University POLITEHNICA of Bucharest
Doctoral School of Automatic Control and Computers

PhD THESIS

A real-time monitoring system for Hospital Acquired Infection prevention
(Sistem de monitorizare în timp real pentru prevenirea infecţiilor intraspitalicești)

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ACRONYMS

Acronym	**Definition**
IoT	Internet of Things
HAI	Hospital Acquired Infection
ICT	Information and Communication Technology
HAI-OPS	Hospital Acquired Infections - Outbreak Prevention System
RFID	Radio Frequency Identification
NFC	Near Field Communication
WSN	Wireless Sensor Network
BLE	Bluetooth Low Energy
IC	Integrated circuit
MANET	Mobile ad-hoc network
GPS	Global Positioning System
LR-WPAN	low-Rate Wireless Personal Area Network
FHSS	Frequency Hopping Spread Spectrum
Bluetooth SIG	Bluetooth Special Interest Group
GSM	Global System for Mobile Communications
1D Barcode	One Dimensional Barcode
2D Barcode	Two Dimensional Barcode
UPC	Universal Product Code
QR	Quick Response
HC2D	High Capacity two Dimensional
ASCII	American Standard Code for Information Interchange)
HCC2D	High Capacity Colored Two-Dimensional
(D&S	The dynamic and Sensitive Printable Barcode

	Technology
RF	Radio Frequency
POS	Point of Sale
ITU	International Telecommunication Union
GUI	Graphical User Interface
SE	Secure Element
GPRS	General Packet Radio Service
IEEE)	Institute of Electrical and Electronics Engineers
WPAN	Wireless Personal Area Networks
AES	Advanced Encryption Standard
MIC	Message Integrity Code
OQPSK	Offset Quadrature Phase-Shift Keying
WLANs	Wireless Local Area Networks
WHO	World Health Organization
M-health	Mobile Health
m-IoT	Internet of m-health Things
IPV6	Internet Protocol Version 6
6LoWPAN	IPv6 over Low-Power Wireless Personal Area Networks
USB	Universal Serial Bus
ECG	Electrocardiography
EEG	Electroencephalography
BMI	Brain Machine Interfaces
BCI	Brain Computer Interface
ADC	Analog to Digital Converter
DSP	Digital Signal Processing
SPI	The Serial Peripheral Interface
HDP	Health Device Protocol
WBAN	Wireless body area network
ASL	American Sign Language
FES	Functional Electrical Stimulation
RFIC	Radio Frequency Integrated Circuit
FPCB	Flexible Printed Circuit Board
HCWs	Healthcare Workers
ICUs	Intensive Care Units
VAP	Ventilator Associated Pneumonia
CR-UTI	Cranimals Urinary Tract Infection
CR-BSI	Catheter-Related Blood Stream Infection
MRSA	Methicillin-Resistant Staphylococcus Aureus
ICC	Infection Control Committee
HF	High Frequency
HVAC	Heating, Ventilation and Air Conditioning system
MHS	Mobile Healthcare Service

SARS	Severe Acute Respiratory Syndrome
HIS	Hospital Information System
FTDI	Future Technology Devices International
PWM	Pulse Width Modulation
DMP	Digital Motion Processing Engine
HCW	HealthCare Worker

Chapter 1. Introduction

1.1. The thesis's subject

Types of bacteria existent inside hospitals differ from other types, which exist in other places due to their resistance to the repeatedly used antibiotics. Currently, infection causes and transmission pathways have been varied and the Hospital Acquired Infection (HAI) became a real problem. HAI needs to be solved quickly to save people lives.

The principal goal of this thesis is to use the Internet of Things (IoT) and Communication technologies to design a low-cost system for combating the HAI and thus reducing both the mortality rate and the financial burden.

The author has designed and implemented in this thesis a monitoring system includes a low-cost SmartBand built based on Radio Frequency Identification (RFID), sensors, ZigBee technology and electronic boards.

The designed SmartBand enables tracking and collecting data about the physicians and patients' activities inside a hospital room.

The implemented prototype is able to perform the following tasks:

- Recognizing the SmartBand holder's identity basing on ZigBee technology so that the system identifies the SmartBand holder's name as he is within the system range,
- Tracking of SmartBand holders and identifying their positions (door, bed1, bed2, sink, and toilet) in real-time based on RFID and ZigBee technology,
- Monitoring the hand hygiene procedure by measuring the hand hygiene duration identified by the World Health Organization (WHO),
- Reading the hands' motions during the sanitation using an accelerometer sensor and ZigBee technology,
- Issuing alerts appropriate with the nature of each event and the place to remind and encourage physicians and patients to comply with the hand hygiene rules in proper times,
- Storing the data gathered by the monitoring system about the personnel activities in a special file stored in the base station.

The alerting mechanism is done on the SmartBand independently by means of light led colors in green, red and orange according to the event.

The communication mechanism was built based on ZigBee communication technology so that all the data related to the physicians and patients' activities are transmitted to the base station. The base station's Graphical User Interface (GUI) has been designed based on LabView that allows presenting the details of the system functioning mechanism and personnel activities.

1.2. Structure of the thesis

In chapter 2, the author introduced a survey and analysis of the Internet of Things (IoT) technologies, definition and characteristics for each one, advantages and drawbacks, the working mechanism, in addition to the comparisons and relations between them.

Chapter 3 shows the role of healthcare applications, which depends on recent ICT technologies in raising the life level of people, their use advantages in both hospitals and homes in performing a permanent healthcare, especially for handicapped and elderly people.

In chapter 4 a definition of the concept of Hospital Acquired Infection (HAI), problems and burdens caused by the HAI in nowadays hospitals in various countries was introduced, presenting the different HAI causes, the role of physicists and management team in addressing the HAI and different solutions used for combating the HAI by combining the ICT and traditional ways.

Chapter 5 describes in details some existent integrated ICT monitoring systems, which are used for combating the HAI, their components, their operation's ways, in addition to the comparison of their features. The author presents the Intelligent$^{\mathbf{M}}$ system, the BioVigil system, MedSense system, a comparison between them, and RL6, an advanced software application that provides the ingredients needed to manage the patient's safety and safer medical care quality, having its own mechanisms for surveying and detecting the HAI. The chapter makes also a short description of the HAI-OPS (Hospital Acquired Infections - Outbreak Prevention System) project, an ongoing European project, in which is involved the Department of Computer Science and Engineering from the University POLITEHNICA of Bucharest. The aim of the project is to develop a comprehensive real-time monitoring system for combating the HAI, their causes, and their transmission tracks. The project tries to overcome the shortcomings of the existent similar systems, by integrating the HAI prevention solutions in the main workflows of the hospital activities.

Chapter 6 presents the author designed system dedicated to combating HAI transmission ways, particularly contaminated hands, inside a hospital room, by monitoring physicians and patients activities. The system can recognize physicians and patients identities, identify their places, and track their compliance with the hand hygiene rules including the hand hygiene duration time and recognizing hand motions during sanitation. For real-time tracking of physicians' positions and activities inside the hospital room, the author designed a multifunctional SmartBand which can be held by all physicians and patients within a hospital. This chapter presents in detail the design and implementation of the SmartBand, the alerting mechanism, the wireless network and other hardware-software aspects of the implemented prototype.

Chapter 7 presents the conclusions of the thesis and the future work.

1.3. Scientific publications in connection with this thesis

1. Zaid Ali SHHEDI, Alin MOLDOVEANU, Florica MOLDOVEANU, "Traditional & ICT Solutions for preventing the Hospital Acquired Infection", 2015 20th International Conference on Control Systems and Computer Science, IEEE, Bucharest, DOI: 10.1109/CSCS.2015.125, pp. 867 – 873, ISBN: 978-1-4799-1779-2, 27-29 May 2015.
2. Zaid Ali Shhedi, Alin Moldoveanu, Florica Moldoveanu, Cristian Taslitchi, "Real-Time Hand Hygiene Monitoring System for HAI Prevention", the 5th IEEE International Conference on E-Health and Bioengineering (EHB), IEEE, Iaşi, Romania, DOI: 10.1109/EHB.2015.7391474, Pages: 1 - 4, Print ISBN: 978-1-4673-7544-3 November 19-21, 2015.
3. Zaid Ali Shhedi, Alin Moldoveanu, Florica Moldoveanu, Cristian Taslitchi, Hesham Alabbassi "EVALUATING SMART COMMUNICATION AND MONITORING TECHNOLOGIES FOR HOSPITAL HYGIENE WORKFLOWS", Journal of

Information Systems & Operations Management (JISOM), 2016 - accepted paper. The article will be published in the following JISOM issue: volume 10 no.1. ISSN: 1843-4711.

4. Zaid Ali SHHEDI, Florica MOLDOVEANU, NETCONF PROTOCOL, A NEW SOLUTION NETWORK MANAGEMENT, Lucrarile celei de A XV-a conferință internațională- multidisciplinară "Profesorul Dorin Pavel-fondatorul hidroenergeticii românești" SEBEȘ ştiinţă și inginerie, volumul 28, Editor: Prof.em.Dr.Ing. Mircea BEJAN. Editura AGIR, Bucureşti, pp. 33-42, ISSN 2067-7138, 2015.
5. Zaid Ali SHHEDI, Alin MOLDOVEANU, Florica MOLDOVEANU, Dragoş Ioan SĂCĂLEANU," Designing a Real-Time Hand Hygiene Monitoring System for HAI Prevention", Scientific Bulletin of UPB, accepted paper.
6. Hesham. ALABBASI, Florica Moldoveanu, Alin Moldoveanu and Zaid Shhedi," Facial Emotion Expression Recognition With brain activities Using Kinect Sensor V2", International Research Journal of Engineering and Technology (IRJET), vol. 02, Issue 02, May-2015, pp 421- 428.

Chapter 2. Overview of the Internet of Things (IoT) technologies

Identification and tracking technologies such as the Radio Frequency Identification (RFID), Barcodes and Near Field Communication (NFC) have enabled humans to interact with daily things and service machines, and have allowed objects to interact with each other. Nanotechnology, ubiquitous Wireless Sensor Networks (WSNs), attached and embedded sensors and tags have given the ability to connect to physical objects. These technologies have enabled monitoring and gathering data about animals, machines, difficult access areas, whether and human vital signs.

Previous technologies in addition to communication technologies, such as Bluetooth technology, Wi-Fi, ZigBee and smart devices such as smartphones, tablets, and robotics brought new services which formed together with the current Network services the foundation of the Internet of Things (IoT) growing.

Basing on the above mentioned technologies, many applications have been built in various domains which in turn have facilitated peoples' lives and have created more well-being.

In the few coming years, the rapid growth of these technologies will contribute to narrowing the gap between physical and digital world at typical speed.

In this chapter, many (IoT) technologies have been highlighted, their features and functioning methods were clarified and interrelations with each other have been analyzed.

2.1. Sensors

2.1.1. Definition and Types

Internet of Things (IoT) includes a large number of applications, which basically depend on sensors; practical applications vary from taking simple measurements done by one sensor to half complex applications such as: smart home automation up to highly complex systems as smart grid. As IoT is growing quickly the number of needed sensors is growing accordingly and it may arrive to 45 trillion in the next 20 years [Ahme, 2015], [U. Gho, 2014].

Sensing is a vital need for both artificial and human-related applications for allowing the interactivity with the surrounding in intelligent ways. Users can interact with a large size of information without the need to be conscious of it [Hans, 2003].

Sensors are tiny electronic devices which are considered the foundation stone of IoT. They are made of sensitive materials and have the ability to sense and measure changes of physical parameters (measurable quantities) and convert the captured signals into analog or digital values. Sensors can cooperatively gather and transmit data to sensor nodes through wires or wirelessly. In future Internet, including the IoT intelligent algorithms and the cognitive capabilities into sensors will enable them to act as intelligent objects not just as sensors.

Sensor types vary depending on the measured parameters:

- Nuclear and electromagnetic sensors amount the radiation concentration average
- Thermal sensors compute the temperature degree and the heat flow
- Mechanical sensors determine the pressure, the force, etc.
- Chemical sensors sense the chemical materials and measure the gas concentration,
- Military sensors track enemy movements
- Motion sensors perceive the persons and materials movement [Haki, 2010]
- Fingerprint sensors could be capacitive, pressure, optical or thermal sensors. They are used for taking a digital image of the fingerprint prototype and after processing the taken images; they are saved and used later for corresponding purposes, other sensor types include light sensors, carbon dioxide density sensors, air flow and humidity sensors [Lunj, 2014].

2.1.2. Sensors placements

Selecting the optimal places for fixing the sensors offers significant benefits:

- Enhancing the controlling and monitoring mechanisms,
- Using less number of sensors with better results,

- Reducing the application cost,
- Saving energy.

2.1.3. The sensor interface

The sensor’s interface has specifications which differ according to the version and sensor type. Each sensor has a unique interface which could be either digital or a low resistance voltage output. The sensor interface is enabled to connect to a microcontroller and its performance stands on the sensor type [Haki, 2010].

The recent digital platforms such as Arduino and Raspberry Pi are compatible with most sensors and provide highly adaptable interfaces which enable the digital processing of gathered data. Integrated Circuits (ICs) are joined to sensors to provide the interfacing with other digital components [U. Gho, 2014], and they can be connected to the sensor indirectly (separated chambers) [M. Roc, 2012], [Haki, 2010].

2.2. Wireless Sensor Networks (WSN)

Wireless Sensor networks occupy a decent position and play a major role in IoT deployment. They contribute providing a better monitoring and tracking of the daily objects and thus wider awareness of the surrounding. WSNs are easy to use that sensors can be deployed anywhere, and they have the feature of speed setting that WSNs can be installed in few hours [Haki, 2010].WSNs are adaptable with the hard environments that a large number of WSNs can work independently of the Internet and sensor nodes have features of flexibility, heterogeneity, and mobility [Urvashi, 2015]. Nowadays, several kinds of WSNs are used in a variety of domains such as environment, agriculture, structure and healthcare.

A number of low power, low cost, easy to use, inexpensive and disseminated sensor nodes are connected to each other via wireless communication and in a wireless multi-hope way to form a WSN which has an ever-present nature [Jing, 2012]. WSNs are used in a large number of surveillance and monitoring applications and classified as one of the mobile ad-hoc network (MANET) kinds. Sensed changes include moisture and temperature changes, rainfall, increasing the concentration of pollutants or radiation in the air, the movement of animals’ flocks in a particular region. The sensor node sends a site reference to the main server which in turn locates the region of occurred changes [Jeril, 2014]. Some applications allow users to get information about the temperature by using their smartphones to interact with dedicated sensor nodes placed in their region [Jing, 2012].

WSNs were firstly used in military applications, but due to the ease of sensor's dissemination WSNs started to be used in other domains such as fire detection, machine wellbeing monitoring, intelligent homes, irrigation systems, intelligent transportation systems, E-health, and telematics [R.Nith, 2015], [R. Mah, 2013].

2.2.1. The WSN challenges

WSNs face real challenges, which are:

- The reliability of WSNs communications is considered as an important issue and a real challenge in the practical implementations [Chee, 2003], [Zhigang, 2014]. If the WSN architecture is centralized, so the whole Network will fail if its central node collapses [Haiguo, 2012],
- The power consumption; sensor nodes' batteries are non-rechargeable which can be a critical issue and a factor of instability which may cause WSN fail,
- Storage capacity and memory size,
- Possibility of interference with other wireless communications,
- Network size and the place supposed for deploying the Network components (harsh environments or underwater) [Haki, 2010].
- Building WSNs using the distributed design can strengthen the WSN reliability [Haiguo, 2012].

2.2.2. The sensor node structure

A wireless node is composed of a battery-powered circuit board with a number of interconnected integrated circuits (ICs) [Haki, 2010]. Most of wireless sensor nodes are made of ready to use materials [Jeril, 2014] and have various types and sizes [Haki, 2010]. Each sensor node is composed of the following components:

- The sensing part which consists of one sensor or more in addition to a number of analogs to digital converters for sensing changes in the area and gaining the data;
- A memory for storing programs, algorithms, and collected information;
- A microcontroller, which is a small processor, represents the main part of the sensor node, [Haki, 2010]. It is dedicated for processing and controlling the collected data for making a suitable decision;
- The communication part, which is composed of a radio transceiver and an antenna so that the processed data are sent through the transceiver to the antenna to be transmitted wirelessly to other WSN components within the communication range [Haki, 2010];
- An interface for communication with other sensor nodes and the main server by using digital or analog ports [Haki, 2010];
- The power source which can be a battery or sun cells.

Sensor node components are considered as power-consumers even when they are in the sleep mode [R.Nith, 2015], [Gius, 2009], [Haiguo, 2012].

2.2.3. The sensor node Lifetime, Cost and Size

Energy is an important issue in WSNs that is the lifetime of the sensor node stands on the amount of energy which can be stored or absorbed from the surrounding. Storing or capturing the energy is standing on two other factors which are the cost and size. The cost of power sources used in WSNs is classified as a weighted factor to be taken into account more than the size when applying solutions practically; therefore, designers prefer to use low-cost energy sources such as cheap C-cell batteries.

When energy sources are with equal costs, then the power source with the longest lifetime will be chosen then the size of energy source will be taken into consideration.

In the case of using small batteries, such as coin cell batteries without satisfying the energy consumption requirements; this will not be a good choice for building a WSN, thus bigger size C-cell batteries must be used. In the case of the size and lifetime satisfy the desired requirements; the size will be the deciding factor so that the energy source with the smallest size will be chosen.

Big batteries will not be a choice to be used in most of practical applications and C-cell batteries are not a good choice when it comes to wearable sensors and medical applications due to their unsuitable sizes [Haki, 2010].

2.2.4. The sensor node lifetime stages

The lifetime of the wireless sensor Network is divided into four stages:

- Planning phase includes searching and choosing the most suitable site for distributing and setting up the sensors to meet the desired goal,
- Deployment phase where the connections are tested and sensor nodes send type and connection characteristics in addition to the routing ways to the main station,
- Monitoring phase where the server receives values measured by means of distributed sensors,
- Controlling phase where the server software is able to send notifications including control commands and alerts to sensor nodes [R.Nith, 2015], [A.K. Dwiv, 2011].

2.2.5. Positioning the WSN sensor nodes

Localization of sensor nodes is considered as an important factor for achieving the desired goals of the WSN such as monitoring and surveillance. Identifying positions of WSN nodes can be done using various mechanisms which differ in their effectiveness.

These mechanisms are:

- Range and distance based methods,
- Angles based methods,
- Proximity methods,

- GPS based methods, which face some obstacles as in the case of WSNs composed of a huge number of sensor nodes that a Global Positioning System (GPS) transceiver must be included into each sensor node which is an expensive solution,
- Sending the location reference of the sensor node can offer good localization results [Jeril, 2014].

2.3. Bluetooth Technology

2.3.1. Classic Bluetooth

Bluetooth is a wireless technology dedicated for low-power devices where the device's battery could last up to few years [H. LAB, 2007], and it is widely used in small wireless networks such as Low-Rate Wireless Personal Area Network (LR-WPAN). Bluetooth technology allows short range communication between various devices so that the class 1 Bluetooth has an effective range up to 200 meters, and the class 2 Bluetooth range is between 20-30 meters.

Using the Frequency Hopping Spread Spectrum (FHSS) method for broadcasting the signals [Shah, 2008] reduced the interference between Bluetooth signals and other sources signals. Bluetooth is considered as a low power consumption technology in case of short range communications. Bluetooth chips are integrated into most of mobile devices which enable Bluetooth technology to be a suitable choice for a lot of applications in daily life. Compared with Wi-Fi; Bluetooth technology can provide faster, stronger and more reliable connection [Hide, 2014].

The main advantages of Bluetooth technology are:

- Using a small and a widespread integrated circuit in several types of devices,
- Low power consumption and therefore low-cost applications [H. LAB, 2007].

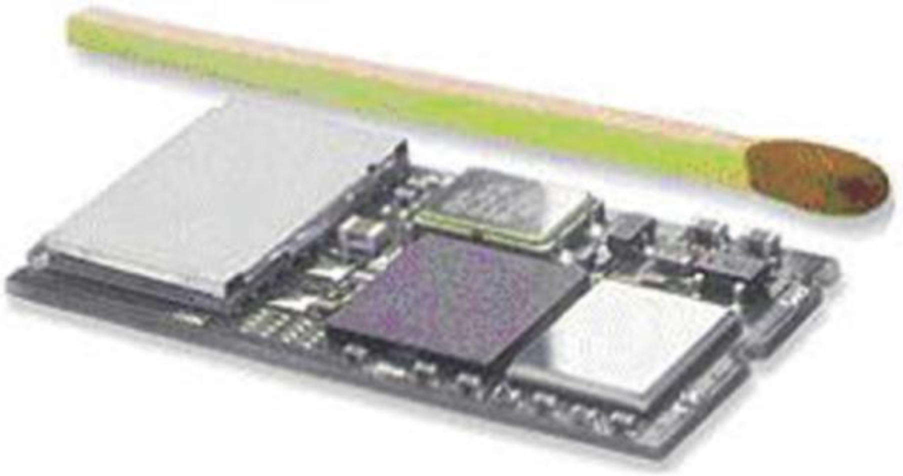


Fig 1. Bluetooth chip   [H. LAB, 2007]

Security considerations

Bluetooth Security issue is more accurate than that in Wi-Fi technology but at the same time, it has some shortcomings as following:

- Dynamic keys are not enough and the authentication procedure includes connected devices but it does not include users and data, thus, sensitive information can be exchanged. So, authorization procedures must be improved by modifying the security management and related procedures in addition to enhancing system of keys management,
- Security subject does not take into consideration hard security problems, Instead of it; they offer solutions for issues of less value.

There are some suggestions to enhance the Bluetooth security side such as exchanging dynamic keys between connected devices in addition to permanent alteration of pseudonym addresses which hide the device's physical addresses. Wider Bluetooth networks have their own security considerations [H. LAB, 2007].

2.3.2. Bluetooth Low Energy (BLE)

2.3.2.1. Definition

Bluetooth Smart (Bluetooth 4.0) is the latest version of Bluetooth wireless technology which was published in 2010 [Zhe-M, 2014], but it has totally different characteristics and purposes. It is a low cost, low bandwidth, and low power wireless technology [Hide, 2014].

Due to the fact that BLE sensors are with coin cell batteries that can live up to two years; BLE has a feature of low energy consumption [Hide, 2014] and has the ability to deal the power consumption problem [Zhe-M, 2014]; so it is considered as a promising choice for IoT deployment. BLE is a radio standard and a flexible format for data exchange through a low complexity connection which uses the frequency hopping spectrum as the classic Bluetooth [Kevi, 2014], [Matt, 2012], [Zhe-M, 2014].

BLE has a fast growth rate; it has already been used in healthcare-related applications which do not require a high bandwidth [Raph, 2014].

2.3.2.2. BLE Concept & features

The operating range of the wireless devices stands on multiple factors, obstacles and barriers, the environment, the device steering, the antenna design, the antenna size, the antenna broadcast power and the used frequency. The trusty range of the BLE-enabled device is 30m-50m line-of-sight, but the effective range which is able to last the battery lifetime is between 2 & 5 meters. Increasing the transmission power leads to expanding the wireless device range, thereby increasing the consumption of resources such as battery lifetime. BLE is a widespread that number of electronic devices which include an integrated BLE chip will reach 2.9 billion by 2016 according to Bluetooth SIG (Bluetooth Special Interest Group) [Zhe-M, 2014].

2.3.2.3. BLE working mechanism

The BLE device uses two mechanisms to communicate with other wireless devices within its broadcast range.

- The broadcasting method which broadcasts data -in one-way connection- to any listening device capable of capturing data within the sender device range (data can be sent to one or more communication devices at the same time),
- The “connections” mode which means establishing a secure encrypted connection between two BLE devices for exchanging data in both directions (the connection includes only two devices) [Kevi, 2014]. This approach depends on the frequency hopping spread spectrum which reduces the radio interference and may consume less power than the broadcasting method [Kevi, 2014]. The channel width of classic Bluetooth is 1MHz with 79 hops, but the BLE has 43 hops and 2MHz channel width [Matt, 2012].

