Wireless Tag and Reader Module Design for Automated Hand Hygiene Documentation and Reminder System in Hospitals

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***Abstract*—This paper presents a design of a wireless tag and wireless reader for the automated hand hygiene documentation and reminder system (AHHDRS). This system addresses the problem of healthcare associated infections mainly caused by lack of hand hygiene among clinicians and costs $35.7-$45 billion annually in direct medical costs to the U.S hospitals alone. AHHDRS works by creating ultrasonic hotspots with unique Identifier which can be ultrasonically tagged into the wireless Tag based on clinician's movement among hotspots. Correct movement of the clinicians with Tag among the Wash zone/Bed zone hot spots ensures hand hygiene compliance. Tag accumulates the compliance data and periodically transfers it to the wireless reader through 915MHz RF link. Wireless reader consolidates compliance data from Tags in its vicinity and sends it to hand hygiene server through Wi-Fi link. Hand hygiene server processes and reports compliance data and stores for future reference.**

***Index Terms*—AHHDRS, Wireless Tag, Ultrasonic front end Wireless Reader.**

I. INTRODUCTION

Worldwide the Healthcare Associated Infections (HAI) is one of the major concerns both to hospitals and health care authorities. Estimate on the annual direct costs on the health care system to be $4.5 billion in 1992 dollars in the US, with an incidence rate of 4.5% for hospital admissions [1]. HAI are among the leading causes of death in the US, accounting for an estimated 1.7 million infections and 99,000 associated deaths in 2002 alone [2]. It is estimated that HAIs incur an estimated $28 to $40 billion in excess healthcare costs each year [3]. Due to the enormity of this, hospitals and health care authorities are trying to put systems in place to ensure the hand hygiene compliance of their health care workers. One of the ways to ensure hand hygiene compliance of the health care workers is to appoint secret observers to monitor clinician's hand washing patterns before and after attending their patients. This systems works well at the beginning and over a period of time these secret observers identity is known to the clinicians and they tend to comply only in the observers vicinity. A fool proof way to ensure hand hygiene compliance is to have an automatic system which actually monitors clinicians and records the activity without any human intervention. This system should also have ways to store the collected compliance data for analysis and reporting purposes.

There have been attempts to implement an automated hand hygiene compliance systems using RFID or Infrared for compliance detection. RFID based systems require the patient area to be periodically illuminated by interrogating RF beam from RFID reader [4], which may interfere with the hospital equipments. Infrared based systems rely on line of sight for reliable compliance detection which may not be always feasible in a dynamic hospital environment and may require a grid of infra red emitters to define monitored area which makes the system complex and raises the cost [5]. Hence, the proposed system uses 40KHz on air ultrasonic transmission bursts for compliance detection, which neither require line of sight nor interfere with hospital equipments.

II. SYSTEM ARCHITECTURE

The *AHHDRS* system designed to ensure hand hygiene compliance in hospitals is shown in Fig 1. It has the following major components Ultrasonic hotspots, Wireless Tags, Wireless Readers, Hand hygiene server.

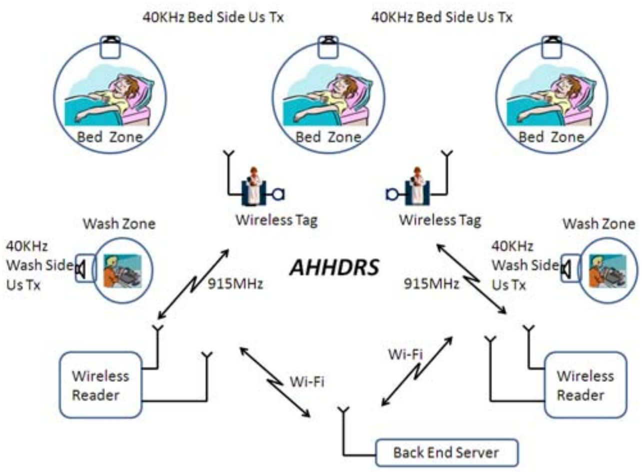

Fig. 1. Architecture of the AHHDRS system

This system works by creating ultrasonic zones for localization of patient bed area as well as the hand washer

Manuscript received June 6, 2012; revised September 5, 2012.

This work was supported by the Agency for Science and Technology Research (A-STAR), Singapore under grant number A*CIMIT 001.

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DOI: 10.7763/IJIEE.2013.V3.255

area. When a health care worker washes hands in the wash zone before and after entering the bed zone within predetermined time, the hand hygiene is ensured.

