9. http://www.sciencedaily.com/articles/m/microchip_implant_(animal).htm.
10. Graafstra A., "Hands On- How Radio-Frequency Identification and I Got Personal," IEEE Spectrum, Vol. 44, No. 3, Mar. 2007, pp. 18-23.
11. Foster K. R. and Jaeger J., "RFID Inside – The Murky Ethics of Implanted Chips," IEEE Spectrum, Vol. 44, No. 3, Mar. 2007, pp. 24-29.
12. http://www.ewh.ieee.org/soc/embs/comar/phone.htm.
13. Setian L., Antennas with Wireless Applications, Upper Saddle River, New Jersey: Prentice-Hall, Inc., 1998.
14. Cheng D. K., Fundamentals of Engineering Electromagnetics, Upper Saddle River, New Jersey: Prentice-Hall, Inc., 1993.
15. Johnson C.C. and Guy A. W., "Nonionizing Electromagnetic Wave Effects in Biological Materials and Systems", Proceedings of the IEEE, June 1972, Vol. 60, Issue 6, pp. 692-718
16. Elachi C., Introduction to the Physics and Techniques of Remote Sensing, New York, New York: John Wiley & Sons, Inc., 1987.
17. http://www.theregister.co.uk/2004/10/14/human_rfid_implants/.
18. http://www.rfidupdate.com/articles/index.php?id=885.
19. http://www.zdnetindia.com/print.html?iElementId=169562
20. http://www.freewifi.com.au/hotspots_wifi_info.htm.

Andrew Nguyen is a premed student at the University of California, Irvine. He has presented and published 6 conference papers and 3 journal papers. He is interested in a career in oncology with current research interests in biomedical sensing and imaging.