The BLE device cannot play a role of a client and a server at the same time [Raph, 2014]. The using situation and the communication conditions identify whether the BLE device will be used as a master, a slave or both [Kevi, 2014]. Devices that start the communication, such as smartphones, are called masters and each master device can communicate with many other devices known as slaves (small devices with constrained resources such as individual sensors). BLE slave devices -which normally receive the connections- can be connected to many master devices at the same time (e.g. a smartphone connects to a lot of remote thermometers placed in some place) [Kevi, 2014].

The master device scans the three dedicated advertisement channels permanently and when the slave advertises on one of them; the master discovers the slave and then the communication is founded for exchanging data. This situation represents asynchronous wake-up for both ends and when the data transmitting ends, they come back to the sleep mode again [Matt, 2012].

2.3.2.4. BLE Advantages& drawbacks

Due to the rapidly growing in smart devices industry the great number of devices which include BLE chips, and the big number of companies interested in producing BLE-equipped devices, BLE is well ahead of other competitor wireless technologies which are asynchronous. BLE products are cheaper and faster than other wireless technologies such as: Wi-Fi, GSM (Global System for Mobile Communications) and ZigBee that the communication does not require pairing before exchanging data. BLE is easy to use by any person without the need to understand the underlying technology [Raph, 2014]. BLE is fitted with small-size electronic products such as medical devices and remote controllers. It can be considered as a solution to power consumption problem of the wireless communications [Zhe-M, 2014].

The main disadvantage of BLE is that the “Broadcasting” system is not a secure way for exchanging data, especially sensitive data that each listening device can receive the broadcasting data. But the connection mode is considered as safe due to the data is exchanged over a secure encrypted link [Kevi, 2014].

2.4. Barcode technology

2.4.1. Definition

Barcode is considered as the first breakthrough which founded to spread the RFID technology [G´abor, 2014]. Barcode is a specific drawing which is printed on daily objects such as commercial packages, train tickets, and advertising posters. It is an embodiment of objects’ data and can contain texts, the object ID, price and other related information, it simply identify physical objects [Zhigang, 2014] which in turn allows tracking those objects [Veda, 2012].

Barcode represents an image that includes a mixture of bars with different thickness, squares, dots and other forms with white and black colors and it is readable by Barcode readers [Grillo, 2010]. Encryption of barcode information is done by using bars with different widths and different empty distances between the bars [Zhigang, 2014].

In the beginnings, identification of objects has been performed using barcode technology. Barcode includes several forms of codes which have either a fixed length with a specified number of characters or a changing length with a random number of characters. Barcodes can be used in a lot of current applications and cannot be read directly by humans [Melinda, 2012].

2.4.2. The Barcode working principle

As one of barcode readers’ kinds, optical scanners are used to scan the object’s data which are represented as barcodes by reflecting the light on the Barcodes symbols then the data is decoded and processed by means of computing devices connected to the readers [Veda, 2012].

Smartphones equipped with strong processors and cameras are other kinds of Barcode readers which are able to scan, read and decode the Barcodes. Most of current mobile phones can recognize 1D (one dimensional) and 2D (two-dimensional) Barcodes [Puchong, 2014]. Smartphones are successful alternatives of the traditional Barcode scanners and can be invested in a lot of current real-time applications such as comparing prices **[**G´abor, 2014**],** [Zhigang, 2014].

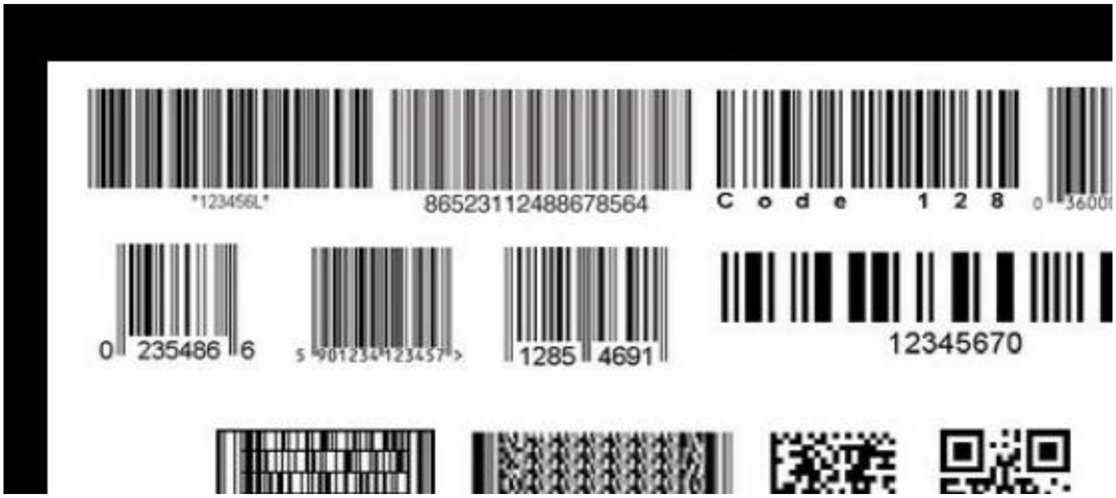
2.4.3. Barcode types

ID and 2D Barcodes are the most common nowadays. 1D Barcode is also known as the linear Barcode such as the Universal Product Code (UPC) and the European Article Number 13 (EAN 13). The two-dimensional barcode has a higher range and able to encode a larger size of data than the 1D Barcode, that’s because the 2D Barcode encodes the information using the width and height, whereas the 1D Barcode uses a way stands on changing lines widths and spaces.

Fig 2. A UPC-A (Universal Product Code) Barcode [Veda, 2012]

The linear Barcode of a certain product is the same in all places (retails, stores, cities and countries). Besides using lines, the 2D Barcode started to use other forms with time such as dots, and two-dimensional forms such as squares and rectangles [Veda, 2012]. QR (Quick Response) code is the trademark and the most common for the two-dimensional Barcode currently.

QR Barcode was firstly designed and developed in Japan, it can store a big size of data (more than 2500 numbers) and it is specified as a space contains a group of various ordered shapes [Grillo, 2010], [Zhigang, 2014]. QR Barcode is used in a variety range of applications and is commonly used in advertising field that it can be read by smartphones.



Barcode patterns (from left to right). Top row (1D codes): Code39, Codabar, Code128, UPC-A; Middle row (1D codes): UPC-E, EAN-13, EAN-8, I2of5; Bottom row (2D codes): Coda block, PDF417, Data Matrix, QR.

Fig 3. A set of standard 1D barcode types and some widely used 2D barcode types [Melinda, 2012]

High Capacity two Dimensional (HC2D) barcode requires a small space and can store a bigger size of data than the 2D barcode. So the HC2D barcode shape is fit to be used in advertising field that it is easy to be printed on posters and papers. Only optical scanners can read the HC2D barcode [Puchong, 2014].

The HC2D barcode is represented as a black shape with four sides, it includes a group of various shapes that's the information is encoded in vertical and horizontal tracks. The HC2D barcode provides data storage which could be up to 7,250 numeric characters or 10.100 ASCII (American Standard Code for Information Interchange) characters. HC2D barcode has a data compression mechanism which could be used in the case of representing a huge amount of data and has an error correction mechanism called "Reed-Solomon" able to detect and correct possible errors; [Jun Yin, 2010].

Fig 4. The HC2D barcode [Puchong, 2014]

Other types of Barcodes use the colored shapes (squares or triangles) such as HCCB which is offered by Microsoft and HCC2D (High Capacity Colored two Dimensional) [Grillo, 2010]. The size of stored information differs according to the difference of shape's colors. Using colors enable storing a larger amount of data in the case of using the same specified space, so the color Barcode capacity is bigger than the QR Barcode capacity [Zhigang, 2014].

In addition to the feature of identifying objects; barcodes have the sensing feature, that Barcode technology is able to sense the surrounding. So, IoT could depend on Barcodes instead of sensors to lessen the cost in some applications. The Dynamic and Sensitive printable barcode technology (D&S) is able to sense the environmental changes so that printing materials which are used in representing the D&S Barcode change according to that and thus stored Barcode information will also change. The higher storage capability over the current "white and black" barcodes [Grillo, 2010] and the environmental perception make the D&S barcode usable in various applications [Zhigang, 2014].

2.5. RFID Technology

2.5.1. RFID Definition and Concept

RFID as one of vital IoT technologies is based on radio waves to build the communication between RFID readers and RFID tags [Lionel, 2004]. The main goal of RFID is to identify and track the everyday objects in addition to monitoring the environmental variables by means of attached tags. RFID technology was firstly used in military applications in the forties of the last century. Low-cost RFID TAGS manufacturing appeared in the last decade of the twentieth century. Each RFID tag consists of a small integrated circuit (IC) for storing and processing data, modulating and demodulating the (Radio Frequency) RF signal. The IC is connected to an antenna which is used for receiving and sending the RF signals [Veda, 2012].

RFID tags can store a little amount of data about the monitored object, in addition to small size applications and they can be attached to daily things to provide them with interactive capabilities. RFID technology marks daily life objects with unique identification numbers, so it facilitates the communication with those objects and thus contributes to spreading the IoT. RFID tags are either passive or active; passive tags do not have power sources, are very cheap, and can survive and keep readable for a long time. RFID passive tags can operate at all radio frequencies, but active tags operate only at higher radio frequencies [Veda, 2012].

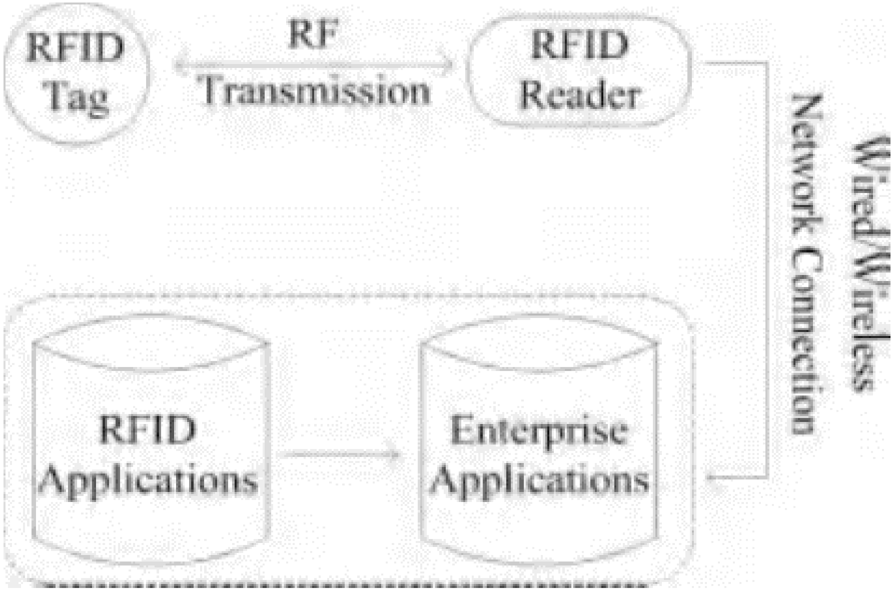


Fig 5. Architecture of an RFID system [Veda, 2012]

2.5.2. RFID Operating Principle and Components

The RFID system has two devices, an RFID reader (interrogator), or a mobile phone provided with an NFC wireless interface, and an RFID tag. The reader can be used individually or connected to a background database or provided with an interface for directing the obtained information to other systems. The communication between the reader and the system application could be wired or wireless. Similarly to NFC (Near Field Communication), the RFID reader generates an RF field to operate the RFID tag (transponder) which does not have a power source. The passive tag can get the required power by means of the RF field signal and thus the IC inside the tag can boot up and send data. The RFID reader can read data stored in RFID tags placed within its range. The reader consists of a transceiver, a control unit decoder for interpreting data and an antenna for broadcasting radio waves signals. When the tag is within the reader's range, it can absorb the required energy from the reader's electromagnetic field. The RFID operating range stands on many factors such as the antenna design, the antenna size (Transmission power), and the used radio frequency and differs from a few CMs to a few meters. So the reader sends its requests and the tag receives the reader's requests and sends data back so that the RFID communication is done in a bidirectional half duplex way [Syed, 2012], [Veda, 2012], [Klaus, 2010].

2.5.3. RFID Barcode relation

- Barcode and RFID have the ability to identify the daily things that RFID allows identifying the real world objects uniquely by using the RFID tags (labels). But the known and familiar Barcode and RFID components do not have the ability to sense the surrounding or the environmental changes. Whereas sensors have the ability to identify the daily objects and sense the environmental changes [Zhigang, 2014]. Nowadays it is possible to obtain an RFID tag with an included sensor so RFID will get the ability to sense the surrounding [Jun Yin, 2010], [Zhigang, 2014],
- RFID technology enables bidirectional communication between readers and tags whereas in the barcode case, the communication is unidirectional and the data can be only read.
- Barcode uses a line of site to recognize any product, so treating with barcodes is somehow difficult; that the Barcode scanner must face each product's Barcode alone to be able to scan it. But RFID does not require a line of site for communication and getting information [Syed, 2012],
- Intruders and thieves can copy both of barcodes and RFID tags, that it is easy to print barcodes or to take photos of them and store them on PCs or mobile phones and then send them to other persons to print them on papers. The data stored in RFID tags can be

encrypted and thus protected against stealing or modification which could be done by attackers. Making copies or original versions of RFID tags is too harder than that in barcodes, so the security side in RFID is stronger than that in Barcodes,

- Printing Barcodes or sticking them on product's papers is unpractical that they could be ravaged so RFID technology is more practical than Barcode,
- Barcodes cannot be adapted to all applications especially applications that handle sensitive information,
- RFID is more expensive than Barcode [Veda, 2012],
- Sizes of data that can be stored in RFID tags are bigger than that in Barcodes; that it can be up to 8 kilobytes [Veda, 2012],
- RFID based applications allow time-saving that the RFID reader is able to interact with a lot of RFID tags at the same time, but in case of Barcodes, each label must be read separately and at a short distance,
- In certain cases, RFID and Barcodes can be used in the same application.

2.5.4. RFID advantages

- It can operate without a line of sight; that it is not necessary for the tags to be situated directly versus to readers, it is enough for them to be in the reader's range,
- The RFID reader has the ability to read from, write to and to modify the RFID tag's data,
- Each RFID tag has a unique code and a unique content, this singularity allows tracking each labeled object or product when it moves from one place to another which in turn can keep track theft cases or product loss [Syed, 2012], [Veda, 2012],
- RFID tags are protected with solid covers so that they can be used in a variety of environments even in difficult ones,
- RFID tags are reusable sustainability which leads to reducing the fanatical burden.

2.6. Near Field Communication (NFC)

2.6.1. NFC Definition

NFC is one of the latest technologies, which was introduced in the last ten years [Syed, 2012]. It is similar to RFID, but with other frequencies. NFC is a high-frequency, quickly deployed, low bandwidth and a short range wireless communication technology; the range is generally less than 10 cm, but it could be up to 20 cm [Syed, 2012], [Vish, 2014]. NFC provides bidirectional communication between electronic devices by only a single touch. NFC is offering new services to facilitate the daily life and can be considered as the best solution for IoT proliferation [Suk-Un, 2014], [Syed, 2012], [Vish, 2014].

2.6.2. NFC Components

NFC system stands on three NFC devices:

- NFC-enabled mobiles which are the most effective and commonly used NFC devices;
- NFC reader is an active NFC device, it is available in one of two designs: **internal** which is included into an NFC-enabled mobile phone, and is able to create its own radio frequency field, except when the NFC mobile is in the standby or sleep mode. And **external** such as a contactless POS (Point of Sale) which operates as an NFC reader able to read data stored in an NFC-enabled mobile phone close enough to it [Veda, 2012];
- NFC tag which is practically an industrial passive RFID tag, easy to use, able to store a little amount of data in addition to a unique identification number [Syed, 2012], [Vish, 2014], [Veda, 2012].

2.6.3. Concept & communication mechanism

The NFC concept is based on the integration of mobile devices, smart card interface, several contactless identification technologies such as RFID and wireless technologies as Bluetooth and Wi-Fi [Veda, 2012], [Syed, 2012]. Contactless smart cards have emerged firstly and nowadays mobile phones are available with NFC technology. Dedicated reader devices provided with NFC technology such as mobile phones can connect to RFID-tagged things in addition to contactless smart cards [Syed, 2012].

According to the International Telecommunication Union (ITU), about 61% of people are using mobile phones [Syed, 2012]. This truth encourages manufacturers to integrate NFC technology with mobile phones which can provide smart solutions [Veda, 2012].

The NFC communication is done between two NFC-enabled mobile phones or between an NFC-equipped mobile phone from one side and either an NFC reader or an NFC tag from the other side [Veda, 2012] by touching an NFC device to another one. NFC technology does not allow more than two NFC enabled devices to communicate at the same time but NFC allows people to interact with the surrounding ubiquitously [Syed, 2012].

2.6.4. The three different operating modes of NFC technology

- **Reader/writer** mode which means exchanging data between an NFC mobile and an NFC tag so that the NFC-enabled mobile phone can read data from or write data to the NFC tag.
- **Peer-to-peer mode** means exchanging data between two NFC supported mobile phones in a bidirectional half duplex communication.
- **Card emulation mode** is the most prevalent mode so that the NFC-enabled mobile phone can operate as a contactless card for payment and ticketing. The NFC mobile phone is activated by the RF field generated by RFID readers located in some places [Veda, 2012].

2.6.5. NFC Advantages and disadvantages

NFC advantages

- Configuring Wireless networks such as Wi-Fi and Bluetooth is not an easy work and takes time and the same when configuring wireless devices to work with wireless networks. NFC can be as a mediator between two wireless devices placed close to each other enabling them to exchange the required settings and to connect to wireless networks without needing to introduce their network parameters [Syed, 2012],

- NFC technology can be integrated into many devices and can be used in a huge variety of applications and services,
- NFC tags can be implanted into or fixed on everyday objects that they have small sizes, which makes NFC an adaptable technology,
- A lot of companies are interested in incorporating their services into users' mobile phones such as identification service, payment with debit and credit cards and access control. NFC provides implicit matching and fast communication that the NFC mobile’s application is activated routinely when discovering the matching pairs within its range and is communicated directly without the need to pairing as with Bluetooth,
- NFC technology takes into account the users’ privacy as in the case of using the NFC-enabled mobile phone as a smart card. [Syed, 2012], [Veda, 2012], [Suk-Un, 2014],
- NFC technology is deeply adapted with mobile phones that it does not consume the mobile battery as with Bluetooth,
- NFC technology does not require a line of sight to operate [Nurb, 2014],
- NFC is higher safe technology than RFID due to its short communication range. It is difficult for counterfeiters to catch signals during the communication between two NFC parties [Syed, 2012].

Benefits of NFC Systems

NFC Systems provide Benefits for a multitude of domains:

Transportation systems: passengers no longer need to use cash in order to buy tickets and drivers no longer need to sell tickets, neither to use money nor to make calculations, or even to check tickets in and out. These facilities make the NFC a time-saving technology**.** Transport companies can save operating and maintenance costs that there is no longer a need for ticket dispensers or printing tickets and it is easier to change the ticket’s price or to apply discounts. NFC mobile phones can be used as electronic cards (credit or debit), keys, travel cards and health smart cards and they provide flexibility to users so that they no longer have to carry a lot of cards which will not be lost or stolen as real ones.

Proximity services: enable users to access services or share information simply by touching or waving their NFC-enabled mobile phones near other NFC components.

Borderless services: when people travel to other countries with their NFC devices; they do not need to use those country's coins, and they can get the tourist information directly from smart posters and tags by means of their NFC enabled mobiles. By using location-based services; users will be able to pay for tickets very simply [NFC, 2015], [Syed, 2012].

NFC drawbacks

NFC technology has a lot of advantages, but unfortunately, NFC commercial applications are vulnerable to attacks. The most common threats are tag cloning and tag impersonation [Veda, 2012]. Some attacks want to change the tag's content by displaying false information such as fake phone numbers and counterfeit person identities [Veda, 2012], [Coll, 2008].

Some attackers replace the original tags by their own tags, so they are able to control the system as they want. These problems can be faced by making the threats more difficult by using cryptographic tags and authentication protocols [Syed, 2012]. NFC readers also are vulnerable to theft, vandalism, removal, impersonation, or imitating the identity of a legal reader for obtaining the high importance information [Veda, 2012].

2.6.6. NFC working principle

When two NFC enabled devices become so close to each other (within the range), or one of them touches the other; then the NFC active device which is called the initiator and has its own embedded power source will generate an electromagnetic field to activate the other NFC device which does not have a power source (passive device), and thus, communication is founded. The NFC communication is similar to the client-server paradigm. The NFC device which receives the communication is called the target, it can be a passive device gets its power from the initiator's electromagnetic field, or active has its own power.

NFC technology has two communication modes:

- Active communication mode so that each of the communication ends generates his RF field to start the communication and exchange data;
- Passive communication mode so that only one NFC device generates an RF field [Veda, 2012].

The NFC application is designed to boot up when the NFC enabled mobile phone touches an NFC component with the expected form of data. A particular application installed in an NFC mobile phone can read information about the university departments from an NFC tag. This application can run directly when a mobile phone touches an NFC tag that stores the required information [Syed, 2012]. NFC tags and smart cards are always targets and passive devices and NFC tags cannot connect to each other because they don't have the required power source. These devices are dedicated for storing data which is readable by the initiator [Syed, 2012], [Veda, 2012].

2.6.7. NFC in HealthCare domain

NFC plays a vital task in healthcare domain in both homes and hospitals especially in telemedicine and it provides a group of services:

- **Identification and health monitoring:** NFC technology enables people to send their medical information such as blood pressure and heart beats rate from homes to their doctors. Handicapped and the elderly people can get many services from their homes by using of NFC technology [Veda, 2012].
- **Medical record storage**: NFC-enabled devices allow storing information about patient's situation which can be measured at homes such as blood pressure and blood glucose. These parameters (vital signs) are analyzed and evaluated and saved in records explain the patient's situation.

  NFC-enabled devices can also be used to store health information to be analyzed and evaluated directly at the same place, especially in urgent situations. NFC helps physicians to get detailed reports about the patient's situations and thus more accrued diagnostics.

- **Tracking medical practitioner's location**: NFC technology can also be used for tracking doctors and patients by using NFC readers placed in many places in the hospital. When a doctor touch one of the NFC reader, the system will be able to know his position (floor, room) and thus to save his track. At the same time, the system can identify the patients who were treated by this doctor and also NFC can provide blind people with audio medicine identification.
- **NFC-Enabled Blood Glucose Measurement:** patients can measure their blood glucose levels at their homes and send the results to a monitoring system in order to get the proper medication in real time [Syed, 2012]. The same thing could be applied in hospitals to treat and track the patient's situation in real time.
- **Inventory tracking and Medication care**: the unique identification of patients in hospitals based on NFC technology facilitates giving the suitable medication to the suitable patient and removes the possibility of giving treatments to the patients wrongly especially in crowded hospital.

Using NFC technology in healthcare facilities provides efficiency, safety, accuracy and saves money [Syed, 2012], [Vish, 2014].

2.6.8. NFC and Mobile Phones

Mobile phones are suitable devices for many IoT services and have the ability of processing and storing. In addition to the voice dealing service which was basically found for, mobile phones had a lot of services with time such as peer to peer services (Bluetooth and Infrared) and gained more technologies over time such as NFC technology [Veda, 2012].

The relationship between mobile devices and NFC technology is deep. Mobile possibilities such as a mobile interface with touch screens, the possibility of viewing photos, videos, music and sounds recording and the possibility of surfing Internet based on network technologies such as 3G and 4G can be considered as an important part of NFC services environment. This combination of technologies also allows downloading the readable information over the Internet and enable accessing different types of services. The NFC mobile phone plays a role of a mediator between external NFC devices from one side and services distributed over the Internet from other side and it provides notifications to users to show the interactivity result. The NFC mobile phone is able to filter the input data [Syed, 2012].