Wireless tag worn by the health care worker detects the sequence of wash zone entry followed by bed zone entry/exit by receiving the 40 KHz ultrasonic bursts from Wash/Bed Zone transmitter and stores the hand hygiene compliance information. Compliance data stored in the Tag is periodically transferred to the Reader through 915MHz RF link with a protocol similar to 802.15.4. On receipt of acknowledgement the compliance records cleared for future storage.

III. Wireless Tag

The design of the wireless Tag to be used for hand hygiene compliance has the following requirements. Notably, the wireless tag should either be integrated into the existing access cards or attached with the access cards without much increase in the size and volume. It should also have an integrated 915MHz antenna to efficiently radiate RF power. This has been achieved by using surface mount devices and by laying out a high density PCB board with components on both sides and by using a surface mount monopole antenna. As these tags to be worn by clinicians, it should operate from battery and consume as little power as possible to provide extended battery life. This has been achieved by implementing the sleep modes for processor, RF transceiver as well as the ultrasonic front end which minimizes the power consumption. Since, the number of wireless Tags to be used will be more compared to other components in AHHDRS cost of the Tag should be low to bring down the system cost. Fig. 2. Shows the architecture of the wireless Tag designed for the AHHDRS. The 915MHz radio connected to the processor through an SPI link and the ultrasonic front end is connected through an Interrupt pin.

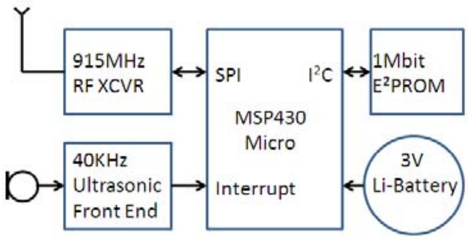

Fig. 2. Wireless Tag Architecture

A. Wireless Tag Processor

Heart of the Tag is a low power micro controller MSP430F5510 from Texas Instruments [6] which does most of the heavy lifting. It can operate up to 25MHz clock and consumes only 1.56mA at 4 MHz in active mode and in consumes a mere 2.1 µA in standby mode. It has 32Kbytes worth of Flash PROM and 6KB SRAM. In the Tag processor operates at 8MHz in active mode to conserve battery power and it goes into sleep mode with 32 KHz clock when there is no activity on the RF and Ultrasonic link is detected. When the wireless tag reaches the vicinity of Wash/Bed Zone transmitter, micro controller receives the processed ultrasonic bursts from the ultrasonic front end. It is then fed to the interrupt pin of processor. On this interrupt it measures the frequency of ultrasonic pulses during ON period of the burst and also the inter burst duration. Based on this measurements source of transmission and its unique identifier is determined and recorded along with the event's time stamp. Subsequent events like Wash zone Entry followed by Bed zone entry within a predetermined times are identified to declare and store hand hygiene compliance. Micro controller puts the 915MHz RF transceiver in sleep mode by default to conserve battery power.

Wireless tag has a serial I^2C 1Mbit E2PROM for recording compliance data, with this storage Tag can store many week's worth of compliance data at a stretch. When the compliance data stored in the Tag exceeds a certain threshold, the micro controller wakes the RF transceiver to establish a connection to the Reader and pushes out the data through the 915MHz wireless link. On successful transmission of the records, the micro controller erases stored records and frees up the space for future compliance records.

When there is a non compliance occurs micro controller also generates an alert tone through a buzzer connected to it. There is an LED provided for status and debugging purposes. Since, this is an USB capable microcontroller the Tag can be debugged through the USB port. There is also a push switch provided to effect various configurations and for restoring default configurations.

B. Ultrasonic Front End

Ultrasonic front end consists of a 40 KHz piezo receiver transducer, a low noise amplifier and a limiting amplifier. The piezo receiver transducer 40KR08 [7] is from Senscomp whose center frequency is 40 KHz and specifically intended for operation in air at ultrasonic frequencies. It has been found that the received ultrasonic signal across the receiver transducer terminals ranges from 0.15- 3.5mV for the distances of 0.3-3 meters between Wash/Bed zone transmitter and the Tag. Gain of at least 60dB required before the limiting amplifier to produce the ultrasonic bursts without any artifacts at the input of micro controller.