NFC enabled mobile phone has an NFC interface (GUI application) which provides interactivity between the user and the mobile phone and enables reading from and writing to different NFC devices. The mobile NFC interface includes a controller which allows the NFC communication with other NFC devices, an antenna, and analog/digital contactless front-end. SE (Secure Element) is an integrated circuit that ensures a secure connection with other NFC-enabled devices and a secure storing of sensitive user data and NFC services [Veda, 2012].

2.6.9. RFID - NFC Relation

NFC is just a branch or an extension of RFID technology; it joins smart card interface and a reader into one device such as a mobile phone. This RFID son is a new wave of RFID but it operates within a shorter range [Veda, 2012], [Vish, 2014].

NFC technology is able to interact with RFID tags by means of smartphones, or other readers and it can be considered as the incorporation of RFID into mobile phones. NFC is a kind of mediator between users and everyday objects; it allows more than half of the planet population to interact with the surrounding via RFID technology. NFC adds further developments to RFID technology by integration of NFC reader chips into mobile phones. NFC supports the RFID tag simulation mode so that the mobile phone operates as an RFID tag as if the phone holder is an object provided with an integrated RFID tag [Syed, 2012]. Security issues are similar for both NFC and RFID regarding the communication mode [Coll, 2008]. As a closest brother or sun to RFID, NFC devices can play a role of RFID tag or RFID readers and they are able to interact with accessible RFID devices.

2.7. ZigBee

2.7.1. Definition

ZigBee is a wireless mesh networking standard and low power technology based on the IEEE 802.15.4 and developed by ZigBee Alliance. It defines a set or a suite of high-level communication protocols for battery-powered applications with low cost and long battery life (it may operate until several years) [H. LAB, 2007], [Prins, 2014]. It operates with low-data-rate (the maximum data rate is 250 K bits per second), short-range (10m – 70m) [Firdaus, 2014], highly reliable and highly secure [H. LAB, 2007], [Prins, 2014].

The maximum communication range of ZigBee protocol is about 200m in the open-air vicinity with obstacles [Firdaus, 2014]. ZigBee is an optimal and integrated solution for the commercial applications especially for wireless sensor networks applications [H. LAB, 2007], [Mohd, 2014], [ZigBee, 2015], [Shah, 2008], [A. Moh, 2013].

ZigBee is a technology specified for a Wireless Personal Area Networks (WPAN) due to its suitable features. So it can be used widely in a huge number of wireless control and monitoring applications such as home automation (controlling doors and lighting), military applications, home-based healthcare, medical monitoring and consumer electronics [Prins, 2014].

ZigBee is a global hardware and software standard for wireless network devices; it works with three frequencies 868 MHz, 915 MHz, and 2.4 GHz. These devices can send data over longer distances, using intermediate devices to achieve this goal. ZigBee devices stay a very little time in active mode and they keep in a sleep (power saving) mode for the rest of the time. ZigBee devices take only 30 ms or less to wake up whereas Bluetooth takes about 3 seconds to move from sleep mode to dynamic mode, so the latency with ZigBee is low. ZigBee characteristics make implementing a wireless ZigBee network easier that other standards such as IEEE 802.11 [Veda, 2012], [Shah, 2008], [A. Moh, 2013].

2.7.2. ZigBee Advantages & Disadvantages

The IEEE 802.15.4 standard supports the possibility of encrypting the departing messages by using the Advanced Encryption Standard (AES) [Vish, 2014]. The recipient is able to detect any modifications or changes in the receiving message by means of the Message Integrity Code (MIC) included in each coming message, so ZigBee has the possibility of data authentication. In a ZigBee wireless network, intruders can get sensitive information from the network devices memory such as security keys when these devices are not tamper-resistant nodes. If the devices are tamper resistant, they can remove their sensitive information in order not to be stolen [Shah, 2008].

ZigBee nodes could stay alive for several years without the need to exchange their batteries. Interoperability is an essential issue in ZigBee network which may have thousands of tiny sensors, so that it is able to coordinate the communication among them easily [H. LAB, 2007].

2.8. Wi-Fi communication technology

2.8.1. Definition

Wi-Fi is a high data rate and long range technology, dedicated to the Wireless Local Area Networks (WLANs) and based on the IEEE 802.11 standard. Wi-Fi is a wireless version of an Ethernet network developed and owned by Wi-Fi Alliance [Veda, 2012].

2.8.2. Wi-Fi Advantages and drawbacks

The high data rate and the long range communication of ZigBee make it better and faster than other technologies which have the same frequency band. Wi-Fi is integrated into most of nowadays devices such as tablets, smartphones, printers, laptops and personal computers which allow these devices to access the Internet as they are within any Wi-Fi network range.

Wi-Fi networks can provide a lot of services for users in local areas such as restaurants and other public places, and they can be competitors or harmonious with other wired or wireless communication technologies page [H. LAB, 2007].

Wi-Fi network used by smartphones will consume their batteries quickly [Raph, 2014], [Firdaus, 2014]. Wi-Fi networks are almost everywhere and they represent real danger and could cause coexistence interference to other technologies such as ZigBee and Bluetooth which operate with low energy; that is because it runs with higher power and the same ISM 2.4GHz band [Wang, 2014].

The main features of Wi-Fi are:

- The big consuming of power, and the difficulty for minimization [Hide, 2014].
- Wi-Fi products manufacturers support security mechanisms proposed by IEEE 802.11 standards (802.11b/802.11i/WPA/WPA2). But Wi-Fi networks still have many faults in the security side.
- Wi-Fi security issue suggests some mechanisms to solve the problem such as access control, which is not an optimal solution because intruders can listen to the communication and pick up the MAC addresses.
- Wi-Fi uses other mechanisms such as authentication, encryption, decryption, confidentiality and integrity of data by exchanging Encryption/decryption keys between stations. The entire mentioned mechanisms do not provide a suitable solution and do not ensure a secure communication [H. LAB, 2007].

Table 1. Comparison of studied wireless technologies

parameter	NFC	RFID	Bluetooth	ZigBee
Flexibility	High	Low	High	High
Power Consumption	Low	No	High	Medium
Security	High	High	Low	Low
Personalization	High	High	Medium	Low

Source: [Veda, 2012]

Table 2. Overview of some wireless technologies

Wireless Technology	Operating Frequency	Data Rate	Operating Range
802.15.4 ZigBee	2.4 GHz	250 kbps	70 m
802.15.1 Bluetooth 2.0	2.4 GHz	3 Mbps	10 m

802.11b/g Wi-Fi	2.4 GHz	54 Mbps	100 m
802.11a Wi-Fi	5 GHz	54 Mbps	100 m
NFC	13.56 MHz	106, 212, 424 kbps	0–4 cm
RFID	125–134 kHz (LF) 13.56 MHz (HF) 400–930 MHz (UF) 2.5 GHz and 5 GHz (microwave)	1–200 kbps	20 cm for passive 400 cm for active

Source: [Veda, 2012]

Table 3. Comparison of active tags and passive tags

Parameters	Active Tags	Passive Tags
Power Source	Embedded power source	Power from RF field
Battery	Yes	No
Data Storage Capacity	High	Low
Manufacturing Cost	Expensive	Cheap
Operating Range	Long range	Up to a few meters
Signal Strength to Tag	Very low	Very high

Source: [Veda, 2012]

Table 4. Mobile interaction techniques

Mobile Interaction Technique	Communication Range	Smart Object Awareness
Pointing	From 10 to 100 cm	Yes
Touching	From 0 to 10 cm	Yes
Scanning	Based on wireless communication Technology	No

Source: [Veda, 2012]

2.9. Conclusions

In this chapter, the most recent technologies have been reviewed in details; the concept was demonstrated, the working mechanism, the advantages and the drawbacks for each of them. The RFID - NFC Relation, the RFID - Barcode relation, in addition to NFC – mobile phone relations were explained. At the end of the chapter, a comparison was made to show the characteristics and the features of each technology.

Chapter 3. IOT applications for healthcare

Internet of Things (IoT) allows the possibility of collecting and analyzing information efficiently and rapidly. In healthcare domain, medical devices such as sensors, diagnostic and imaging devices and electronic boards are considered objects with the ability to gather, exchange, and make data sharable over the Internet. In this sense IoT permits connecting those devices to the Internet [Alok, 2014], [Istep, 2011], [RIAZ, 2015].

IoT delivers healthcare services management at healthcare institutions and homes. Nowadays, many IoT products such as wearable devices (smartbands), gadgets and other healthcare devices currently exist in the market and provide solutions for many healthcare applications [RIAZ, 2015].

In the USA, around 100000 people are dying annually in healthcare facilities due to the fruitlessly used healthcare systems which let medical staff members do mistakes during diagnostic and treatment stages. The traditional healthcare systems, especially those used for monitoring patient’s vital signs are considered costly, they require employing a number of medical staff members and they include devices, wires and connections attached to patient’s bodies and cause them to be restricted and uncomfortable.

This truth has led to improve and apply healthcare monitoring systems that depend on up to date technologies such as biosensors, which could be either attached to the skin or implanted in the human body. Biosensors can provide continuous measurement of the patient vital signs without any human interfere. Biosensors can be used for nerve stimulation, diabetes monitoring in addition to monitoring the electric signals from the brain [Ashr, 2011]. The Internet and communication technologies have been invested in a multitude of healthcare systems.

Healthcare applications contribute to raise the level of life, increasing the well-being of service users and shrinking the financial expenditure through the localization of health care services at homes. This procedure can reduce the number of patients in hospitals, because the available hospital clinical resources, human resources and infrastructure are not enough to satisfy the increasing demand of health monitoring operations. Regarding healthcare applications, IoT promotes rationalization and allocation of hardware restricted resources through their optimal use and increasing the number of served patients [Yun, 2015], [RIAZ, 2015].

3.1. Healthcare applications types

IoT supports and promotes many kinds of healthcare systems. These systems could be divided into the following categories:

- Clinical applications such as: fitness applications and other applications for helping the elderly;
- Remote monitoring applications dedicated to monitoring the chronic diseases and the newborns [Alok, 2014];
- Medical applications for monitoring the patient's compliance with the treatment program at homes such as: early diagnosis, real-time monitoring, and medical emergencies applications [RIAZ, 2015].

From another perspective, healthcare applications can be divided into two categories:

- Applications which are interested and focused on a specific disease and called "single-condition applications ";
- Applications which are invested in treatment and controlling many diseases at the same time. They are known as "clustered-condition applications". Services, applications, and solutions may interfere with each other in terms of meaning and definition [RIAZ, 2015].

Healthcare applications rely to a large extent on wireless sensor networks and wireless communication technologies, which are the foundation stone of the IoT healthcare projects. Healthcare applications depend on servers with databases for storing the gathered data of the patients, surrounding the physician's activities, health records and can control the authorizations [RIAZ, 2015].

3.2. IoT-based healthcare applications

3.2.1. Glucose sensing applications

Diabetes is one of the biggest challenges and one of the most prevalent diseases at present due to the growing number of diabetes patients. The hormone insulin secreted by the pancreas normally transports glucose to various members of the body to carry out metabolism and produce the necessary energy for body members. Insulin regulates the glucose level in the blood naturally, but the lack of insulin secretion, the cell resistance of it and the disability to use it effectively leads to increased blood glucose and thus diabetes. Permanent monitoring of blood glucose is very important to adjust its ratio. Glucose monitoring can be performed by providing the required insulin ratios and thus mitigating possible complications which could occur in long term. Diabetes causes lack of human resources which are required for the labor market, negative impact on the economic growth rates, as well as increased fiscal spending for combating the disease [Brin, 2012], [Istep, 2011]. Around 100 million people have diabetes nowadays and this number is expected to double in the next years according to the World Health Organization (WHO) [Nour, 2013].

Skin is the human organ which passes most of the blood quantity and since the needs human organs of blood are changeable; thus the blood contents of nutrients and other various parameters such as glucose are also variable. Continuous monitoring of blood glucose levels of patients gives them a sense of security, comfort and improves their psychological state, more importantly, it allows rapid intervention in critical situations [Istep, 2011]. IoT enables monitoring and determining the blood glucose levels all the time, thus the ability to deal the high glucose levels by determining the appropriate food and sports programs [Istep, 2011], [RIAZ, 2015].

3.2.1.1. Data gathering mechanism and advantages

Real-time monitoring systems rely on sensors to collect data related to patient’s vital signs, then the collected information is sent to the healthcare providers permanently for further analysis. Results can be uploaded to the cloud to be shareable. Monitoring and data collecting process is done automatically, which leads to raising the healthcare level, reducing the cost, and saving labor and time [Alok, 2014]. A number of sensors dedicated for measuring the glucose levels are fixed on the patient's skin and connected to wireless sensor nodes which are provided with communication ability to transmit the gathered data to the main server [Istep, 2011].

The term "Mobile health" or (M-health) means using clinical sensors, mobile devices, and communications technologies for performing healthcare applications with a permanent connection. "Internet of m-health Things (m-IoT) is a combination of mobile 4G networks and the IPV6 (Internet Protocol Version 6) - based communication technologies such as 6LoWPAN (IPv6 over Low power Wireless Personal Area Networks) for providing IoT-based m-health services" [Istep, 2011].

Communication mechanism between Blood glucose sensors and the healthcare provider are based on IPv6 and 6LoWPAN to report the gathered data to the server that the wireless sensor nodes are based on IPv6. 6LoWPAN enables transmitting the IP packets (data messages) using the IEEE 802.15.4 standard (the specified standard for the WPAN) and allows low power sensor nodes with constrained resources to be a part of the IoT. The designed platform nodes have the feature of low power consumption that they use USB (Universal Serial Bus) communication and a low power microprocessor. Reporting the diabetes data could be in real time, depending on critical events or at equal intervals [Istep, 2011].

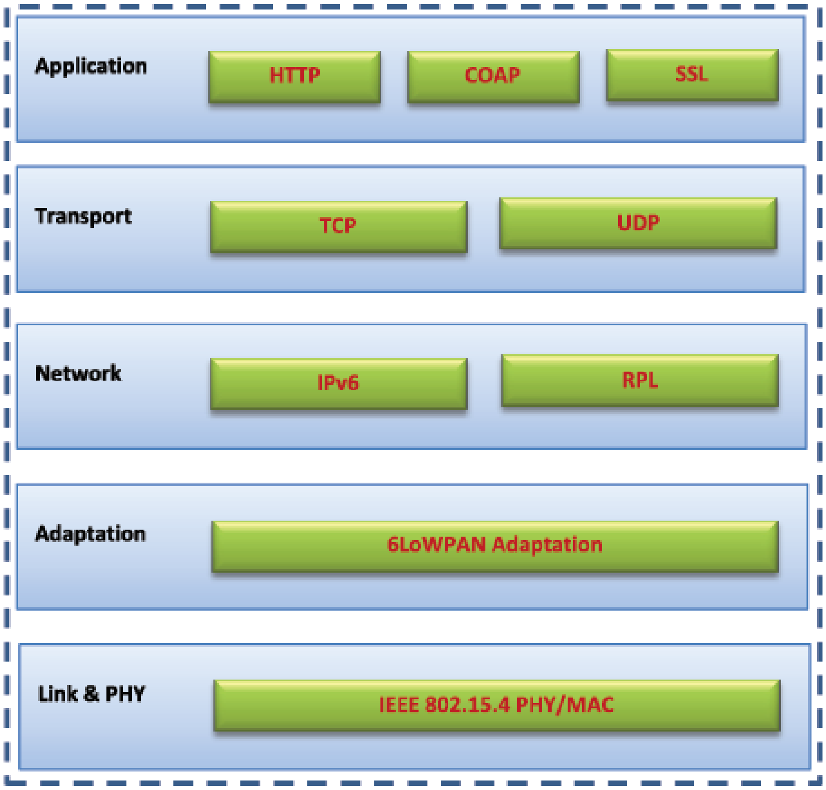


Fig 6. LoWPAN based IoT layers architecture [RIAZ, 2015] [Istep, 2011]

3.2.1.2. Implanted Microsystems for blood Glucose monitoring

The system is composed of a micro biosensor (glucose sensor) which is implanted under the patient's skin and is able to measure the blood glucose level, a transponder chip which is connected to the sensor for obtaining the data and can be charged by an external reader (13.56-MHz). The transponder is not able to send the signal without the reader's power. The reader receives the data sent by the transponder and analyzes them for making the right decision.

Such systems have shortcomings, that the human body rejects the exotic objects usually and needs some time to adapt to them. The tissue around the Biosensor changes continuously, which in turn causes an irregularity of the output signal, therefore, the resulted readings will not be truthful in the beginning [Nour, 2013].

3.2.1.3. Wireless system for monitoring the tear Glucose rate

Since the eye tear contains glucose percentage as in the blood, so the capability of measuring this percentage is possible based on real-time wireless systems. The system is composed of a biosensor attached to a contact polymer lens and provided with a telecommunication antenna for transferring energy and data, reading circuitry and a wireless interface. The gathered data are sent wirelessly to an external reader. The system is effective because it is capable of measuring the glucose rate in eye tears continuously as opposed to conventional measurement methods which are based on sampling. The system is restricted with some limitations that using an energy source very close to the human eye could cause eye harm and could raise its temperature [Nour, 2013].

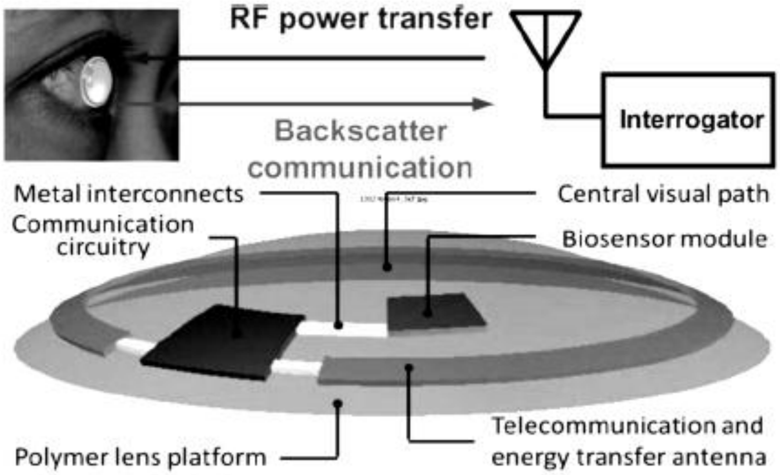


Fig 7. Tear Glucose monitoring system [Nour, 2013]

3.2.1.4. Monitoring the Blood Glucose Level using RFID technology

This system uses RFID technology for monitoring the Blood Glucose level and it is composed of:

- An RFID reader station that operates over short distances. It is composed of a popular and easy to use transceiver, an antenna provided with a wireless power charging coil for broadcasting power and thus charging the transponder wirelessly. The reader station's transceiver controls and steers the antenna, receives and demodulate the transponder's signal and it is twinned with a microcontroller for processing the received signal.

- An implantable Biosensor with a transponder (an RFID tag), which can be woken up and read by means of the RFID reader signal at a low or high frequency. This transponder is a small-size glass cylinder, it includes a convoluted antenna, a capacitor for storing energy and a microchip fixed to the patient skin. The reader signal generates a current in the transponder's loop and activates it to send its data back to the reader.
- A chargeable power source (battery) and a dedicated IC (completely integrated battery charger) are part of the RFID reader station, so that the system is working independently and the battery could be charged either by using the USB connector or an AC/DC adapter. The microcontroller is connected to a PC using Bluetooth technology for sending the gathered data to a PC or a smartphone application [Anis, 2014].

3.2.2. ECG and EEG concept

ECG (electrocardiography) which is monitoring of the electrocardiogram means measuring and recording the electrical activity of the heart by means of the electrocardiography. ECG comprises a number of measurements such as: the basic rhythm of the heart, the analysis and identification of the multifaceted arrhythmias, measuring the myocardial ischemia (atherosclerotic) and the measurement of the simple heart rate in addition to the extended QT intervals which means the total time of electrical depolarization and repolarization of the ventricles. QT intervals represent the time elapsed between the start of the Q wave and the end of the T wave in the heart's electrical cycle [RIAZ, 2015]. ECG is used to record the electrical activity of the fetal cardiac muscle [Muha, 2015] and thus showing the fetal heart rate, congenital heart disease, abnormality of heart rate and the breathing rate. ECG also shows the fetal behavior and fetal development [Pani, 2015]. As Cardiovascular disease is considered as one of the most dangerous diseases which causes high mortality rate for people, ECG monitoring can be a very vital factor to diagnose the cardiovascular disease in its earlier stage and thus saving people lives [Yun, 2015].

EEG (Electroencephalography) is a technique for measuring and recording of electrical activity of the scalp and neurons activities graphically [Sana, 2015], [Haya, 2015].

It is a medicine tool used for improvement of new Brain Machine Interface (BMI) and Brain Computer Interface (BCI) in addition to analyzing the emotion data and the brain activities. EEG signals are produced by numerous synapses [Haya, 2015] and the abnormality of EEG signals can be recognized [Peng, 2015]. Depending on many electrodes fixed on multiple sites of the brain, EEG can record the changeable voltage and thus measuring electrical activity variations of the brain [Sana, 2015].

3.2.3. Wearable systems

Recently, the acquired development in mobile networks and smart devices accompanied with the emergence of smart technologies and wearable healthcare devices started to be used for permanent monitoring and collecting patients' vital signs such as ECG, EEG and blood pressure [Kaush, 2014]. The integration of electronics industry with the textile industry led to the emergence of wearable sensor systems that have been used beginning in the field of sports and daily health- care especially at homes.

Due to the increasing mortality rate caused by heart diseases (more than seven million annually), diabetes and blood pressure, monitoring of these diseases especially the heart's electrical activities drew a special concern [Osma, 2011]. Permanent monitoring of Newborns electrocardiogram led to a reduction of the sudden mortality rate.

3.2.3.1 Wearable devices fixing way

Electronic components and devices such as sensors, electrodes, and antennas are fixed within the human's textile clothing especially into the patient underwear [Joha, 2005], [Osma, 2011], [Yun, 2015]. They are fixed suitably in required areas of the patient's body to reduce the potential harm which could happen by external factors such as: frictions, clashes or patient's movement caused by coughing or breathing [Yun, 2015].

Body sensors measure the physiological parameters such as body temperature, blood pressure and heart pulses rate. All the electronic items are brought together on one electronic board which can be integrated into the patient surrounding very easily [Joha, 2005], [Osma, 2011].

Electrodes are attached to the patient’s body and work as transducers, capture the body vital signs and translate them into electronic current which reaches a readout circuit to be amplified. In this way, vital signs can be obtained and analyzed [Ashr, 2011].

Fig 8. Measuring the breathing rhythm and ECG [Osma, 2011]

3.2.3.2. Wearable devices workflow stages

Wearable monitors (devices) send the data securely to mobile devices like smartphones, tablets, or PCs using wireless technologies such as: ZigBee, Bluetooth or SMS. Received readings appear in the form of a diagram (curve of waves), which enables the physician to analyze and diagnose the patient’s status. The readings represent small voltage values which are sent in small intervals (few milliseconds) [Kaush, 2014].

Signals gathered by ECG have low frequency and they are prone to interference and noisiness caused by different resources such as neighboring power lines. So, the ECG signal becomes interfered with the noises partially. Due to interference possibility, amplifier circuits, filters and ADC (Analog to Digital Converters) are needed [Yun, 2015].

EEG circuit constitutes a part of the wearable system equipment so that an electronic board senses the signals issued from the ECG circuit. The preamplifier amplifies the received signal, and then the ADC receives the analog ECG signal and switches it to a digital signal. The digital signal then reaches the DSP (Digital Signal Processing) through the SPI (The Serial Peripheral Interface) input, and there the signal is filtered and processed till it reaches a PC provided with a dedicated software for showing the received signals [Osma,2011].

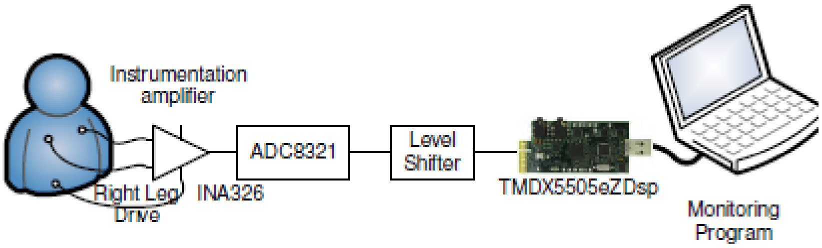


Fig 9. The wearable system workflow stages [Osma, 2011]

The data size transmitted through the ECG and EEG systems is very big and causes an extra overload on the storage space and the transmission system. Decreasing the generated data size can be done depending on various mechanisms like decreasing the sampling rate and bit resolution and also by using compression algorithms which can provide a high compression rate in real time [Gohe, 2011], [Kaush, 2014].

3.2.3.3. Wireless Personal Area Network (WPAN) for monitoring patient's vital parameters

Wearable healthcare devices fixed or worn by patients as ECG, blood pressure, glucometers and pulse oximeters monitors form together, the so-called Wireless Personal Area Network (WPAN). All these devices are capable of transmitting the patient vital signs over Bluetooth to a Bluetooth supported mobile device, which operates on Android platform. Java applications of the Bluetooth-mobile can detect Bluetooth devices in the surrounding, manage the connection and transmit data. At the mobile device side, the data sent by the wearable healthcare devices are received, compressed, coded and then transmitted to the particular physician in the form of SMS [Kaush, 2014].

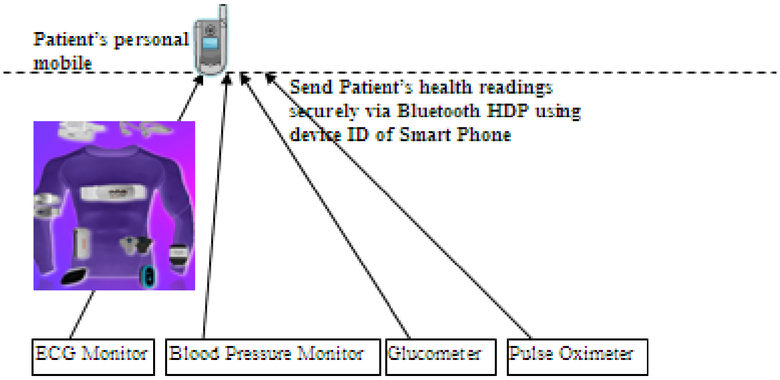


Fig 10. The system architecture [Kaush, 2014]

3.3. Home healthcare concept

Currently, the trend is to raise the level of the home healthcare through localization of health services in homes which leads to shrinking the fiscal spending in hospitals and customizing them for patients with chronic diseases. Home healthcare requires using ICT solutions and real-time systems in homes for monitoring the patient's vital signs and taking the prescription on schedule. Proliferation of IoT provides the possibility of connecting devices, sensors and physical objects to the Internet [Geng, 2014]. Using of IoT technologies and IoT applications in the home healthcare field and particularly on monitoring applications for disabled and elderly people made their lives more comfortable [Lin, 2014], [Amir, 2013].

Home healthcare applications include home environment, home automation and patient's healthcare. These applications have been performed based on WSNs and the Internet. Once an abnormal event occurs to a disabled or an elderly patient, the system issues a warning in real-time [Lin, 2014]. Many applications allow monitoring the home environment and tracking the elderly or disabled people activities and then sending the data over the Internet. The data are analyzed for understanding the patients' behavior and the results are sent back to the family members to help the patients properly [Faus, 2013].

In some cases, disabled and elderly people can monitor, collect and send data about their health situation to caregivers over the Internet by using their smart devices. The data are analyzed and results are sent as a feedback to the patients to make an action [Debo, 2010], [Lin, 2014].

3.4. Wheelchair applications

The increasing rate of elderly people in developed countries has led to increasing interest in designing high standard wheelchairs which provide well-being and independence [Ying, 2011]. Mobility is considered as a very vital factor for people with disabilities in order to participate in public life [Jich, 2013].

In the USA, more than 200000 disabled people depend on wheelchairs in their daily life [Coop, 2008], [Jich, 2013]. Using wheelchairs could face problems, thus multiple applications have been performed in this field for monitoring and avoiding the possible accidents.

Many wheelchair systems are available currently, among them, a healthcare system included on the wheelchair for measuring the vital patient parameters but it lacks the mobility and it is restricted in places where Wi-Fi hotspots are available. Another wheelchair system includes a smartphone with a number of embedded sensors for gathering data about the wheelchair user’s activities [Lin, 2014].

3.4.1. Wheelchair system for measuring the vital parameters and sensing the surrounding

A WBAN (Wireless Body Area Network) composed of a group of sensors is able to sense the surrounding and measure the vital parameters of the disabled and elderly people. It also can detect the abnormal cases as in the case of patient’s falling down depending on a resistive pressure sensor embedded in the wheelchair cushion. A number of distributed sensor nodes such as humidity, temperature, smoke, light and air conditions sensor nodes sense the surrounding and send the captured data to a central node using ZigBee protocol.

A smartphone is used for controlling the home environment; it works as a gateway between the WBAN and the Internet. The smartphone communicates with the central sensor node using Bluetooth. It also can process and store the gathered data and contains embedded sensors (GPS and compass) to determine the user's location. The smartphone uploads the data over the Internet to the data center to be analyzed and shared. Alerts can be sent as a feedback to family members or caregivers in the case of detecting abnormal data [Lin, 2014].

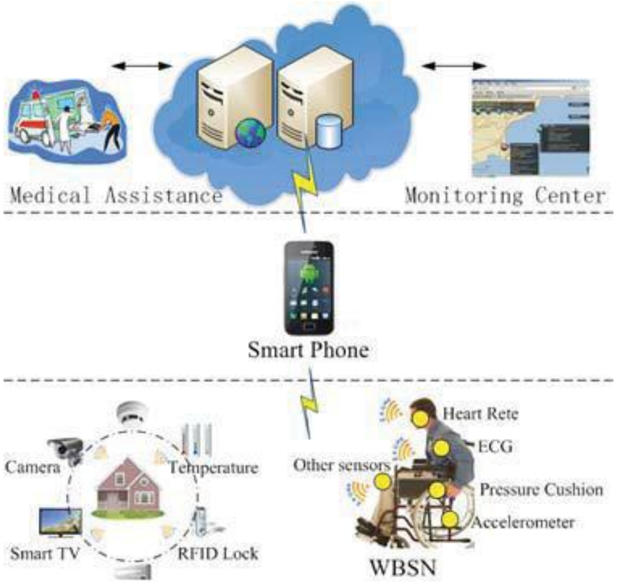


Fig 11. The architecture of home m-Health system [Lin, 2014]

3.4.2. Wheelchair system for determining sitting position and motion direction

This healthcare application is used for monitoring wheelchair users, it is composed of 4 supersonic sensors fixed in many points of the wheelchair for determining the user sitting position in addition to 3D accelerometer for determining the motion direction and detecting the anomaly position of the wheelchair as to be inverted and the user has fallen down.

The supersonic Sensors capture the data about user's sitting position and send it to a sensor node (sink) through ZigBee. The sensor node analyses the collected data and sends the results to a remote server by using an Internet connection such as Wi-Fi. The gathered data are stored in the server's database and displayed to healthcare providers. A smartphone which is provided with GPS and compass sensors and suitable software is fixed on the wheelchair armrest to enable presenting the analyzed data to healthcare providers. The compass sensor and the accelerometer help detecting the wheelchair movement and the right/left turning.

The data captured from the GPS and the compass is also sent to the server through the Internet. The system is enabled to issuing alerts in the case the patient's position is not normal [Ying, 2011].

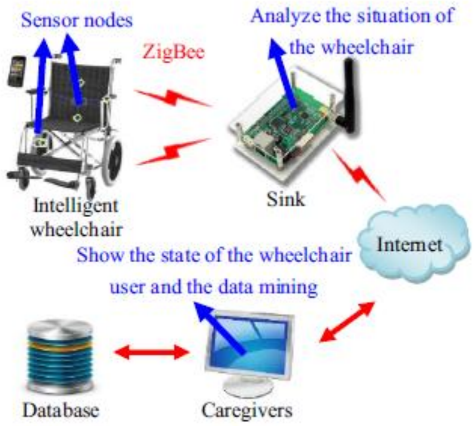


Fig 12. The system structure for monitoring the wheelchair users [Ying, 2011]

Monitoring the wheelchair movement tracks and directions is a very important issue. Therefore, a smartphone (Android phone) equipped with an accelerometer and a gyroscope is fixed to the wheelchair to capture movement directions data in real-time.

The SmartPhone works as a temporary storage of the collected information which is uploaded to the cloud at intervals. The founded connection is a low cost and does not cause a network overload. The data related to wheelchair movement directions are analyzed and the results are stored in the cloud which has an enormous storage capacity. Users can obtain the results from the cloud in many ways [Jich, 2013].

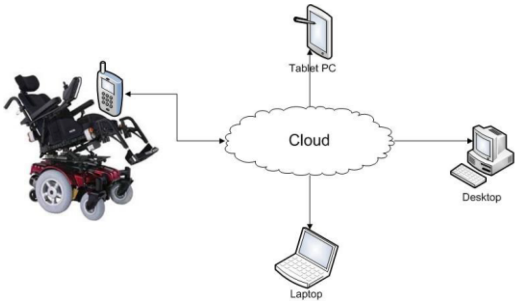


Fig 13. The mobile cloud computing framework [Jich, 2013]

3.5. IOT healthcare Applications for people with disabilities

Millions of people suffer from some kind of disability which makes them ineffective in both of society and economy and thus a burden for their families. IOT can help handicapped people and support them to be effective in daily life. Handicapped people face a lot of problems in their daily lives such as rising upstairs, using the transportation and communication devices and the difficulty of mobility for blind and paralyzed people.

3.5.1. IOT applications for visually impaired people

3.5.1.1. Using body micro and Nano-sensors

Human eyes could be affected by some diseases like retinitis pigmentosa and age-related macular degeneration which may cause blindness because of the loss of rod and cone cells which receive the external light [Mari, 2012].

Using a special camera fixed on the patient glass and an artificial implant composed of body micro-sensors placed on the affected outer retina can solve the problem. The camera works as a receiver of the images and then transmits them to the implanted chip. The images data, which are received by the camera and are transmitted as electrical impulses activate the goal neurons, which in turn convert the impulses into nerve signals transmitted to the brain through the optical nerve.

In the future, scientists could design an artificial retina by using Nanotechnology which will transmit images to the brain in the same way. The artificial retina could also send images to the caregivers to facilitate the guidance of visually impaired people and help them to avoid obstacles [Mari, 2012].

3.5.1.2. RFID- based assistive devices

The navigation system helps visually impaired and blind people to walk safely on the sidewalk or through a new road, keeps them far from obstacles and protects them from exposure to accidents [Mari, 2012]. The system stands on two kinds of components: RFID tags, which are distributed through the middle of the way in a predefined track and separated by particular distances, and an RFID reader placed on the blind cane [Moha, 2009].

The RFID reader broadcasts radio waves and the RFID tag within its range receives the signal, uploads its stored data (the tag ID) on the signal and sends it back to the reader. The reader, in turn, sends the tag data to the monitoring station by using a communication technology such as ZigBee or Bluetooth and the monitoring station sends the data to the remote server [Shii, 2007].

The system is able to identify the blind person position and the distance between him and the road edge [Edoa, 2007]. The system is able to send alerts in the form of voice messages or vibration when the blind person is close to the sidewalks border [Moha, 2009]. Directing the blind person to his destination is also done through voice messages reaching the monitoring station (his smart phone) when the separation distance between him and the obstacle is short, allowing him to walk safely **[**Shii, 2007**],** [Mari, 2012], [Zhan, 2010].

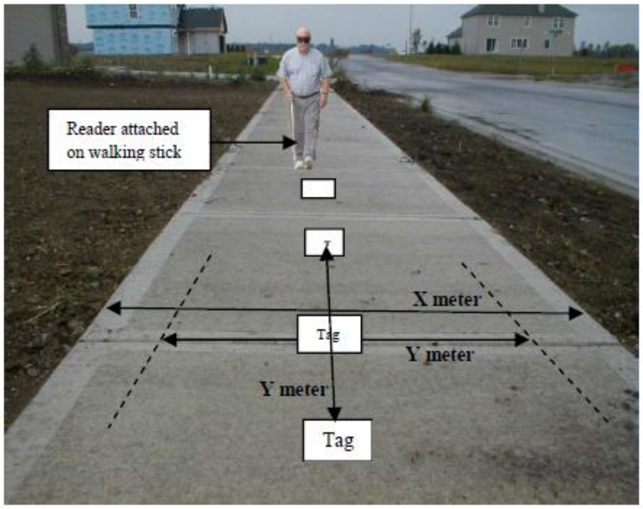


Fig 14. Distance of the frequency detection [Moha, 2009]

For identifying the obstacles and keeping away of them, an ultrasonic sensor is attached to the RFID cane and many sensors are fixed on the blind’s shoe. Both of them extend the range of perceiving the obstacles which in turn increases the safety level [Will, 2009].

A combination of GPS and RFID technologies can also be used to help visually impaired and blind people to wake safely [Mari, 2012].

3.5.2. IOT applications for hearing impaired

Sensors can be distributed everywhere, they are of different types, able to sense and record different events and to interact wirelessly with assistive devices attached to hearing impaired ears. Assistive devices can be external or internal (inside the ear) sensors able to detect sounds and events like door bell, telephone bell, clock alarm sound, and oven alarm sound and send alarm signals to monitoring stations which in turn amplify the signals and resend them to the assistive devices. Hearing impaired persons can receive vibration and visual signals [Hong, 2006].

Glove equipped with a wireless communication technology is used to enable hearing-impaired people to interact with other people who are not used to deal or understand the American Sign Language (ASL). The wireless glove is cheap and equipped with sensors able to sense and record the fingers flexion related to the (ASL) and to send the sensed data to a monitoring station such as a smartphone using Bluetooth technology.

At the monitoring station, the received data are compared to ASL signs data stored in the station database; if they correspond with the stored data, they are converted into text and voice [Davi, 2008], [Mari, 2012].

Fig 15. The hand Talk glove [Davi, 2008]

3.5.3. IOT applications for physically impaired people

3.5.3.1. Using Body sensors, actuators, and neuro-chips

Sensors implanted close to the motor nerves have the ability to sense the desire of the physically impaired people to use a particular muscle. Sensors and actuators are used to stimulate the paralyzed extremities and actuators can trigger and activate paralyzed muscles to move again [Wei, 2007], [Mari, 2012]. An external power resource connected wirelessly to the Sensors, neuro-chips or actuators is used for generating radio frequency waves and digital command data to the micro-implants which in turn transmit electrical pulses to stimulate the motor neurons and the paralyzed muscles.

The motor neuron disturbances which occur after a stroke or spinal cord damage could cause disability in extremities or other limbs. Using sensor technology enables the paralyzed body parts to regain the movement by means of the electronic stimulation operation.

Many applications used this technology to perform Functional Electrical Stimulation (FES) such as neuroprostheses applications which enable restoring the movement ability [Rich, 2000], [Mari, 2012]. Neurochips applications which are tiny battery-powered implantable brain-computer interfaces (BCIs) have been developed by American researchers. Neurochips have been implanted in animals firstly and nowadays it was launched to be used on humans [Mari, 2012], [Reza, 2011].

The body's willing movements like extremities movements are done and controlled by the motor cortex cells in the brain which sends commands to the spinal cord to control the contraction of extremities muscles.

Neurochips have the ability to save the activity of motor cortex cells which works as a stimulus used over and over again to send signals to both of spinal cord and muscles as an artificial neural connection used by the human brain as an alternative to other impaired neural connections inside the body. BCIs (Brain Computer Interfaces) are classified as the future technology for controlling the human brain [Mari, 2012].

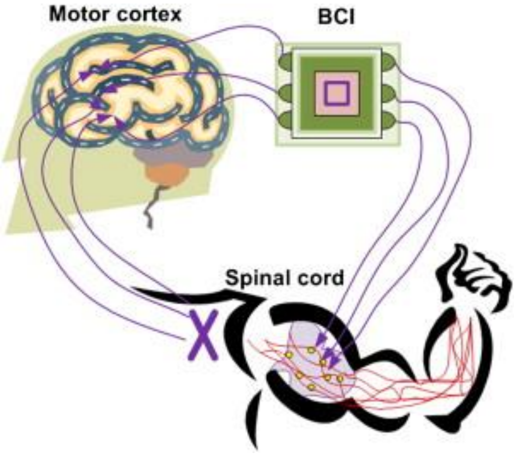


Fig 16. BCI for spinal cord injury [Mari, 2012]

3.5.3.2. Body sensors and RFID technology

Physically impaired people may suffer from bed wetting problem; integrating sensors with RFID technology can help them to treat the problem. Wetness sensors with Radio Frequency Integrated Circuit (RFIC) antenna are combined together on an FPCB (Flexible Printed Circuit Board) and implanted into the patient bed. They can sense the wetness and send the data to a close RFID reader unit provided with Bluetooth transmitter for transmitting the gathered data to the monitoring station in real-time where caregivers can take the suitable decision [Mari, 2012], [Chen, 2008].

3.6. IoT Platforms for monitoring patient's vicinity

3.6.1. Monere: Tele-care Platform

Monere is a small size electronic card similar to the credit card and used for management of the patient vicinity remotely. It works as a mediator, easy to use, easy to integrate, robust and extensible platform between the patient and various kinds of sensors. It uses several protocols to provide the connection between medical devices with superior capabilities, environmental sensors, patient monitors and systems. They gather data of the patient vital signs and the environmental parameters. Monere uses Linux operating system, which simplifies upgrading its components and provides new horizons in networking in addition to lessening the medical mistakes [Jara, 2013].

Monere platform is adapted and integrated with the communication technologies such as USB and RS232 to 6LoWPAN which works as a mediator for transferring the gathered data to the server. It also integrates RFID technology with medical devices which enables identifying both patients and physicians, thus more accurate monitoring and better definition of responsibilities.

Monere provides a high privacy which is a very sensitive issue regarding the patient's information. The platform can also be used with mobile devices, permits mobile's monitoring of the patient surrounding and uses lithium batteries in order to prolong the duration of service [Anto, 2011], [Jara, 2013].

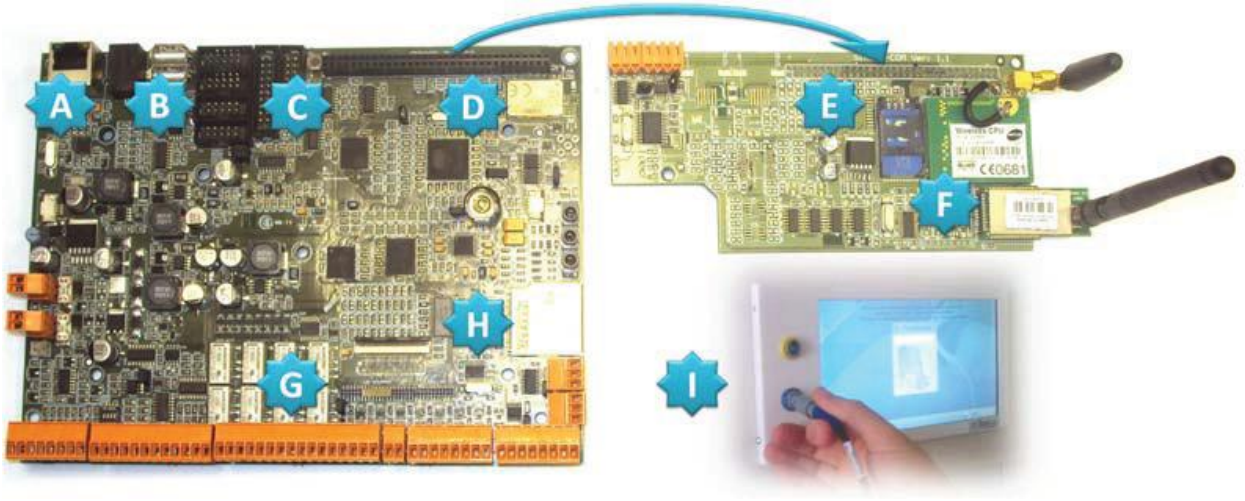


Fig 17. Monere platform with the communication board and the integrated touch screen [Jara, 2013]

3.6.2. Movital: Mobile Vital Signs Monitoring platform

An intelligent system for insulin treatment and ECG monitoring uses the infrared technology to build a connection with the Movital platform and with an interactive user screen [Jara, 2013], [Jara, 2011].

Movital based Home Respiratory Therapy

Besides using the Movital platform for controlling of diabetes, it has also been used with IoT technologies to treat respiratory diseases at homes. A number of sensors are used to measure continuous and discrete values related to breathing diseases. In cases where the patient does not get enough oxygen ratios, sensors are used to monitor oxygen saturation continuously and other sensors are used to measure the CO2 ratio and blood pressure. All previous sensors can be connected to a Movital platform placed in the patient vicinity. MONERE platform also can be used to monitor breathing diseases at homes [Jara, 2013].

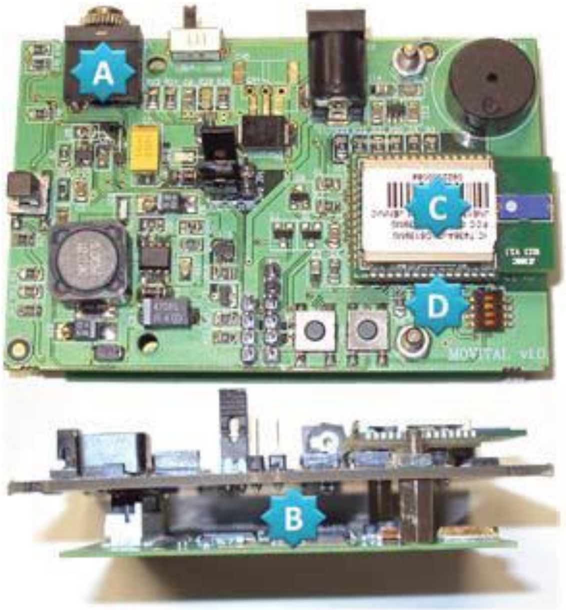


Fig 18. (Top) Monere platform. (Bottom) Movital platform [Jara, 2013]

Both platforms offer the possibility of direct and remote addressing to monitor and assess the patient’s situation and to detect the emergency conditions.

The opportunity is still opened for more researches in the IoT healthcare applications for developing new services and achieving higher interoperability with the already existing structures, in addition to enhancing the security side and building new applications and solutions. This process requires promoting and improving additional programs and policies by governments and institutions to support the growing use of the IoT technologies in the healthcare field [RIAZ, 2015].

3.7. Conclusion

This chapter highlighted the recent technologies based healthcare applications and their role in raising the life level, reducing the financial burden and providing comfort and safety to patients. A number of blood Glucose sensing applications have been presented that show the blood glucose level and allow a rapid interfere to adjust its percentage in time. These applications use biosensors which are implanted into the patient's skin or attached to a contact polymer lens to sense the glucose level in the eye tear.

Electrocardiogram (ECG) and Electroencephalography (EEG) concepts have also been reviewed.

Wearable systems mean the integration of the electronics industry with the textile industry and they include a way for placing sensors and other devices within the patient' clothes which in turn play a vital role in measuring the body parameters. The working way of these systems and the mechanism of data transition to the monitoring station have been presented.

The importance of home healthcare for monitoring and tracking the elderly and handicapped person's activities have been presented and particularly the importance of wheelchair applications for those people for enhancing their life type, providing a permanent measurement of their body's vital signs, detecting cases of patient's falling down, their sitting position and the wheelchair movement orientation.

A number of healthcare applications for people with disabilities, including visually impaired, hearing impaired and physically impaired people applications have been detailed.

Using implanted sensors and a camera can provide vision to blind people. Systems that use RFID technology can help blind people to walk safely on the sidewalk and keep them far from obstacles or exposure to accidents. External or internal assistive devices and sensors attached to hearing impaired people's ears help them to detect sounds. Wireless glove equipped with sensors is able to sense and record the fingers flexion related to (ASL), which can be interpreted later to a text or voice. Sensors and actuators are used to help physically impaired people by stimulating the paralyzed extremities and triggering paralyzed muscles to move again.