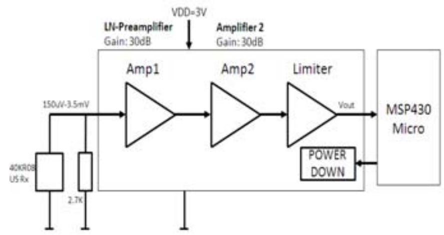

Fig. 3. Wireless tag - ultrasonic front end

Linear amplifier portion of the ultrasonic front end is implemented as two stage amplifiers with 30dB gain each and with an overall 3 dB bandwidth of 40 KHz +/-10 KHz. Output of this amplifier is fed to the limiting amplifier which produces 3V logic pulses at the ultrasonic frequency for the micro controller to detect the received ultrasonic burst signals. There is also a provision for microcontroller to put the ultrasonic front end to sleep if required; this may help conserve battery power during off duty hours of the clinicians.

C. Low Power 915MHz Radio

Three different 433/915/2.4GHz radios were considered for the use in Tag and Reader RF link. To obtain a given SNR over a fixed distance, a radio operating in 900MHz needs 9dB lower power than that of 2.4GHz radio and the 433MHz radio needs 15dB lower power than that of 2.4GHz radio. This would mean substantial savings in battery power for a 433MHz radio, but increased antenna size makes this 433MHz radio is an unviable option for the Tag designs. Though the 2.4GHz is favored for its ubiquitous device availability and miniature antenna sizes, the power consumption and the possible interference with hospital Wi-Fi infrastructure ruled out the usage of 2.4GHz. Hence the wireless link between the Reader and Tag chosen to be 915MHz with a reasonable antenna size and acceptable average power consumption.

Sub 1GHz low power RF transceiver IC from Texas instruments [8] is used for implementing the 915MHz RF chain in the Wireless Tag. It has a sensitivity of -104dBm with 38.4Kbaud GFSK and its programmable transmit power is limited to 0dBm. This device has a sleep current of 200nA, receive mode current of 15.6mA and with 0dBm transmit power consumes around 17.2mA. So, it becomes necessary to put this device into sleep whenever possible to conserve battery power. Tag micro controller wakes up this device whenever its compliance data storage exceeds a preset value. Then the RF link between the Reader and the Tag is established using customized protocol similar to 802.15.4. On successful completion of data transfer the RF transceiver is put into sleep again and to be woken up only when the preset threshold reaches.

D. Lithium Battery

Battery used in the wireless tag is 3v 0.66AH Lithium primary battery due to its smaller size and volume. Supply from this battery is connected to the rest of the circuitry through a reverse polarity protection circuit to prevent damage to the Tag due to accidental reverse connected battery. The battery voltage is periodically monitored through 10 bit ADC in the micro controller and recorded in the Tag. This information can be accessed from the Server through the Reader. This helps to monitor the battery health of every Tag deployed in the AHDRSS network and helps to keep the down time of the Tags to minimal.

IV. WIRELESS READER

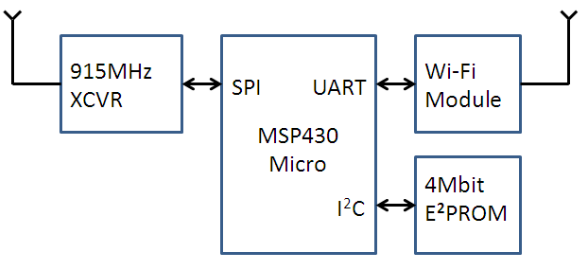

Fig. 4. Wireless reader architecture

Fig. 4. Show the architecture of the wireless Reader. One of the goals of the Reader design is to make sure that it is easier to install and maintain and has a minimal impact on the hospital infrastructure. Reader should also be able to tap the power from the existing AC wiring and should be able to leverage the existing hospital networks. In view of this, the Reader is designed with a Wi-Fi module to communicate to the Server through the Wi-Fi link, which removes the cabling requirement for the networking purposes. Reader is powered by an off the shelf AC/DC adaptor which taps power from the AC wiring. Main purpose of the Reader is to consolidate and pass on the hand hygiene compliance data from the Tags in the vicinity to the hand hygiene server while acting as an intermediate buffer. It uses an off the shelf enclosure with mounting holes to easily mount this unit on a wall or on the roof.

A. Wireless Reader processor

Micro controller used is same as that of in Tag but it is operated at the peak clock of 25MHz to leverage the maximum possible MIPS out of the micro controller. This is required as the Reader needs to service many Tags in the vicinity at the same time while communicating with back end Server. Microcontroller talks to the 915MHz RF transceiver through SPI port and it communicates to the Wi-Fi module through UART port.