MONERE and MOVITAL are tele-care platforms, which manage the patient vicinity. They play a role of a mediator, which provides the connection between medical devices, environmental sensors, patient monitors and the monitoring system. Both of them can gather the patient’s vital signs and the environment parameters.

Chapter 4. Hospital Acquired Infections and their prevention

The Hospital Acquired Infection (HAI), also known as the nosocomial infection is an infection acquired by the patient during his stay in the health care facilities due to a completely different reason than the original entry reason. The HAI problem is classified as one of the main problems in health care facilities nowadays, owing to the increasing mortality, prolonging the duration of stay in hospitals, and then increasing financial burden.

In this chapter, we will highlight the infection problem through using official statistics from many countries that expresses the infection causes in details, especially the contaminated hands which are a critical issue; we will clarify the role of Health Care Workers (HCWs) and the hospital management in preventing the infection, and we will identify which is the best existing system devoted to the avoidance of hospital acquired infections.

Also, an analysis will be presented here of both the traditional and the latest ICT solutions committed to HAI deterrence. The chapter reveals that traditional methods are not enough to solve the problem and that ICT solutions could contribute to solve the HAI problem to a larger extent.

4.1. The Hospital Acquired Infection rates and statistics

Today, the incidence of infections in health-care facilities, as hospitals, is classified as one of the main causes of people death, and the mortality caused by the HAI is considered as one of the first ten causes of death [Rhodes, 2015].

In the developed countries, such as USA, and EU states, a percentage of 5–15% of the patients becomes infected during their stay in the hospital for treatment, while infection ratio rises (9–37%) during their stay in the Intensive Care Units (ICUs).The infection rate in hospitals is ranging between 4.6% to 9.3% [WHO, 2009], [Kim, 2000]. In U.S.A, the mortality rate resulting from the infections is higher than that caused by Breast and prostate cancer.

In 2002, the HAIs ratio was almost 4.5%and the (HAIs) rate was around 5% of hospitalized patients or 1.7 million infected patients each year in U.S.A. This situation in turn increases the level of financial spending to US$4 billion, raising the mortality rate up to 100,000 deaths per year [Rhodes, 2015], [Suya, 2009], [Ryan, 2012], [Klev, 2002].

In addition, the annual financial loss caused by the HAIs in U.S.A was around 6.5 billion dollars in 2004 [Rhodes, 2015], [Ston, 2005].

In Europe, the number of HAIs cases is almost 5 million per year; the percentage of cases that may lead to death was nearly 2.7% (135,000 persons each year) [Rhodes, 2015], [Suya, 2009], and the financial expenditure was evaluated to range between 13–24 billion Euros, in addition to prolonging the duration of stay in hospitals (around 25 million additional days) [Rhodes, 2015].

A study that was conducted in India, between July 2004 and March 2007 showed that the HAIs average was 4.4%, in addition to 9.06 infections per each 1000 ICU-days [A. Meh, 2007]. In Argentina and Turkey, the ICU acquired infection rate exceeded 50 cases per 1000 patient-days [Cevi, 2005], [Rose, 2003] and the mortality rate was 35.0%, 25.0%, and 5.0% for the following infections: VAP (Ventilator Associated Pneumonia*)*, CR-UTI (Criminals' Urinary Tract Infection) and CR-BSI (Catheter-related bloodstream infection) in the same order. In an "800-bed, tertiary care, university hospital in Malaysia", the HAI rate was 13.9%, and the used antibiotics cost was around US$ 521 000 annually, [Hugh, 2005], [Anil, 1997]. The nosocomial sepsis rate in India was 1.5% to 37%, and in USA was 0.9% to 7% [Anil, 1997].

4.2. The HAIs causes

The HAI causes are mainly:

- The decreased patients' immunity.
- The increasing variation of clinical procedures.
- The lack of proper staff training guidelines and policies regarding HAI prevention.
- The deficiency of proper equipment and maintenance.

- The contaminated surface, a piece of equipment, clothes and supplies can host other types of pathogens [Sara, 2013].
- Vectors of site-dependent HAI such as catheter insertion, post-operative care and intubation/ventilation.
- The poor infrastructure and the crowding in the hospital [Chan, 2014];
- Environmental sensors, such as ventilation and oxygen level sensors, are affecting pathogen propagation.
- The absence of a proper air flow inside the hospital rooms[1].
- The respiratory associated infections are the second most common HAI in critically ill patients and affect 27% of all such cases. Of these, 86% are associated with mechanical ventilation and are called Ventilator Associated Pneumonia (VAP). Most cases of VAP occur in invasively intubated patients due to bacteria finding its way into the lower lung segments using inserted end tracheal or tracheotomy tubes used for ventilation. With over 250 thousand cases yearly in the USA alone, VAP has an attributed mortality rate between 0% and 50% depending on target patient groups [Stev, 2006]. VAP patients incur lengthened stays between 4 and 13 days in ICU units and significant per-patient added cost of treatment [Stev, 2006].
- Contaminated hands are an essential reason for infection, that the drug resistant pathogens and bacteria, such as Methicillin-Resistant Staphylococcus Aureus (MRSA), and microorganisms such as resident flora which lives on the skin, and transient flora [D.Pitt, 2001], represent around 5% of all HAI cases. But they constitute 50% of the mortality rate, which is around 19.000 patient deaths per year in U.S.A [A. Meh, 2007] [Abel, 2008]. Infection spread may happen when one of the HCWs touches a patient or a

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- [1] The proper airflow must be ensured within the operation room, and tests must be performed by using the smoke which confirms that the airflow is done correctly. The preferred direction of airflow must be taken into account, that air flow direction from one place to another is based on the pressure difference principle between one room and the other (for example: from the operating room to the elimination room), thus, the polluted place should be with a low pressure [Chan, 2014].

contaminated surface and then proceeds to treat another one, without being complied with the hand-hygiene protocols.

Self-infection can occur by touching sensitive body parts, such as the face by hands if they are home to virulent transitive flora.

The previous idea highlights the importance of focusing on hand hygiene for fighting the infection. Hands, as the most touching human organ with patients and contaminated surfaces, are considered the crucial factor to spread or prevent the infection transmission. Sometimes, hand washing is enough to take the contaminants away and thus stopping a significant part of the infection, but hand disinfection is the safest solution to stop the transmission of pathogens in the case of high contamination such as drug-resistant germs. Fighting microbes and thus reducing the infection require permanent compliance with hand hygiene rules [D.Pitt, 2001].

4.3. The “Five moments” for hand Hygiene

Due to the importance of hand hygiene, W.H.O encouraged the HCWs to comply with the hand hygiene protocol and identified five essential times where the hand hygiene protocol should be performed at the point where the HCW is close to the patient. Following these rules, can keep both of HCWs and patients safe [Rhodes, 2015]. From the early 2010 to 2012, HCWs’ adherence with the Five Moments for Hand Hygiene ranged between 20% - 86% maximum [A. Hig, 2013].

The importance of hand hygiene in reducing the HAI is based on the following statistics. When compliance with hand hygiene rules increases from 60% to 90%, the infection resulted from MRSA drops with 24%. Also, raising the compliance from 35% to 60% diminished the HAI level from 16.4% to 10.5% [Abel, 2008]. Combating the HAI, leads to saving lives, preserving of resources, and saving time and labor.

The Five Moments for Hand Hygiene are:

- Before touching the patient, to protect him.
- Before executing the required procedure.
- After performing the procedure, or body fluids exposure to protect the HCW.

- After touching the patient and its surroundings.
- After touching the patient surroundings, even in the case of non- touching the patient [Rhodes, 2015].

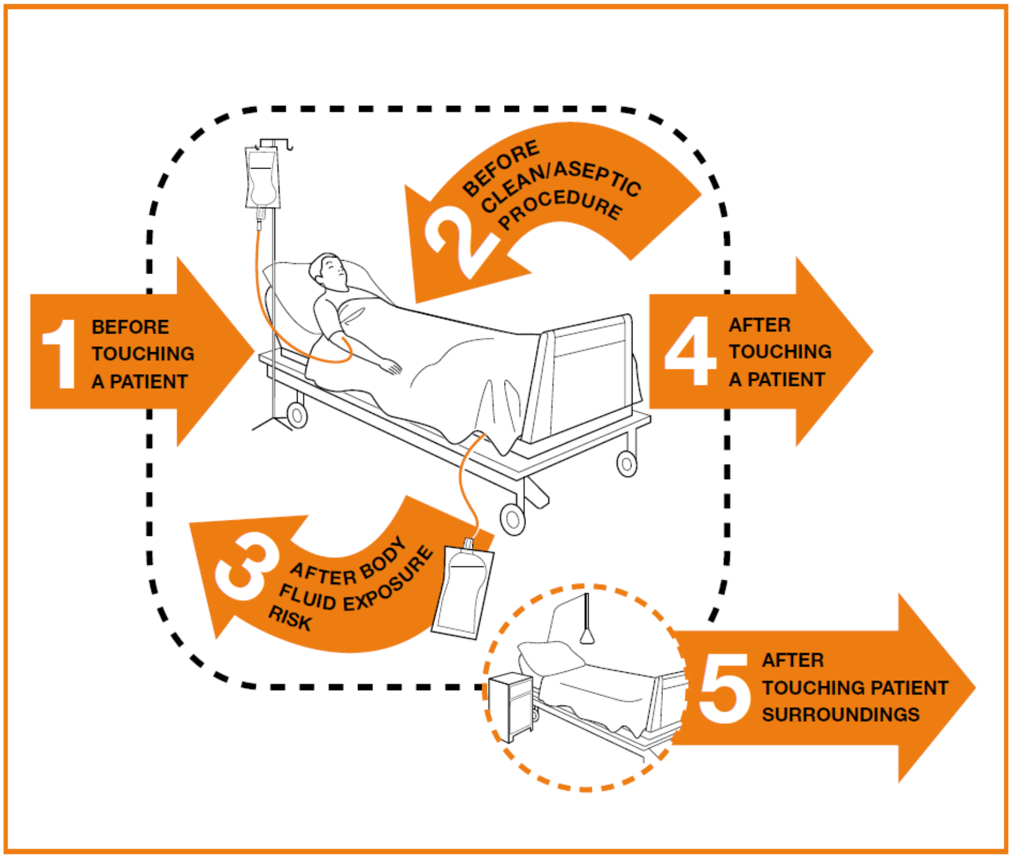

Fig 19. The five moments for hand hygiene at the patient location [WHO, 2009]

4.4. Role of Hospital Management, physicians and nurses for infection prevention

The Hospital Management

The hospital management is responsible for:

- Providing the necessary resources needed for infection prevention.
- Monitoring and evaluating the nosocomial infection situation.

- Monitoring the execution of the required procedures, which are standardized by the ICC (Infection Control Committee) for preventing the infection.
- The hospital management is also responsible to develop a comprehensive plan for training and educating the HCWs [WHO, 2002].

The physicians are responsible for:

- Practicing the necessary measures regarding the patient care**.**
- Fighting the HAI and the outbreak prevention (sterilization, isolation, and antibiotics polices).
- Sending reports to the hospital management.
- Providing education and guidance for patients, visitors and hospital staff members [WHO, 2002].

The role of the nurse

Nurses are responsible for:

- Surveying and detecting the HAI; this can be achieved by the participation in educational programs, improving the training methods and monitoring the procedures execution to prevent the infection transmission, such as: hand hygiene and patient isolation.
- Making sure that the nursing staff complies with these procedures and that the necessary equipment and drugs are available in their places.
- When signs of an infectious disease appear on some patients, nursing staff should directly apply the HAI combating measures and its transmission methods in case of physician’s absence, in addition to notifying the hospital management [WHO, 2002].

4.5. The traditional ways for combating the HAI

The manual monitoring raises the compliance rate with the HAI combating protocols and the direct observation methods can collect information about the compliance with the hand hygiene procedures. But, they cannot include all the available opportunities for the hand hygiene within the hospital environment and they require a high cost and waste of time.

Traditional methods to reduce the HAI include:

- Monitoring the infection rate, if it is high, then the compliance with hand hygiene is minimal, so promoting the compliance is needed, [Tosh, 2013].
- Monitoring the consumption ratio of disinfectants used for hand hygiene such as soap and alcohol (e.g., 3 L/day) [biov, 2014]. Thus, the higher is the consumption, the higher is the compliance and the more is the HAI reduction.
- Identifying and practicing the correct cleaning and disinfection methods of hospital environment and patient equipment, that an appropriate sterilization and complying with the hand hygiene rules must be performed especially during the treatment of patients.
- Maintenance procedures must be followed to limit the spread of endemic or epidemic exogenous environmental infections. They include maintaining of medical equipment and the healthcare buildings especially old ones which should be performed periodically [Chan, 2014], [Debb, 2008].
- Hospitals must continually provide hand hygiene products, high-filtration masks, tissues, waste containers, and medical equipment in all wards and facilitate the access of HCWs and visitors to these stuffs.
- Signage with guidelines must be spread in corridors, patient rooms and waiting places to show the necessary instructions that should be followed [Chan, 2014].
- Provision of necessary resources is very important to support the infection prevention programs.
- Infection control programs, which include the right use of nutrition and antimicrobial.
- Managing of sterilization, checking the materials and product safety level must be applied permanently [jstor, 1997], [Debb, 2008].
- The permanent updating and improvement of medical guidelines within hospitals represent a real need to reach an optimal healthcare and then performing the HAI prevention.
- The permanent monitoring of the hospital activities can be achieved in real-time by providing a feedback to the management team.
- Surveillance and evaluating of the nosocomial infection status and promoting the procedures used to reduce the nosocomial infection should be performed periodically for finding proper solutions in due course [WHO, 2002].

- Isolation principle is vital for infection prevention.[2]
- The medical equipment must be checked and sanitized before and after using, and then stored in suitable places. Decontamination conditions of medical equipment include temperature, duration, pressure, humidity and any equipment deficiency must be reported to managers**.**
- Medical equipment are preferred not to be reusable among patients, so, disposable medical products are preferable to the reusable ones [Chan, 2014], [Debb, 2008].

The personal measures which should be followed to reduce the nosocomial infection include:

- Permanent cleaning of hair, nails, and beard, with keeping the hair and nails short,
- Towels have to be used only once.
- Using masks and gloves for protecting HCWs and patients by covering their mouths and noses when it is necessary, so that patients must wear a mask when they are out of their rooms.
- HCWs who are entering the operating room must have their heads and face hair completely covered by caps or hoods and without any accessories or jewelers which must be removed before entering.
- Sanitizing hands is necessary after shifting or taking the gloves off [Rhodes, 2015], [Ryan, 2012].
- Shoes must be easy to be cleaned [WHO, 2002], [Chan, 2014], [jstor, 1997] [Park, 2008].
- Prescribing and using the antibiotics must be monitored precisely [WHO, 2002], and the policy of antibiotics prescribing must take into consideration a group of factors such as site of infection, the hospital ward, identifying the most prevalent pathogens, the most sensitive antibiotics, and the patient situation.

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[2] It means to leave a space (3 feet at least) between patients beds, with a blind between each twin. Patients who suffer from the same disease can be put together in the same room. Patients must be taught to follow the respiratory protocols to reduce spreading of pathogens [JULI, 1987], [Chan, 2014]. Isolation types vary depending on the disease type and the patient's situation. The isolation principle and the hand hygiene rules implementation must be taken into consideration in some hospital wards more than others that the possibility of the nosocomial infection in some wards such as operating rooms, intensive care units, and newborns is higher than other wards. So the hand hygiene procedures must be implemented before, and after any touch case [WHO, 2002].

A proper filtration system is vital factor for infection prevention; so that the airflow must be in the correct direction. The contaminated hospital air should be disposed of outside, or purified inside through the filtration system. Air pressure and airflow tests must be done inside the facility rooms by using the smoke to be sure that the airflow is done properly [Chan, 2014]. The airflow direction from one place to another is based on the pressure difference principle (from the operating room to the elimination room with the low pressure) [Chan, 2014].

Appropriate procedures must be followed for storing the sanitizing products and appropriate preparations for operating room environment must be performed before and after the operation which include:

- Leaning and sterilization of all surfaces [Chan, 2014] and surgical equipment.
- Using the appropriate attire such as double gloves for the high risk procedures, and the staff attire should be water proof, easy to be washed and decontaminated, and must be changed after exposure to body fluids or sweating.
- It is preferred to include the less number of staff and without conversation if possible.
- The patient body must be cleaned by using appropriate antimicrobial product before any procedure, and it must be covered except the part identified for the procedure [Beur, 2014], [JULI, 1987].
- Provisioning adequate human resources and the concentration on monitoring the hand hygiene protocols are considered vital factors for infection prevention.

Protocol watch supports making clinical decisions within hospitals very quickly; that it includes guidelines to combat the surviving sepsis, it simplifies sepsis treating, and has its own mechanism to check the monitoring data according to the protocol criteria, it identifies the required interventions and urges the clinicians to perform them and helps the HCWs to detect variations in patient's situation rapidly. The resulted data are invested to improve the performance quality [prot, 2015].

Until now, most hospitals are still using traditional methods for combating the HAI which cannot be considered as effective solutions. These methods may reduce the HAI rate with a certain percentage; but they remain under the required level. That is because the indicators and statistics of the HAI cases and death rates coming from hospitals even in the more advanced countries.

Science looks for human well-being, and for developing their life style. Hence, the interest and concentration started for combating the HAI and fighting its causes. The world needs to unite the working methods and efforts to find and use the best techniques for monitoring the hospital activities and especially the compliance with the hygiene guidelines which would reduce the HAI rates. The most accurate indicators about HCWs compliance with the hand hygiene are obtained by using the modern technologies which give a high compliance ratio.

4.6. ICT technologies used for HAI prevention

Many ICT solutions were used to monitor and prevent the HAI; they are ranging from simple solutions up to integrated systems. These solutions are based on IoT technologies such as sensors, ZigBee, and RFID. The features of these technologies have been discussed in chapter 2.

In the beginnings, devices similar to sinks were used; they had two gaps dedicated to the personnel hands, and a motion sensor. When the hands are put into the gaps, the sensor can detect them and provide a mix of water and an antiseptic.

In a more sophisticated solution, ZigBee ID badges powered with a battery are dressed by the HCWs, and broadcasts electromagnetic waves. ZigBee monitors are located at the patient area. A soap or alcohol dispenser provided with a chemical sensor senses when one of the HCWs uses the dispenser and informs the server’s application, which in turn registers the hand hygiene compliance event in the server’s database. The communication in this case could face an interference with other devices in the hospital.

The RFID technology is used to monitor the staff compliance with the hand hygiene. The hospital staff identification badges are provided with passive RFID tags which have unique ID numbers. Soap or alcohol distributers are located at the entrance of each patient room, provided with RFID readers, and able to recognize each RFID tag singly.

When one of the staff members comply with the hand hygiene procedure, the soap dispenser’s RFID reader informs the server which have software to collect and store the data in the server database [Ryan, 2012].

RFID technology was also used for monitoring and promoting the compliance with the hand hygiene procedures. The used system is composed of four parts: a hand hygiene place which comprises antiseptic dispenser, HF RFID reader with an antenna and a wireless transceiver. The door place includes HF RFID reader, antenna and a wireless transceiver. The promoting place comprises a wireless transceiver and a display screen. The last part is the server with a wireless transceiver. The RFID reader at the washing place reads the hospital worker’s ID number stored in a passive RFID tag embedded in his badge, and the wireless transceiver sends the ID number to the server.

This means that the worker has sanitized his hands, and this event will be stored in the server’s Database as clean. When the worker enters into the patient room, the other RFID reader at the door can read the worker’s ID and the wireless transceiver can send it to the server.

At the server application, the time interval between the two readings is checked and compared with a stored value (e.g., 5 minutes).

If the second reading at the door is done during the specified time, then the event will be registered as clean and no prompting decision. And if not, then the event will be registered as unclean, and a visual prompting will be displayed. Also the prompting decision will be taken if the worker has visited the patient(1) before visiting the patient(2), and did not comply with the hand hygiene procedure within the specified time before the second visiting [Suya, 2009].

Different types of sensors connected in Wireless Sensor Networks (WSNs) are used for infection prevention in a hospital. An environment sensor is used for gathering temperature and humidity information. A control sensor is used to control the building’s HVAC (Heating, Ventilation and Air Conditioning) system, locking and unlocking the doors. A movement sensor is used for tracking substances and personnel movement, such as the HCWs, medical equipment and cleaning materials. Contact sensors are used for gathering touch information between two persons or between human and equipment, material or a surface. And temperature & humidity sensors record the temperature and humidity information, for patients, and equipment.

These sensors can be attached to patient’s bodies, walls, doors, or attached to HCWs badges or bracelets with their IDs. The gathered information is transmitted through gateways to the main server for processing, and storing. The gathered values from the hospital are compared with preferred values stored in the system’s database. If the values are not corresponding, the system issues its commands to the wireless network, such as an alarm or a control command to make an action [Park, 2008].

Using a WSN for monitoring the hospital activities provides automation, shareable and high availability information, and transmission of information to the central system is done in real-time. This leads to saving time and effort, therefore focusing on raising the efficiency of the services provided within the hospital and thus increasing the hospital prominence and fame [Park, 2008].

A MHS (Mobile Healthcare Service) system uses RFID technology and mobile devices for identifying and positioning persons and items for controlling the SARS (Severe Acute Respiratory Syndrome) infection in a hospital. The system uses RFID readers fixed in sensitive places, and RFID tags attached to all patients, and persons who are entering the hospital to collect their vital signs.

The RFID readers read the stored information from the tags and send them to the server. Based on the mentioned technologies, the MHS system is able to continually monitor the infected parts, gather and analyze the information, and indicate the infected personnel to be isolated [Chen, 2004].

4.7. Conclusions

This chapter presented the hospital acquired infections as a big problem nowadays, with figures and statistics to indicate the risk of infection and the importance of its combating. Various infections causes in the hospital environment, especially the contaminated hands and the role of medical staff in fighting them have been reviewed. This chapter also includes an exploration of the traditional methods of combating the HAI, the importance of hand hygiene and the importance of following the five moments specified by the World Health Organization (WHO) as a vital factor for infection prevention. The existing ICT technologies used to fight the hospital acquired infections have been discussed. This chapter showed that traditional methods contribute to solve the HAI problem by giving certain compliance rates, but they stay unpractical and don’t provide successful solutions to stop the HAI spread, whereas ICT solutions are a better choice for solving the HAI problem.

Chapter 5. Monitoring systems for HAI prevention

This chapter presents in details some integrated systems and solutions specified to monitor medical staff members' compliance with the hand hygiene rules, and a comparison of their main features.

5.1. The Intelligent^{M} system

5.1.1. Intelligent^{M} system's components

The system design bases on the idea of modifying the HCWs actions and urging them to comply with hand hygiene procedures in the right way and in the right time which means "how" and "when" to wash their hands [inte, 2014]. The system consists of an intelligent bracelet (smart band) as displayed in Fig. 20, which comes with an HF RFID reader (13.56 MHz), a group of motion sensors, an alerting tool (vibrator) and a rechargeable battery worn on the HCW wrist, able to track all the activities associated to hand hygiene and to broadcast alerts [Clai, 2013]. A group of RFID passive tags are distributed in many points. The RFID passive tags can be fixed on the medical equipment, the automatic soap and alcohol distributors, the HCWs ID badges, the surgical leakages, serum injection or blood withdrawn points [Clai, 2013].

Fig 20. The Intelligent^{M} wristband [Clai, 2013]

5.1.2 Intelligent^{M} system's operation

The Intelligent^{M} system performs several tasks, including collecting data about the HCWs compliance level with the hand hygiene, and modifying their behavior. The HCWs behavior modification is implemented by providing them with a real time feedback. This feedback comprises information for reminding them to be complied with hand hygiene protocol when they forget, or whether they carry out the required procedures for the hand hygiene properly, at the washing stations, and at the patient bed side. The collected data is uploaded and stored into the server, the feedback is sent as weekly reports to the HCWs e-mails, or it is shown through a web console [Clai, 2013], [Ki Ma, 2015].

The wristband RFID reader which stores the HCW ID number interacts with the RFID tags and Bluetooth tags distributed in the hospital. It is designed to question the RFID tags and to pinpoint their places by using its own software, which inspects its database that stores the previous events in details.

When the RFID reader recognizes the soap distributor tag, it knows that the HCW is going to sanitize his/her hands, so it issues a warning pulse to boost him/her to comply with the hand hygiene protocol. And it issues three warning pulses if the HCW did not respect the duration specified for the washing event, or when he/she did not comply with the required hands motions for washing as displayed in Fig. 21, or when a long time passed since the latest compliance event with the hand hygiene [Ki Ma, 2015]. The same thing happens at the patient bed vicinity [Clai, 2013].

The real-time collected data includes compliance and noncompliance events with hand hygiene (year, month, day, hour, and place), and allows the system managers to track the hand hygiene procedures in places and situations where the infection is more expected [Inte, 2013]. The smart band is able to track when, how, and where the HCWs must comply with hand hygiene rules [Ki Ma, 2015], [Inte, 2013].

The Intelligent^{M} has a feature that is consistent with the WHO recommendations regarding the duration of the hand hygiene procedure identified between 20 to 30 seconds, the hand's required motions during the sterilization process, and the five moments for hand hygiene needed to be taken into consideration at the patient location.

Hand Hygiene Technique with Soap and Water

Duration of the entire procedure: 40-60 seconds

0 Wet hands with water;

1 Apply enough soap to cover all hand surfaces;

2 Rub hands palm to palm;

3 Right palm over left dorsum with interlaced fingers and vice versa;

4 Palm to palm with fingers interlaced;

5 Backs of fingers to opposing palms with fingers interlocked;

6 Rotational rubbing of left thumb clasped in right palm and vice versa;

7 Rotational rubbing, backwards and forwards with clasped fingers of right hand in left palm and vice versa;

8 Rinse hands with water;

9 Dry hands thoroughly with a single use towel;

10 Use towel to turn off faucet;

11 Your hands are now safe.

Fig 21. The required motions for Hand Hygiene [WHO, 2009]

5.2 BioVigil System (Integrated Hand Hygiene Compliant System)

This system [biov, 2015] is used for monitoring HCWs compliance with hand hygiene, and their visits to patient rooms to reduce the (HAI) rate, by ensuring that the HCWs perform the hand hygiene protocols.

5. 2.1.BioVigil system's components

BV-140 healthcare badge and alcohol sensor:

It is a small device, operated by battery for 24 hours continued, provided with a wireless interface to connect to the base station, by using low power ZigBee protocol [Mike, 2014]. It is worn on the chest of the HCWs as displayed in Fig. 22, and includes chemical-detecting sensors to sense sterilization materials on HCWs hands [biov, 2015].

Fig 22. The BV-140 healthcare badge and the alcohol sensor [Mike, 2014]

The BV-120 room sensor

It is a secondary sensor placed at the entrance of any monitored room, with a range of about 10 meters [Mike, 2014]; it connects to the BV-140 badge by an infrared sensor. System engineers may install two sensors, indoor and outdoor of each room, to survey HCWs movement precisely [biov, 2015].

The BV-150 base station

It is a small device, easy to use, connected via USB cable to a PC placed in each hospital ward, with an adequate range for the whole floor or ward. The base station can get its own power from the PC itself, without any other power resources, and each PC has the necessary installed software to run the BioVigil system [biov, 2015]. These components have the ability to record the information routinely and run without human interference.

5.2.2 BioVigil system's operation

The room sensor can determine the entry and exit of people into the room, depending on motion detectors, or by being able to detect an energy released from the human body; it can discover a thermal change in its work range.

When the HCW enters the patient room, the temperature rises in his/her vicinity, from the room temperature to his/her body temperature, and then returns again to the room temperature [Mike, 2014]. So, the BioVigil badge, which contains an infrared receiver knows that the HCW entered the patient room, based on the infrared sensor [biov, 2015].

The HCW should sanitize his/her hands two times; the first one is done before entering the room, by using antiseptic material found at the entrance of the room, or in the corridor and the second one is done before going out of the patient room.

The BioVigil badge contains a chemical sensor, which functions with an advanced metal oxide technology, and is activated when the HCW enters the room. When the HCW puts his hand over the badge, the chemical sensor can sense a chemical material on the HCW hand. So, if the HCW hand is sanitized, the badge will hint a green light [Mike, 2014]. And if the HCW forgets to put his hand on the badge, or he puts it without to be sanitized, then the badge would hint a yellow light, with an acoustic warning, as an alert to the HCW to perform the procedure. If the HCW continues ignoring the required procedure for some reason, the badge will hint a red light.

As the procedure is visible, then anyone such as the patient himself or any colleague can remind the HCW to perform it. The same procedure is repeated when the HCW leaves the room [biov, 2015].

The base station uses its PC to interface with the other BioVigil components, by means of the wireless Ethernet standard IEEE 802.11, known as Wi-Fi. It communicates wirelessly with the BV-140 badge to receive the hand hygiene compliance information automatically when the badge is placed for charging each 24 hours.

Compliance information comprises the number of times the HCWs complied with hand hygiene, and the number of times they moved in or out the patient room. The base station sends commands and updates to the badge and uses the Internet, or the hospital local network to send the information to the cloud securely [biov, 2015].

The BioVigil system provides + 95% of compliance rate and monitors the HCWs visits to the patient rooms. The chemical sensor senses the chemical material on the HCW hands, but that does not mean for sure that the entire surfaces of hands and fingers have been covered by the sterilization material. WHO identified the duration of the hand hygiene procedure between 20-30 seconds, also identified the hand's required motions and the five moments for hand hygiene at the patient location. But the system omitted that. The BioVigil system lacks the idea of "how and where" to perform the hand hygiene procedure.

5.3 MedSense (General Sensing system)

MedSense is a wireless electronic system that uses sensor technology which leads to improving the hand hygiene compliance and achieving the patient safety and thus reducing the (HAI) by providing an accurate extensive monitoring of the HCWs activities, analyzing the resulted information and boosting the compliance with the hand hygiene rules in all hospital wards [gene, 2015].

5.3.1. MedSense system's components

The badge

It is worn on the HCWs clothes; it is able to collect data on all the activities related to HCWs compliance with the hand hygiene and store it automatically.

MEDSENSE HQ

It is a modern tool designed by using best web technologies. It gives HCWs the ability to have access to their hand hygiene compliance information at any time during their shift, by using a visual dashboard, or their laptops, tablets, and smart phones provided with an Internet browser.

This will create a competition between the HCWs and increase the compliance ratio. The MedSense provides hand hygiene compliance up to 90% [gene, 2015].

The base

It is a wireless base station that works as a mediate between the badge and the MedSense HQ. The compliance data is uploaded to the MedSense HQ through the base. It is used as a charger for the badge.

The beacon

It is a device that helps the badge to distinguish the available opportunities of hand hygiene. It is provided with a battery and installed in the care area side.

The dispenser monitor

It is a device that monitors the sanitizer bottles utilization as displayed in Fig. 23, and sends information to the badge, so the badge can store the hand hygiene events [gene, 2015].

Fig 23. The MedSense system components [gene, 2015]

5.3.2. MedSense system's operation

Communication between the bacon and the badge makes the system able to recognize the required moments for the hand hygiene when the HCW go into or go out of the patient room.

The system has the ability to remind the medical staff members to sanitize their hands in real time when they forget, that the badge issues alerting tones.

The hand hygiene compliance data are gathered automatically, that the dispenser monitor detects all the hand hygiene events and notifies the badge, so that the compliance data are recorded by the badge and uploaded to the MedSense HQ automatically when the badge is within the base range (10 meters) or when it is placed for charging at the end of the HCW shift [gene, 2015].

MedSense is able to recognize when and where the HCW must comply with hand hygiene procedures (the five moments dedicated by WHO for hand hygiene), but it does not take into account the hand's required motions, neither the duration of the hand hygiene procedure.

5.4. Comparison between Intelligent M, BioVigil and MedSense systems

The table below contains a comparison of the three systems taking into account their main features.

Table 6. Comparison between the three systems

Feature	**Intelligent M**	**BioVigil**	**MedSense**
Monitoring the duration of the hand hygiene 20-30s	Yes	No	No
Monitoring the hand's required motions during hand hygiene	Yes	No	No
Monitoring the five moments for the hand hygiene	Yes	No	Yes
Compliance rate with the	99%	+95%	Up to

hand hygiene			90%
Used technologies	RFID & Bluetooth	ZigBee, Wi-Fi, infrared & sensor technology	sensor technology
Alerting mode	Vibration pulses	Visible and acoustic alerting	Alerting tones
Gathered data	Compliance & non-compliance events in time and place	Number of compliance times with hand hygiene+ number of entry and leaving times	Hand hygiene events+ the available opportunities of hand hygiene

5.5. RL6

The RL6 is an advanced software application that provides the ingredients needed to manage the patient's safety and provides a safer medical care quality; it has its own mechanisms for surveying and detecting the H AI. The system provides:

- The ability for monitoring and tracking the system users' activities, that it allows tracking the hand hygiene activities easily using the personal smart devices.
- Monitoring the abnormal and dangerous situations.
- Rapid intervention for stopping the outbreak and the HAI occurrence and shrinking the potential risk.
- Monitoring, tracking and reducing the medical mistakes, and determining the associated responsibilities.
- Collecting data about patients, HCWs and visitors and analyzing sharing and reporting collected information to the administration team as real-time alerts shown on their smart phones and tablets; this information includes the most likely places of the HAI

and risk, their severity and impact, determining suitable ways for minimizing the risk thus preventing the emergency events before they occur.

- Identifying the root causes of malfunctions and determining the HAI cases.
- Identifying who read or changed the medical files.
- Access to all the HAI data within the hospital quickly including the patients data using the text search possibilities offered by the application.
- A list of priorities for possible HAI causes; the system interface allows interaction with users and enables them to get answers related to the HAI, which in turn minimizes the time and labor of research and investigation.
- Financial management of the hospital including expenditure control.
- Flexibility, reliability, automation and suitability to the healthcare facility regardless its needs and size.
- High-efficiency management of all matters related to the patient
- The ability of improving and maintaining the system along the time by experts [Rlso, 2015].

5.6. HAI-OPS project

HAI-OPS (Hospital Acquired Infections - Outbreak Prevention System) is a European project that has started in January 2016, University POLITEHNICA of Bucharest, through the Department of Computer Science and Engineering, being one of the partners. The aim of the project is to develop a real-time monitoring system, which will contribute to the reduction of the HAI rate by combating their causes and their transmission tracks.

5.6.1. Project objectives

The main objectives of the system are the following:

- The possibility of deploying a network of sensors and communication devices, in addition to employing modern technologies in any hospital, reliably and at low cost. Effective integration with the hospital workflows, monitoring the healthcare worker’s compliance with the predefined rules, in addition to specifying and monitoring the other medical workflows without harming the existing workflows or any negative impacts on the HCWs work. A successful incorporation with the hospital information system is done using the medical standards.

- Setting out the network of sensors and other required devices to evaluate its performance is considered as a part of the project development policy, which can avoid the possible errors and thus reach the best solution.

5.6.2. Systems' components

The HAI-OPS will include the following components:

- A Network of sensor nodes.
- A Smart wristbands (or badges) with accelerometers and gyroscopes sensors, and with integrated sensor-rich cells provided for both patients and HCWs. These will be used for position monitoring and recognizing patterns-based gestures and the hand's motions, which show whether the hand washing is correct or not, or if the HCWs use gloves or not.
- A group of tags distributed in the required sites, or worn by the HCWs and patients or included into their smart wristbands or badges.
- Electronic boards such as Arduino boards, and communication transceivers such as ZigBee or BLE (Bluetooth Low Energy) transceivers for communication between the sensor nodes from one side and the smart wristbands or badges from the other side.
- Programmable video cameras for recognition of hand's motions, person's movements, or accounting the number of persons who are entering a hospital room, in addition to capabilities for improving the clinical infrastructure such as the wireless communication and the electric power.

Different types of alerts will be used depending on each event or site; the alerts could be light, acoustic visible or a vibration form and they may be displayed on screens in the future. The HAI-OPS is scalable and uses RFID/BLE capabilities at the control points in addition to using NFC technology to introduce new solutions.

These technologies can be used at equipment, doors, sinks, beds, disinfectant dispensers, and monitoring clinical workflows such as equipment transporting, cleaning and disinfection, in addition to the clinical processes related to the patient such as surgery operations, catheter insertion, and ventilation. Ultra low power Wi-Fi transceivers can be used also for setting the connection with the central server.

5.6.3. The Superiority points of the HAI-OPS project

The HAI-OPS will provide the positives of existing solutions and overcome their shortcomings.

The HAI-OPS will use an effective way for tracking all the clinical workflows efficiently. It will receive and combine information gathered from many types of sensors and nodes in addition to data regarding patient's vicinity and patients' situations and HIS data obtained from other hospital sites. HAI-OPS will support the advanced vertical and horizontal workflows used for preventing the HAI, making the clinical workflows suitable and adapted according to each site within the hospital.

The HAI-OPS will have the ability to track and monitor all the HAI paths at multiple levels (room, ward, department, and the whole hospital), the basic line of defense for HAI prevention within the hospital in addition to a more effective and flexible alerting system.

5.7. Conclusions

This chapter discussed some integrated systems used to monitor the HCWs compliance with the hand hygiene procedure, their positives and negatives, the components and the functioning method for each system, their compliance scheme with the WHO recommendations. Unfortunately, the compliance with the five moments is still below the desired level. The traditional methods may give certain compliance rates, but they remain under the desired level, and require a high cost and waste of time. The traditional methods provide 50% compliance ratio at best, while the high compliance ratio with hand hygiene (90% - 99%) and the low infection rates are provided by the integrated systems.

All the HAI prevention solutions done right now are inadequate to stop the problem and they suffer from critical shortcomings**:**

- None of these solutions addresses all the possible ways of HAI transmission, and each of them is interested in treating one of the HAI reasons or transmission pathways which are not enough. So, there is no complete solution for combating the HAI in the meantime,
- All the analyzed systems are not integrated with the local hospital systems, such as the Hospital Information System, therefore, there could be problems in implementing the procedures and guidelines related to patients, especially in critical situations, as in the case of infants, elderly, and post-operative patients,
- Available solutions lack the ability to identify all the sources and methods of HAI transmission, especially the non-traditional ones, or those that could overcome the used prevention ways.

CHAPTER 6. A Hospital Room system for Hospital Acquired Infections prevention

This chapter describes the prototype of a system dedicated to the monitoring of hospital room activities, which could be extended to the level of an entire hospital.

6.1. Functional requirements

The aim of this system is to prevent the HAI by fighting with one of its most important causes, which is the contaminated hands, and thus reducing the HAI spread.

The system is intended to monitor the medical staff members' activities inside a hospital room, by identifying their locations within the room in real-time, and recognizing whether they are following the correct hand hygiene rules in the right moments. At the same time, the system will ensure monitoring the patients' entry into the toilet, and their compliance with the hand hygiene rules after going out of the toilet. The system also intended to help the medical staff members to follow the hand hygiene protocols, and to issue alerts in case of breaching the predefined hand hygiene rules.

The main use case of this system is based on a logical sequence of events. It starts at the room entrance during the entry of a medical staff member, where the system is able to recognize his/her identity and the same scenario is repeated when the medical staff member leaves the room. After entering the room, the physicians (doctors/nurses) should use the washstand to sanitize their hands before doing any other action, then they proceed towards a patient to care for him/her, and after that they should go again to the cleaning to sanitize their hands before going to the next patient. The physicians handle the next patient and then they should go to the washstand to disinfect their hands before leaving the room.

Regarding the patients, when any of the patients enters the toilet, the system is able to recognize his/her identity at the toilet entrance, and after the patient comes out of the toilet he/she should proceed to the hands cleaning area to sanitize his/her hands before going back to bed.

Room layout

The considered room (Figure 24) has **two beds** for patients separated by a suitable distance (at least 1 meter); a blind can separate between the two beds which are placed perpendicularly on the inner wall of the room versus to the entrance. A **Hand washing sink** is seated to the left wall, and so close to the entrance, that doctors and nurses should wash their hands directly when they enter the patient room before and after treating the patients. And the room also contains a separate toilet for the patients.

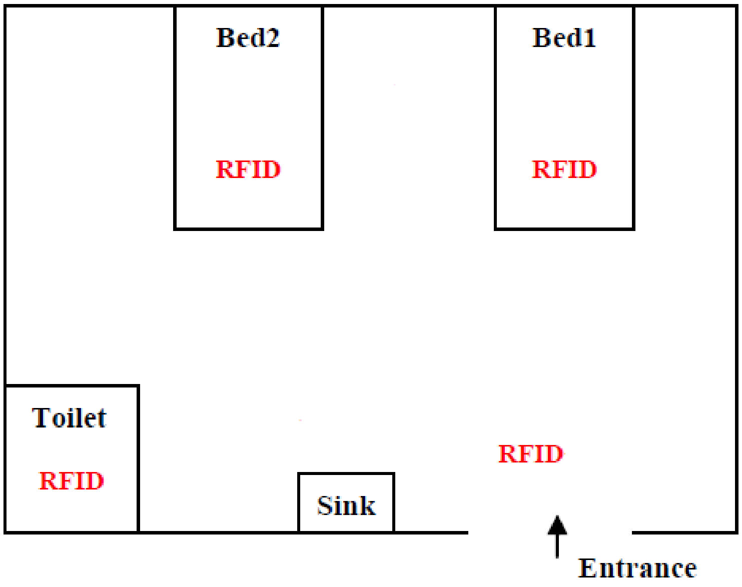


Fig 24. The hospital room layout

6.2. Non-functional requirements

Ease of deployment: This system is very easy to install and it requires only to put each RFID card in the specified place within the hospital room and to provide a SmartBand for each physician/patient in the hospital. The base station will be put in another room which means that the system will not occupy a space in the room.

Ease of operation: The system is very easy to use, the SmartBand holder needs only to bring his/her SmartBand close to the RFID tag to prove that he/she is in the dedicated place (door, sink, bed1, bed2, and toilet) and the data will be sent automatically to the base station.

The system does not obstruct the normal hospital activity. The system will not disrupt the normal hospital activities, because the tags will be fixed in the specified places and the SmartBand will be hold by the physician on his/her hand wrist, thus the system will not interfere with the hospital activities. The system allows respecting the hand hygiene activity without hindering the usual clinical activities.

Reliability: The system centralizes the monitored data to the base station for further analysis, but is not dependent upon the base station functioning (the monitoring is able to work independently if the base station connection is lost). The SmartBand and the RFID tags can work together regardless of the base station, because the alerts are decided by the SmartBand not by the base station.

Safety: The smartband is a low power electronic device that is powered by a rechargeable battery (5 V), so the current is not harmful. All the smartband components are certified according to European laws. The RFID tags are safe and can not cause any harm or injury. The smartband reminds the physician to sanitize his hands depending on short led blinks without bothering him.

Security: The two transceivers have activated an encryption key known only by them for decoding the exchanged messages. For the stored data, the administrator takes the necessary security procedures for the computer.

6.3. Technological choices

Different technologies were analyzed for each monitored event type, according to the following criteria: operating mode and range, power consumption, security issues, cost, flexibility personalization and data rate.

6.3.1. Identifying persons passing the room entrance

At the entrance, the need is to know the personality of people who are entering and leaving the patient room.

RFID technology is a good choice for monitoring the physicians (doctors or nurses) entry and leaving into and out of the patient room. As mentioned in RFID, it is a technology dedicated to identifying and tracking people and daily objects by means of tags, which can keep valid and readable for a long time and can store a unique identity number for each person. RFID tags have very low power consumption, high security that the tag data is highly encrypted and has a high personalization. The RFID communication does not need a line of sight like many other technologies, and the RFID operating range is very suitable for detecting the physician's ID **(**up to few meters).

A positioned RFID reader at the room entrance is able to read the physician's identification number stored in a passive RFID tag attached to the physician's robe pocket and send this data to the server. At the server side, the received data is analysed to detect the physician's ID number. In case of using RFID readers with passive tags, which are very cheap, the solution can be considered as low cost and safe.

NFC technology can also be used for monitoring the physician's passing into and out of the patient room. As mentioned in chapter 2, NFC is considered as a high flexible technical solution, with a high adaptation; it can operate simply by waving or touching one NFC device near the other. NFC performs a fast communication because it does not need to pair the two NFC enabled devices when founding the communication as with other technologies such as Bluetooth. NFC provides a security higher than RFID that the short distance communication prevents the attackers to catch the signal and also it does not require a line of sight communication in order to function. This technology has a high personalization that it takes into consideration person's privacy, and low power consumption, when NFC is used in mobile phones; it does not affect its battery and does not consume a high power. NFC can operate in three modes so it facilitates finding solutions and offers choices to handle the problems which can be considered as an advantage of using this technology.

As it is mentioned in chapter 2, NFC technology supports the RFID tag simulation mode so, NFC-equipped mobile phone can function as an RFID tag which stores the physician's ID number; in this case, the physician can be considered as an object provided with an integrated RFID tag. The physician can bring his NFC-enabled mobile phone (the RFID tag) close to NFC reader fixed at the entrance which can recognize the physician's personality.

The physician can use his/her NFC-enabled mobile phone as NFC reader to read his/her ID number stored in the NFC (RFID) tag fixed on his rob pocket. The data can be sent to the server wirelessly basing on communication technologies such as Bluetooth or Wi-Fi. But this solution requires reminding the physician at the entrance to bring his NFC-enabled mobile phone very close to the NFC tag which is fixed on his robe. RFID technology is a better choice to be used at the entrance due to its wider range.

Taking into consideration the used hardware, RFID and NFC tags have small sizes (around 0.5 mm^2) so they can be integrated easily anywhere. They also are cheap and have a sufficient memory capacity (from kilobytes up to 1Mb and over) to be used.

6.3.2. At the washing sink

NFC technology is a good choice to be used at the sink due to its characteristics previously mentioned. People can interact with this technology very simply by only using their hands to move, or touch their NFC-equipped devices close to other NFC devices. At the sink, we need to know exactly if the doctor complies with the hand hygiene procedures or not. An alcohol dispenser provided with NFC tag will enable the wrist-band provided with an NFC reader to recognize the NFC tag, read the stored data and send it to the server. This solution proves that the physician is at the sink and uses the alcohol dispenser. Choosing NFC technology at the sink is a guaranteed solution because the NFC operating range is so short (0-4 cm) which is enough to confirm that the hand washing event has been performed.

This event can be monitored also by using an NFC reader fixed on the soap dispenser, or could be fixed on the tab tube or the tab key. This reader is able to recognize the physician ID number stored in an NFC tag placed on the physician's wrist hand and to send the data to the server where the event will be recorded that the physician's hands are clean.

The physician could bring his NFC mobile phone (the NFC phone operates in the simulation mode as an RFID tag) close to an alcohol dispenser provided with an NFC reader, which reads his ID number stored in his mobile phone and then send the event data to the server. Or the NFC-equipped mobile phone can be used as an NFC reader and an NFC tag can be fixed on the dispenser. Once the NFC enabled mobile phone is brought close to the NFC tag (within the operating range), it can read its stored data and send it to the server which is a proof that the physician has complied with hand hygiene.

6.3.3. At the patient vicinity

The need is to know exactly if the physician complies with the hand hygiene rules before previewing the patient, after handling him and at the same time to recognize his position. In this case, it is better to have an alcohol dispenser situated near the patient bed. NFC could also be a suitable technology for monitoring this event due to its suitable features.

A cheap passive NFC tag, which can store the place data, could be fixed on the alcohol dispenser and a wristband or a mobile phone provided with NFC technology (NFC reader), can read the tag content when it is within the operating rang. This emphasizes the physician's compliance with the hand hygiene event and also recognizes the physician's position. This event must be repeated after previewing the first patient and also after previewing the next one.

Recognition of the physician's position can be identified also by using an NFC tag placed on the patient's wrist and the physician's wrist band provided with an NFC reader is able to read the patient's data stored in his tag which means that the physician is in the patient area.