Wireless Reader processor periodically scans for any 915MHz RF transmission from the Tags in its coverage area to establish the RF link. If there is a transmission from the Tags then an RF link is established to the particular Tag and then data transmission starts. For every successful reception of a packet an acknowledgement is sent by the Reader micro controller. Reader can receive data from many Tags simultaneously. When the data storage threshold reaches about 75% of the capacity in the Reader, the micro controller establishes a logical connection to the back end server through Wi-Fi link and streams data through the UART port of the Wi-Fi module. Once the compliance data delivered to and acknowledged by the back end server the Reader frees up its storage space for fresh compliance data from the Tags.

B. Low Power 915MHz Radio

RF transceiver used is same as that of the Wireless Tag. But it can be configured to transmit at RF power levels of 0dBm, 5dBm, 10dBm and with a sensitivity of -104dBm for the 38.4Kbaud GFSK. This helps the Readers to adapt based on channel conditions and extend the coverage area of the readers dynamically.

C. Wi-Fi Module

Wi-Fi module is the vital link to the back end server, which monitors and controls the entire AHHDRS network. Wi-Fi module from Roving networks [9] is used in the Wireless reader. This module has complete IP stack built in for the establishment and functioning of a Wi-Fi network node. The hand hygiene compliance data to be transferred to the back end server over the Wi-Fi network is given through the UART port of the micro controller. The built in IP stack minimizes the burden on the Wireless Reader Processor, so that it can take care of 915MHz RF link management and other chores.

Use of the Wi-Fi link in the reader enables centralized control and monitoring of the AHHDRS much easier. In sensitive disease cases if there is a non compliance, even after non compliance alerted by the Tag's buzzer, the Server can automatically alert the supervisor in charge to ensure immediate hand hygiene compliance of the clinician.

V. Conclusion

In this paper, design of Wireless Tag and Reader for the AHHDRS has been explored. It also discussed the requirements in the Tag and Reader design and proposed the architecture and implemented it to meet these challenges.

The main contribution of this work is the design of an easily deployable wireless Reader and very low power and miniature wireless Tags for the AHDDRS. Tag is designed as add on to the clinicians access card and can clipped to it. Next generation Wireless tags will have an integrated circuit for the ultrasonic analog front end and with the space and power savings due to this will be leveraged to integrate the wireless tag into clinicians access card itself.

Wireless Reader is designed to meet the ease of installation and maintenance and by keeping the minimal impact on the hospital infrastructure. Wireless reader is designed with an integrated 915MHz antenna as well as an integrated the Wi-Fi antenna. If required an external Wi-Fi antenna can be mounted to extend the range to the back end server.

Hospitals can use AHHDRS to monitor and improve hand hygiene compliance and reduce the incidence rate of health care associated infections while saving precious lives and money.

References

[1] W. J. Martone, W. R. Jarvis, D. H. Culver, and R. W. Haley, "Incidence and nature of endemic and epidemic nosocomial infections," In*: Bennett JV, Brachman PS, eds. Hospital infections. Boston: Little, Brown, and Company*, pp. 577-96, 1992.

[2] A. Elixhauser and C. Steiner, "Infections with Methicillin-Resistant Staphylococcus Aureus (MRSA) in U.S. Hospitals 1993–2005," *AHRQ Healthcare Cost and Utilization Project Statistical Brief*, vol. 35, pp. 1-10, 2007.

[3] S. Rd. "The Direct Medical Costs of Healthcare-Associated Infections in U.S. Hospitals and the Benefits of Prevention," *Division of Healthcare Quality Promotion, National Center for Preparedness, Detection, and Control of Infectious Diseases, Coordinating Center for Infectious Diseases, Centers for Disease Control and Prevention*, March 2009.

[4] R. Johnson, G. R. Tsouri, and E. Walsh, "Measuring of Compliance of Hand-Hygiene Procedures Using Finite State Machines and RFID" in *IEEE Instrumentation & Measurement Magazine*, vol. 15, no. 2, pp. 8-12, 2012.

[5] A. I. Levchenko, V. M. Boscart, J. P. Ibbett, and G. R. Fernie, "Distributed IR based technology to monitor hand hygiene of healthcare staff," In *Proc. Of Science and Technology for Humanity (TIC-STH), IEEE International Conference*, Toronto, pp. 252–255, 2009.

[6] *Low power mixed signal controller MSP430F550x data sheet*, Texas instruments Inc, July, 2010.

[7] *Senscomp K series Closed Face Piezo Transducer -40KR08 and 40KT08 data sheet*, Senscomp Global Components, July, 2003.

[8] *Low-Power Sub-1 GHz RF Transceiver CC1101 data sheet*, Texas instruments Inc, January, 2010.

[9] *WiFly GSX 802.11 b/g Wireless LAN Module*, RN-131G Datasheet, Roving networks, November, 2010.