6.3.4. At the toilet entrance

We need to know if the patient complies with the hand hygiene rules after coming out of the toilet. Each one of NFC or RFID technology is a suitable choice for monitoring this event due to the reasons mentioned earlier. But, RFID technology is better to be used in this case that's the RFID range is more suitable for monitoring this event and does not need to touch the tag or the reader placed at the toilet entrance.

Recognition of the patient position is done based on an RFID tag fixed on the patient's robe which can be read by an RFID reader placed at the toilet entrance. The gathered data is sent to the server by using a communication technology such as BLE, ZigBee or Wi-Fi, which is a proof that the patient used the toilet and he should go to the sink to comply with the hand hygiene rules when he comes out of the toilet. At the same way as with the physician's case, using each one of NFC or RFID technology at the sink can show whether the patient complies with the hand hygiene rules or not.

6.4. Hardware components of the designed prototype

The designed prototype has the following hardware components:

- A SmartBand for each physician (doctor/nurse) who visits the patients rooms,
- A SmartBand for each patient in the hospital,
- An RFID card for each monitored place of the patients rooms (we used 5 RFID tags),
- A base station, which receives data from the SmartBands for visualization and further analysis,
- Routers can be put in some places in the hospital to extend the system range.

6.4.1. The SmartBand component

- The **RFID reader** (the ID-20LA reader) (38x40x7mm) from ID Innovations is very easy to use, with an integrated antenna; the reading frequency is 125 kHz and the reading range is 20cm with 2.8-5V power supply.

Fig 25. The RFID reader

- **The RFID adaptor (**1,4x1,2x0,57) with USB port. It is the basic unit for reader which converts from USB to serial – interface that connects the reader to the redboard. It simply ties a reader connectors and attach a mini USB cable. The unit is based on FTDI (Future Technology Devices International) chip and it has a LED readout and a buzzer.

Fig 26. The RFID adaptor

- **The RedBoard** is the equivalent to Arduino UNO V3 board, but is produced in the USA by Sparkfun. It uses the same processor, and any code that runs on Arduino UNO will give exactly the same results on RedBoard. It has the following characteristics:
  • Microcontroller ATmega328
  • Micro USB jack
  • Input voltage - 7-15V
  • 14 Digital I / O (6 outputs PWM (Pulse Width Modulation) 0-5V (3V compatible)

- 6 analog inputs
- jack ISP
- 32k Flash Memory
- 16MHz
- SMD (Surface-mount technology)
- Arduino Compatible Shield R3

Fig 27. The RedBoard

- **XBee ZigBee transmitter** (XBee 2mW Wire Antenna - Series 2 (ZB)) from DiGi; its operating distance is 400ft (120m outdoor), which is suitable for our case, it has an integrated antenna, 128-bit encryption, interoperable with other ZigBee-compliant devices including devices from other vendors, industry leading sleep current of sub 1uA and supports binding and multicasting for Home Automation. It provides cost-effective wireless connectivity to electronic devices, high-speed interface, optimizes integration with embedded microcontrollers and the data rate speed is 250kbps. It requires no configuration or additional development; users can have their network up and running in a matter of minutes.

Fig 28. The XBee ZigBee transmitter

- **Accelerometer + Gyroscope IMU MPU 6050.** It includes a three-axis accelerometer, temperature sensor, three-axis Gyroscope and a Digital Motion Processing Engine™ (DMP ™) for supporting 3D Motion Processing and gesture recognition algorithms. The MPU-60X0 Motion Processing Unit collects the3-Axis gyroscope data 3- Axis accelerometer data, temperature data and acceleration and rotational motion. The MPU's calculated output sent to the system processor can also include heading data from a digital 3-axis third party magnetometer. The supply voltage is 2.3 - 3.4V.

Fig 29. The Accelerometer + Giroscope IMU MPU 6050 from DiGi

- **XBee Shield** from DiGi. It does not come with the chip Xbee and does not come with the connector pins on the Arduino. It is used to connect the transceiver to the RedBoard. It is plugged directly on the Arduino (RedBoard), has 3.3V Regulator and a Reset Button. It has a switch control, by which Arduino pins interface with the XBee.

Fig 30. The XBee Shield from DiGi

6.4.2. The base station components

- **A PC**
- **A coordinator** composed of the following components:
- **XBee receiver** (XBee 63mW RPSMA - Series 2 (ZB)) from DiGi. It is cost-effective and interoperable with other ZigBee devices, including devices from other vendors, easy to use. It does not require configuration or additional development, and users can have their network up and running in a matter of minutes. Data rate speed is 250 kbps, the operating distance is 1600m, 128-bit Encryption, supply voltage 3.3 V, current: 295 mA.

Fig 31. XBee receiver (XBee 63mW RPSMA - Series 2 (ZB)) from DiGi

- **XBee Explorer USB**. It is the interface that makes the connection between the XBee transceiver and the PC through a USB port.

Fig 32. The XBee Explorer USB

6.4.3. The RFID tag

We used RFID CARD EM4200 Clamshell (86x54x1.85mm) from EM4200 CS. It is a read only card which has 125 kHz operating frequency and its programmable memory capacity is 64-bit, with a temperature range of (-25°C ~ +75°C).

Fig 33. CARD EM4200 Clamshell (86x54x1.85mm) from EM4200 CS

6.5. The system's wireless network

In low-power applications, where the devices are powered by a battery and the lifetime is an issue, specific data transmitting protocol are used. ZigBee is a simple routing protocol suited for equipment that requires short-range low-rate wireless data transfer.

A classical wireless sensor network implemented with ZigBee protocol contains three types of nodes:

- Coordinator: singular node that creates the network and receives all the data from the network;
- Routers: intermediate the information transfer or transmit their own data towards the Coordinator;
- End-Points (SmartBands): acquire the data and transmit it towards the Coordinator; they can enter in sleep modes to save energy.

The wireless sensor network of our system is illustrated in Figure 34.

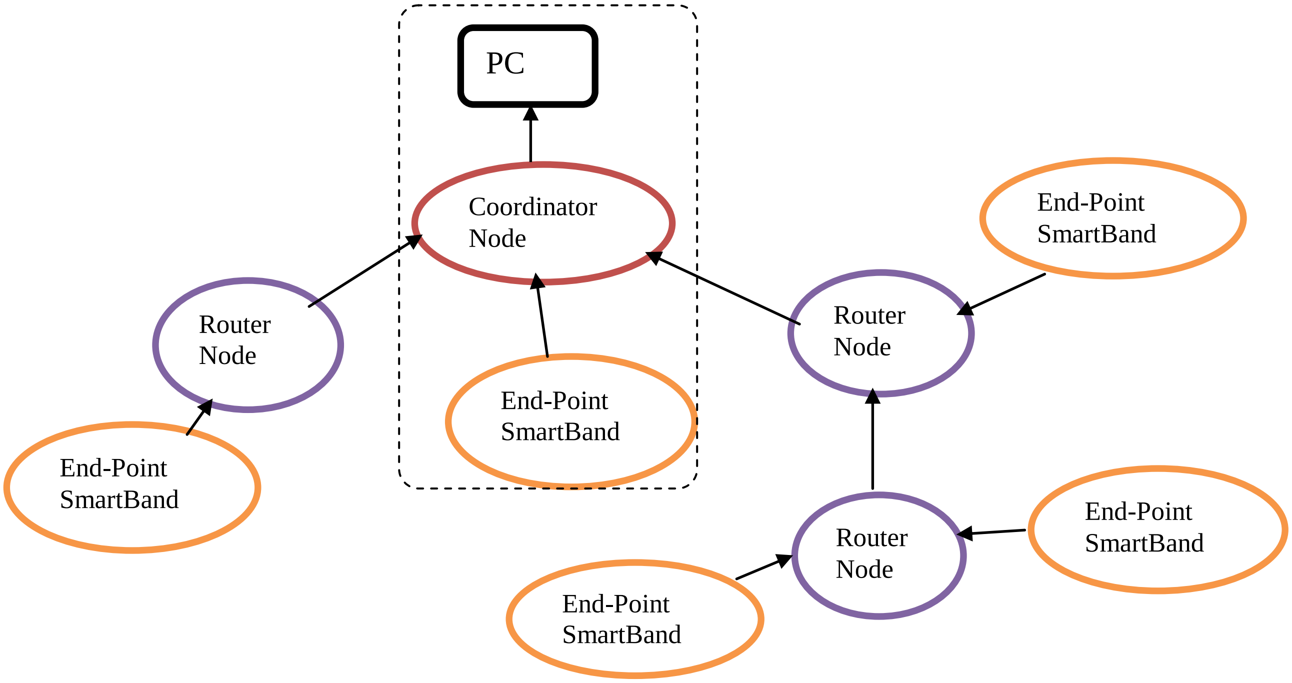


Fig 34. The wireless network of our system

The coordinator (the principal Network node), which is connected to the PC, starts sending signals and when the SmartBand is powered by its own battery, its transceiver receives the coordinator signal and connects to the Network.

The coordinator node acquires the data from the network and transmits it to the PC where it can be displayed and stored. The Coordinator and the PC, which together form the **base station**, can be placed in a server room of the hospital. In each room with patients, a router is placed, which receives data and transfers it towards the coordinator. The people in the hospital (physicians and patients) have SmartBands, which act as end-points and send data about their activities to routers or to the coordinator.

6.6. The implemented prototype

6.6.1. Operation

The implemented prototype contains a Coordinator connected to a PC (base station), a SmartBand and five RFID cards located at the monitored places (entrance door, beds, sink and toilet). This is shown in Figure 34, marked by a dotted rectangle.

Each SmartBand has a unique ID, which represents the ZigBee transceiver ID. The device is assigned to a certain physician in the database implemented on the PC. When it is powered on, the SmartBand connects to the network and transmits a packet, informing that the physician is active. The doctor name and other necessary information about him/her are displayed in the Graphical User Interface (GUI) of the application running on the PC (Figure 35).

The SmartBand is able to recognize the monitored places by reading the RFID tags, and makes the appropriate decision regarding the sanitation. A data packet is transmitted to the PC application for visualization and further analysis.

When the physician is at the sink, the SmartBand acquires the movements of his hands by the accelerometer (two times per second) and sends the parameters of the three axes (x, y, z) to the PC interface in order to be analyzed.

The packet transmitted to the PC is composed of some encapsulation bytes and data bytes. The structure of the data bytes is shown in Table 7. The transceiver address has 8 bytes, the ID of the RFID tag of each place where the SmartBand holder is situated has 12 bytes and the accelerometer data is stored in 6 bytes, 2 for each axis. The last byte is used to represent the decision made by the SmartBand regarding the sanitization: (sanitized, needs sanitization, no sanitized) which are displayed in green, orange and red in the GUI.

Table 7. Data packet format

Transceiver Address								RF-ID												Ax		Ay		Az		D
1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8	9	10	11	12	1	2	1	2	1	2	1

Source: Personal calculation

6.6.2. Alerts

When the physician enters the room, the wrist SmartBand starts to emit alerts. The SmartBand's led flashes orange color for 10 seconds to remind and encourage the physician to sanitize his/her hands at the sink before doing any other action. If the physician ignores this alert, the led color turns into red till the physician arrives at the sink and starts sanitizing the hands. At the sink, the minimum period for sanitizing is 40 seconds. During this time the led blinks orange color. If the physician respects the dedicated duration of hands sanitizing, the led will turn to green. Otherwise, the led turns to red, reminding the physician to restart sanitization of the hands.

After finishing the hand hygiene at the sink, the physician proceeds towards one of the two patients. The physician's position is identified by reading an RFID tag mounted at each of the two beds. The area of the bed in the GUI becomes green.

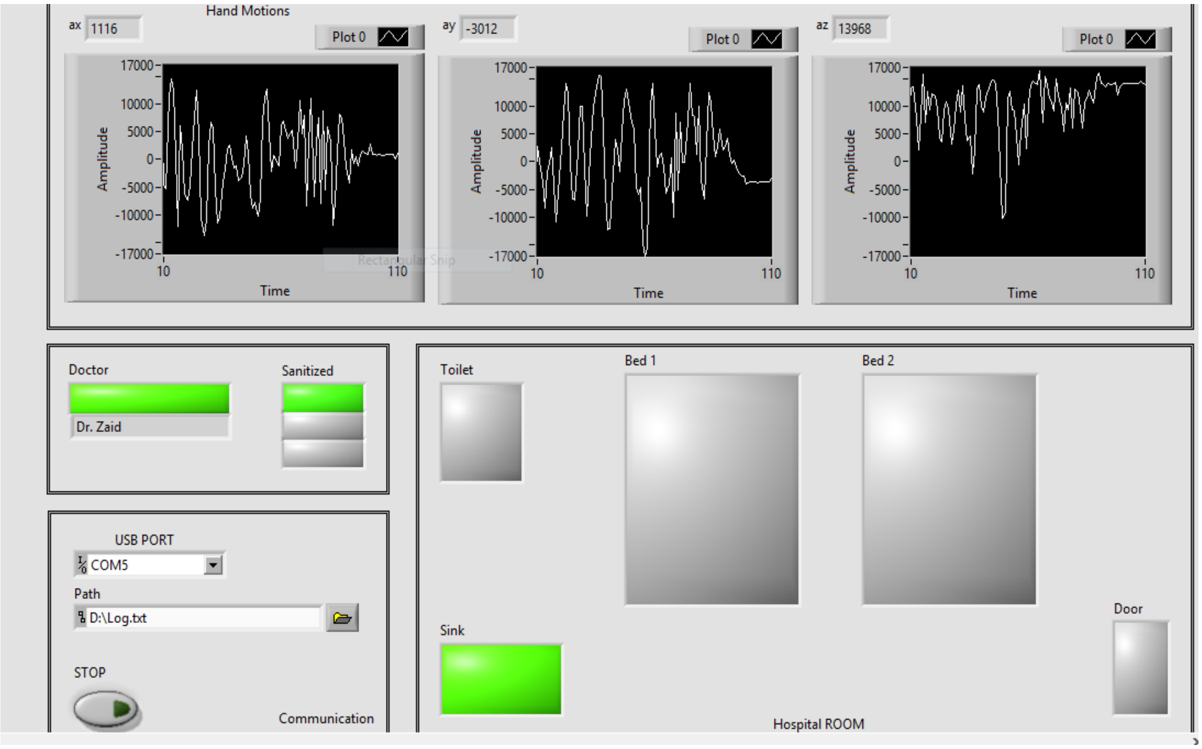
After treating the first patient, if the physician doesn't go to the sink to sanitize the hands, the SmartBand's led starts to blink orange flashes for 10 seconds, reminding him/her to comply with the hand hygiene action. If the physician ignores the alert, the led color converts to red after 10 seconds.

If the physician proceeds to the sink and starts performing the hand hygiene, the led color emits orange flashes for 40 seconds; at the end of the 40 seconds, the SmartBand led color turns to green which means that the physician’s hands became sanitized. Then, the physician proceeds to the next patient with a green color on the SmartBand. The system can identify his/her position in the same way, and after treating the next patient, the physician should go to the sink to comply with the hand hygiene rules as previous and the alerting mechanism works in the same way.

Each patient has his own SmartBand with the same specifications and characteristics as the ones of the physicians. When one of the room’s patients goes to the toilet, the system can detect his position using the RFID tag placed at the toilet door. After coming out of the toilet, the alerting mechanism starts working by emitting orange flashes span for 10 seconds to remind the patient and prompt him to go to the sink and comply with the hand hygiene rules. If the patient ignores the matter, the led color becomes red, telling him to reach the sink and start sanitizing his hands. In the same way as for the physician, at the sink, the led color issues orange flashes for 40 seconds which means that the patient is complying with the hand hygiene rules. At the end of the 40 seconds, the led turns to green to show that the patient hands became sanitized.

6.6.3. The Graphical User Interface

The GUI of the application that runs on the PC displays the actions and the alerts for the physician (Figure 35). It is realized in LabVIEW programming language, which is a graphical language, where blocks with various functions can be connected to perform complex tasks (Figure 36).



ax 1116

ay -3012

az 13968

Doctor Dr. Zaid

USB PORT COM5

Path D:\Log.txt

Fig 35. The Graphical User Interface

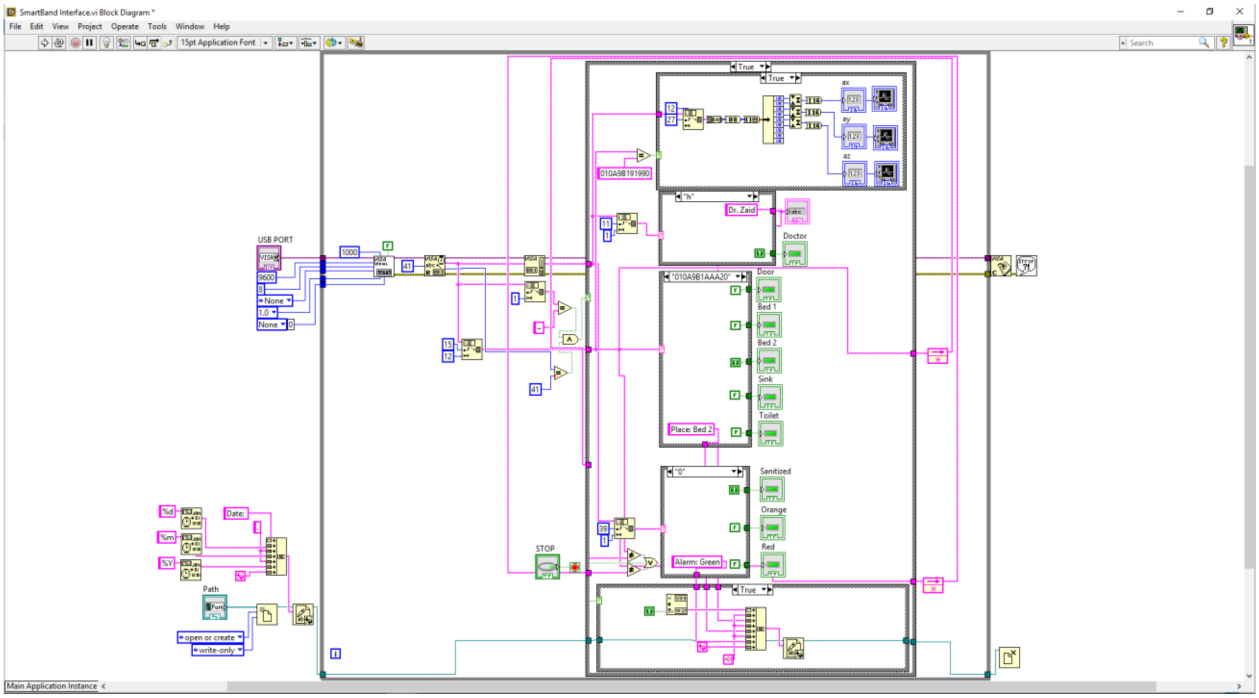


Fig 36. The LabVIEW Background

The Graphical User Interface has four areas:

The communication area is that visualizes the connection with the Coordinator node. The USB port where the Coordinator is connected must be selected. This area also contains a button for turning the communication on or off, so that after clicking the button, the small arrow inside it turns to light green which means that the communication is stopped, and turns to dark green when the communication is on. The communication area also contains the path of the file used for storing the medical activities of the physicians and patients inside the hospital room. The selected file can store the recorded data in real-time; each line includes the time of the recorded event, the name of the person who made the event, the place where the person (physician/patient) exists, and the alarm form. For starting the events recording, we can use a file previously created or create a new file with a new path. A browse button is situated to the right of the file path area which enables choosing the place of creating and storing a new file and then the file path will appear in the path area. To use a new file, we have to open the application, stop the program, start the communication by choosing the com port, chose the path and create a new file before starting the program again.

The SmartBand holder area (above the communication area) gives information about the physician (the SmartBand holder). When a SmartBand connects to the network, the transceiver ID is transmitted to the Coordinator and the interface shows what physician is active (the physician name). If the physician is authorized to make visits, a green indicator will appear; otherwise, the indicator appears grey and the name cell appears empty. The same area shows the alarms transmitted by the SmartBand; three indicators are placed on top of each other: the upper one colors in green when the SmartBand led is green, the middle one colors in orange when the SmartBand led blinks orange light, the lower indicator is colored in red when the SmartBand led emits red light. In this way, the GUI shows that the physician is complying with the hand hygiene rules.

The hand motions (top) **area** displays the amplitudes of the three axes of the SmartBand accelerometer X, Y, Z. The acquisition of hands motions is made only when the physician is at the sink, in order to analyze the hand motions. The motion data can be shown for 100 seconds.

The hospital room area is a replica of the positions where the physician may stay in the room, the door, the sink, the first bed, the second bed or the toilet. When one of these places turns to light green, it means that the physician is at that place and the other places are colored in grey.

6.6.4. The SmartBand design and implementation

We designed a SmartBand prototype with the needed functionalities for our system. It was developed based on a RedBoard system. This is similar with Arduino board and it is equipped with an Atmel ATmega328 microcontroller that offers 14 digital I/O pins (6 PWM outputs), 6 analog inputs, 32k flash memory and 16MHz clock speed. The RedBoard is connected to an accelerometer, an RFID Reader and a ZigBee transceiver as in Figure 38. The SmartBand looks like in Figure 37.

The accelerometer used is MPU 6050 that also includes a gyroscope for further development of acquiring more precise hand motions. Communication with all registers of the device is performed using I2C at 400 kHz. The MPU-66050 features three 16-bit analog-to-digital converters (ADCs) for digitizing the gyroscope outputs and three 16-bit ADCs for digitizing the accelerometer outputs.

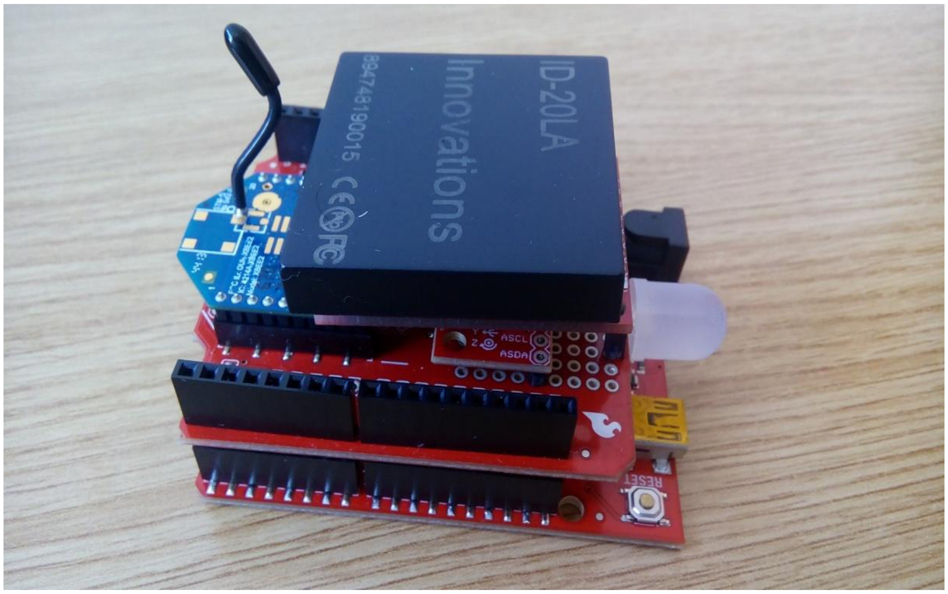


Fig 37. The SmartBand prototype

As RFID reader has used the ID-20LA reader module that supports ASCII, Wiegand26 and Magnetic ABA Track2 data formats. It has a built-in antenna that offers a range up to 25cm using clamshell card.

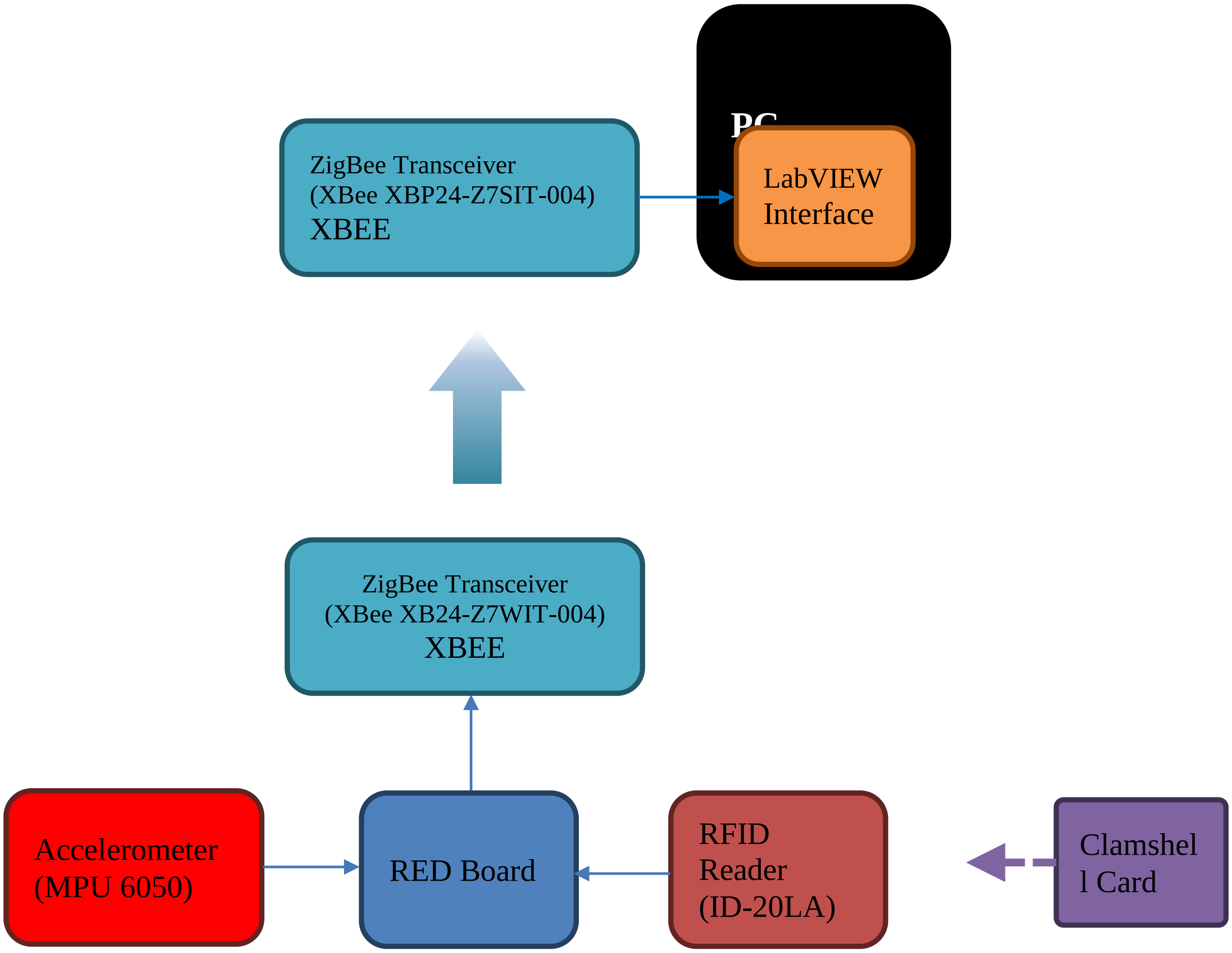


Fig 38. SmartBand Block Scheme

The communication between the SmartBand and the base station is made by transceivers from Digi, called XBEE. They are using the ZigBee protocol suited for low energy consumption in applications powered by batteries. The topology of the implemented wireless sensor network is a star topology with point-to-point communication. The transceiver which is connected to the computer is set as a coordinator. The transceiver from the SmartBand is set as an end point and sends data to the coordinator periodically. The main settings of the transceivers are presented in Table 8.

Table 8. The main settings of the transceivers

Coordinator	
PAN ID	1111 (all the transceivers from the network needs to have the same PAN ID)//id of the network – establish the id
Destination Address	0x000000000000FFFF (for sending the broadcast message in the network)
Power Level	Highest [4] with Boost mode enabled
Sleep Mode	No Sleep
Encryption	Enable
End-Point (SmartBand)	
PAN ID	1111//to communicate with the coordinator has to put its id
Destination Address	0x0000000000000000 (for sending directly to the coordinator)
Power Level	Power Level: Highest [4] with Boost mode enabled
Sleep Mode	Cycling Sleep
Encryption	Enable

Source: Personal calculation

The SmartBand is equipped with the XBee XB24-Z7WIT-004 transceiver, which integrates a wire antenna. This offers an indoor range up to 30m. The Coordinator has an XBEE-Pro XBP24-Z7SIT-004 transceiver with SMA antenna that increases the range up to 60m indoor.

The connections between the RedBoard and the additional components are described in Table 9.

Table 9. Connections between RedBoard and additional components of the SmartBand

No.	Arduino Pins	Components Pins	
1.	Pin 0 – RX	DOUT	XBEE
2.	Pin 1 - TX	DIN	
3.	3.3V	VCC	
4.	GND	GND	
5.	SDA	SDA	Accelerometer + Gyroscope MPU 6050
6.	SCL	SCL	
7.	3.3V	VIO	
8.	3.3V	VDD	
9.	GND	GND	
10.	Pin 7	TX	RFID reader ID-20LA
11.	5V	VCC	
12.	GND	GND	
13.	Pin 5	Green	LED
14.	Pin 6	Red	
15.	GND	GND	

Source: Personal calculation

The RedBoard is programmed to perform the tasks using the Arduino language. This is a commonly used language, merely a set of C/C++ functions that can be called from the code. Some parts of the source code used to program the RedBoard are listed in the annex of the thesis. The coordinator and the SmartBand's transceiver are programmed based on X-CTU software from DiGi.

The SmartBand software runs independently from the PC application (on the base station). The decisions for the right alarms are made on the SmartBand. After the initial setup stage, the SmartBand performs the steps as in Figure 39. If the connection to the Coordinator is interrupted, the data packet is dropped but the Smartband operates normally.

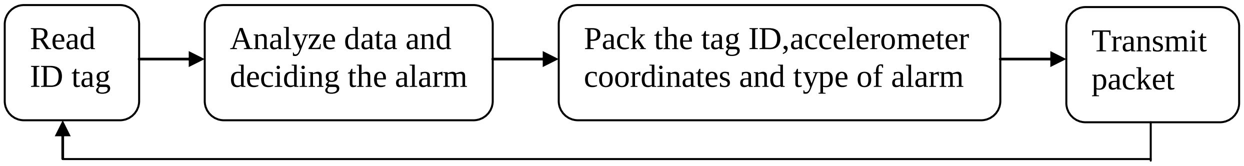


Fig 39. SmartBand software steps. Source: Personal calculation

6.7. Prototype testing

The prototype was tested using different use cases scenarios. The results of a use case scenario execution can be visualized using the sequence of events generated by the SmartBand of a person who visit the room, which is stored in a file by the application running on the PC. In the following we exemplify the results of some use case scenarios execution:

```
Date: 18.02.2016
6:20:33 PM   Dr. X  Place: Outside Alarm: Green
6:20:53 PM   Dr. X  Place: Door    Alarm: Orange
6:21:00 PM   Dr. X  Place: Sink    Alarm: Orange
6:21:43 PM   Dr. X  Place: Sink    Alarm: Green
6:22:58 PM   Dr. X  Place: Bed 1   Alarm: Green
6:24:27 PM   Dr. X  Place: Bed 2   Alarm: Orange
6:24:35 PM   Dr. X  Place: Bed 2   Alarm: Red
6:24:54 PM   Dr. X  Place: Sink    Alarm: Orange
6:25:38 PM   Dr. X  Place: Sink    Alarm: Green
6:25:48 PM   Dr. X  Place: Door    Alarm: Green
6:26:19 PM   Dr. X  Place: Sink    Alarm: Orange
6:27:01 PM   Dr. X  Place: Sink    Alarm: Green
6:27:09 PM   Dr. X  Place: Bed 1   Alarm: Green
6:29:12 PM   Dr. X  Place: Sink    Alarm: Orange
6:29:52 PM   Dr. X  Place: Sink    Alarm: Green
6:30:03 PM   Dr. X  Place: Bed 2   Alarm: Green
```

```
6:35:28 PM    Dr. X   Place: Sink     Alarm: Orange
6:36:11 PM    Dr. X   Place: Sink     Alarm: Green
6:36:39 PM    Dr. X   Place: Door     Alarm: Green
6:38:49 PM    Dr. X   Place: Bed 1    Alarm: Orange
6:38:58 PM    Dr. X   Place: Sink     Alarm: Orange
6:39:42 PM    Dr. X   Place: Sink     Alarm: Green
6:39:47 PM    Dr. X   Place: Bed 1    Alarm: Green
6:41:07 PM    Dr. X   Place: Bed 2    Alarm: Orange
6:41:16 PM    Dr. X   Place: Bed 2    Alarm: Red
6:41:23 PM    Dr. X   Place: Sink     Alarm: Orange
6:41:40 PM    Dr. X   Place: Bed 2    Alarm: Red
6:41:40 PM    Dr. X   Place: Bed 2    Alarm: Orange
6:41:47 PM    Dr. X   Place: Sink     Alarm: Orange
6:42:31 PM    Dr. X   Place: Sink     Alarm: Green
6:42:36 PM    Dr. X   Place: Bed 2    Alarm: Green
6:44:22 PM    Dr. X   Place: Sink     Alarm: Orange
6:45:03 PM    Dr. X   Place: Sink     Alarm: Green
6:45:31 PM    Dr. X   Place: Door     Alarm: Green
6:46:02 PM    Dr. X   Place: Bed 2    Alarm: Orange
6:46:09 PM    Dr. X   Place: Bed 2    Alarm: Red
6:46:29 PM    Dr. X   Place: Bed 1    Alarm: Red
6:46:42 PM    Dr. X   Place: Sink     Alarm: Orange
6:46:55 PM    Dr. X   Place: Toilet   Alarm: Red
6:46:55 PM    Dr. X   Place: Toilet   Alarm: Orange
6:47:06 PM    Dr. X   Place: Toilet   Alarm: Red
6:47:10 PM    Dr. X   Place: Sink     Alarm: Orange
6:47:51 PM    Dr. X   Place: Sink     Alarm: Green
6:47:56 PM    Dr. X   Place: Door     Alarm: Green
6:48:09 PM    Dr. X   Place: Toilet   Alarm: Orange
6:48:19 PM    Dr. X   Place: Toilet   Alarm: Red
6:48:37 PM    Dr. X   Place: Sink     Alarm: Orange
```

```
6:49:19 PM    Dr. X   Place: Sink     Alarm: Green
6:49:31 PM    Dr. X   Place: Bed 1    Alarm: Green
6:49:46 PM    Dr. X   Place: Toilet   Alarm: Orange
6:49:53 PM    Dr. X   Place: Sink     Alarm: Orange
6:50:37 PM    Dr. X   Place: Sink     Alarm: Green
6:50:40 PM    Dr. X   Place: Toilet   Alarm: Green
6:51:27 PM    Dr. X   Place: Door     Alarm: Orange
6:51:36 PM    Dr. X   Place: Door     Alarm: Red
6:51:44 PM    Dr. X   Place: Sink     Alarm: Orange
6:52:27 PM    Dr. X   Place: Sink     Alarm: Green
6:52:32 PM    Dr. X   Place: Toilet   Alarm: Green
6:53:21 PM    Dr. X   Place: Bed 2    Alarm: Orange
6:53:32 PM    Dr. X   Place: Bed 2    Alarm: Red
6:53:40 PM    Dr. X   Place: Door     Alarm: Red
6:53:51 PM    Dr. X   Place: Sink     Alarm: Orange
6:54:33 PM    Dr. X   Place: Sink     Alarm: Green
6:54:34 PM    Dr. X   Place: Door     Alarm: Green
6:54:50 PM    Dr. X   Place: Bed 2    Alarm: Orange
6:55:04 PM    Dr. X   Place: Toilet   Alarm: Red
6:55:33 PM    Dr. X   Place: Bed 1    Alarm: Red
6:55:53 PM    Dr. X   Place: Sink     Alarm: Orange
6:56:32 PM    Dr. X   Place: Door     Alarm: Red
6:56:33 PM    Dr. X   Place: Door     Alarm: Orange
6:56:44 PM    Dr. X   Place: Door     Alarm: Red
6:56:51 PM    Dr. X   Place: Sink     Alarm: Orange
6:57:32 PM    Dr. X   Place: Sink     Alarm: Green
6:57:41 PM    Dr. X   Place: Door     Alarm: Green
```

6.8. Conclusions

A system prototype that the author designed for monitoring the compliance with the hand hygiene rules in a hospital room has been described. Additional system design requirements have been clarified. The system prototype has been presented in details, including the designed wireless sensor network with a diagram showing that the system is scalable. The communication way and the data transmission were also addressed in this chapter with presenting the format of the transmitted packets. A comperhencive description for each component used in designing the SmartBand and the way of connecting them together have been clarified in details. The alerting mechanism and the GUI were detailed in this chapter. Also, the chapter described the architecture of the SmartBand that we designed and implemented for the prototype.

The designed system allows:

- Recognizing the SmartBand holder identity;
- Identifying the SmartBand holder position;
- Measuring the hand hygiene duration;
- Reading the hands motions and presenting them on the base station in real-time;
- Taking decisions and emitting alerts at proper times;
- Recording the clinical activities of the physicians and patients inside the hospital room including the event time, the SmartBand holder’s name, his position and the alarm form. The resulted data is stored in a file in real-time.

7. Conclusions and future work

In the first part of my doctoral studies I have investigated the use of IoT devices in different healthcare areas. Chapter 2 of the thesis presents on overview, an analysis and a comparison between different IoT technologies. Then, in chapter 3, there are presented some existent healthcare applications, which use IoT technologies.

In the last two years I dedicated my work to a very important problem in the healthcare field, where IoT technologies have the right place: the HAI prevention.

The HAI is a problem statistically proven to be a critical issue in hospitals at present; it leads to growing mortality, financial waste and limiting hospital resources. Currently, HAI is a key reason for death in many countries and contaminated hands is classified as one of its major causes.

This thesis has investigated the causes of this problem and how can be solved by combining classical (non IT) and ICT based solutions. In chapter 5 the author have presented some existent ICT solutions including simple and integrated ones, dedicated to monitoring and combating this problem. These solutions are based particularly on sensors and recent technologies such as RFID and ZigBee. These solutions had an important role to reduce the HAI rate and the integrated solutions introduced the highest rate of HAI combating, but unfortunately, none of the existent solutions could process all the problem aspects.

Starting from the ideas of the HAI-OPS (ID. E!9831 - HAI-OPS) ongoing project of the Department of Computer Science and Engineering from UPB, the author designed and implemented a prototype of a system dedicated to monitoring both the physicians and patients actions inside a hospital room. This system is described in detail in the chapter 6 of this thesis.

7.1. The original contributions of this thesis

In **Chapter 2** a detailed analysis of the IoT technologies has been presented, their concepts, features, applications, services, positives and negatives and the functioning way for each technology. **Our contribution was analyzing and clarifying the relations between those**

technologies, especially between RFID-Barcode, RFID-NFC, and NFC-Mobile phone, in addition comparing between their main features, functioning mechanism and services. This deep analysis allows readers to have a very good idea about IoT technologies and make it easier to them to choose and use these technologies in their practical applications.

In **Chapter 3** an overview of the applications for the healthcare domain has been presented. It includes a number of applications, based on different IoT and communication technologies such as sensors, Bluetooth and Wi-Fi. There were presented applications for monitoring blood and tears glucose level, wearable systems, wheelchair applications and other applications for people with disabilities. The aim of this chapter was to highlight the unlimited possibilities of using IoT and communication technologies in healthcare domain, saving people lives and enhancing their life level.

Chapter 4 presented the HAI (Hospital Acquired Infection) risk by showing official statistics from many countries of the world and explaining various HAI causes. It was showed clearly that unclean hands are a main reason for the HAI, confirming the importance of the hand hygiene, the necessity of respecting the "five moments" specified by the World Health Organization (WHO) for reducing the HAI rate and demonstrated the effective role in fighting the HAI for each of nurses, physicians and the hospital managers. **Our contribution was an exploration and an analysis of the traditional methods used for combating the HAI and discussing the latest ICT solutions dedicated to HAI prevention in details, with a demonstration about how these technologies work.**

We revealed that the traditional methods are not sufficient to solve the HAI problem and that ICT solutions could contribute to solving the HAI problem to a much larger extent.

In Chapter 5, the main contribution was analyzing the integrated ICT systems used for monitoring the compliance with hand hygiene in details, with their positives and negatives and a comprehensive comparison of their features. We found that they give the highest rate of compliance with hand hygiene, thus fighting an important rate of infection. The components and the working way for each system, their compliance schemes with the WHO recommendations have been detailed. Unfortunately, the compliance rate with the five moments is still below the desired level. The traditional methods may give certain compliance rates, but they remain under the desired level and require a high cost and waste time. The traditional methods provide 50% compliance ratio at best, while the high compliance ratio with hand hygiene (90%-99%) and the low infection rates are provided by the integrated systems.

We also found that all the HAI prevention solutions (ICT and integrated systems) existent right now are insufficient to prevent the HAI problem and they suffer from critical shortcomings, as underlined in the conclusions of chapter 5**:**

- None of these solutions addresses all the possible ways of HAI transmission, because each of them is interested in addressing one of the HAI reasons or transmission pathways, which is not enough. So, there is no complete solution for combating the HAI right now.
- All the current solutions are not integrated with the local hospital systems such as the HIS; therefore, implementing the clinical procedures may face problems especially in critical situations.
- Available solutions lack the ability to identify all the sources and methods of HAI transmission, especially the non-traditional ones, or those that could overcome the used prevention ways.

Chapter 6 includes our main contributions for combating the HAI. The author designed and implemented a prototype of a system for real-time monitoring of a hospital room. The monitoring is accomplished using a multifunctional SmartBand and RFID tags located in key points of the room. The author designed and implemented the SmartBand using a RedBoard system, which is similar with Arduino board. The software running on the SmartBand is implemented using Arduino language. The hardware design of the SmartBand is described in detail and some parts of the source code that runs on the SmartBand are included in the annex. The software that runs on the base station was implemented in LabView. The designed SmartBand is suitable in the size, weight and shape and can be held on the physicians/patients hand wrist. The chapter includes also an analysis of the technological choices for the system design. Also, the author explained the **designed wireless sensor network** and the main role of the coordinator in building the connection. In addition, the author explained in details the data packet sent by the SmartBand to the base station and the meaning of each transmitted byte. The GUI, which was implemented in LabView graphical programming language, has been detailed.

The system can identify the SmartBand holder's identity and his position, tracking his movement in the hospital room, measuring the hand hygiene duration, reading the hand hygiene motions. The system includes a suitable alerting mechanism, applied in proper times. The alerts are displayed on the SmartBand and also transmitted to the base station to be presented in the GUI and stored for further analysis.

7.2. Future Work

In the future I will continue improving this project by:

- Testing various hardware components such as using High-Frequency RFID readers (HF RFID readers) or Ultra High-Frequency RFID readers (UHF RFID readers) on the SmartBand with compatible RFID tags. These components can extend the range of communication between the SmartBand and the distributed RFID tags up to two meters so that the SmartBand holder will not be compelled to bring the SmartBand close to the RFID tags distributed in identified places (entrance, sink, beds toilet and many other places within the whole hospital) to read their stored data. Extending the communication range between the SmartBand and the RFID tags will allow the system to work flexibly without any effort or discomfort to the SmartBand holder.
- Using Wi-Fi technology (Wi-Fi transceivers) for performing the communication between the SmartBand and the base station can double the operating range of the system thus reducing the number of intermediate devices (routers) when implementing the system on the whole hospital.
- Designing a dedicated site, so that the data gathered about the physicians and patients activities (their names, their positions, their hand hygiene complying data including the hand motions, and the alerts) can be uploaded in real-time to be stored there in their dates and times for further analyses.
- Adding a digital screen to the SmartBand to allow presenting the analyzed data related to patients and physicians as a daily or weekly feedback sent to them to be constantly informed about their activities.

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Annex

```
//include libraries
      #include <SoftwareSerial.h>
      #include <XBee.h>
      SoftwareSerial rfid(7, 6);
      #include "I2Cdev.h"
      #include "MPU6050.h"

      #if I2CDEV_IMPLEMENTATION == I2CDEV_ARDUINO_WIRE
      #include "Wire.h"
      #endif
      MPU6050 accelgyro;

//define global variables
      int16_t ax, ay, az;
      int16_t gx, gy, gz;
      boolean stare = false;
      boolean sanitized = true;
      int reading = 0;
      int prev = 0x30;
      int id = 0x30;
      int cnt=0;
      int snt=0;
      int alert=0;//0x30 - green; 0x31 - orange; 0x32 - red
      int i=0;
      byte packet[] = {0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
0, 0, 0, 0, 0, 0, 0, 0, 0};
      XBee xbee = XBee();
      XBeeAddress64     coordAddress     =     XBeeAddress64(0x00000000,
0x00000000);
      ZBTxRequest   TxPacket   =   ZBTxRequest(coordAddress,   packet,
sizeof(packet));
//initial setup of the board
      void setup() {
          delay (2000);
          rfid.begin(9600); //enable communication with the rfid reader
          pinMode(5, OUTPUT);//green led turn off
          digitalWrite(5, LOW);
          pinMode(6, OUTPUT);//red led turn off
          digitalWrite(6, LOW);


          #if I2CDEV_IMPLEMENTATION == I2CDEV_ARDUINO_WIRE
```

```
          Wire.begin();//enable communication with the accelerometer
          #elif I2CDEV_IMPLEMENTATION == I2CDEV_BUILTIN_FASTWIRE
          Fastwire::setup(400, true);
          #endif
          accelgyro.initialize();
      }

// the loop function runs over and over again forever
      void loop() {
//take  the  accelerometer  values  (a)  and  gyroscope  values  (g)  for
further development
       accelgyro.getMotion6(&ax, &ay, &az, &gx, &gy, &gz);

      #ifdef OUTPUT_BINARY_ACCELGYRO
        Serial.write((uint8_t)(ax >> 8));
        Serial.write((uint8_t)(ax & 0xFF));
        Serial.write((uint8_t)(ay >> 8));
        Serial.write((uint8_t)(ay & 0xFF));
        Serial.write((uint8_t)(az >> 8));
        Serial.write((uint8_t)(az & 0xFF));
      #endif

//test the RFID availability
       while (rfid.available()) {
          reading = rfid.read(); // read byte
          if (reading == 2) {
            stare = true;  // '2' beginning of id
          }
          if (reading == 3) {
            stare = false; // '3' end of id
            delay(500);
          }
          if (stare && reading != 2 && reading != 10 && reading != 13)
      {
      // include the id in the data packet
            packet[i] = reading;
            i++;
          }
//implement an id tag for each place
          if (packet [i-1] ==  0x36 && packet [i-2] == 0x36)
          {id=0x35;} //toilet
          if (packet [i-1] ==  0x30 && packet [i-2] == 0x32)
          {id=0x34;} //bed2
          if (packet [i-1] ==  0x32 && packet [i-2] == 0x42)
          {id=0x33;} //bed1
```

```
    if (packet [i-1] ==  0x30 && packet [i-2] == 0x39)
    {id=0x32;} //sink
    if (packet [i-1] ==  0x31 && packet [i-2] == 0x32)
    {id=0x31;} //door
  }
//Create possible alarms for each place
    switch (id) {
       case 0x31://door
          {
          snt = 0;
          if (prev == 0x32)
            {sanitized = true;}
             if (prev == 0x30 || prev== 0x33 ||
                prev == 0x34 || prev == 0x35)
            {sanitized = false;}
            break;}

          case 0x32://sink
            snt+=1;
            sanitized = true;
            break;

          case 0x33://bed1
          {
            snt = 0;
            if (prev == 0x30 || prev == 0x31 ||
                prev == 0x34 || prev == 0x35)
            {sanitized = false;}
          if (prev == 0x32)
            {sanitized = true;}
            break;}

          case 0x34://bed2
          {
            snt = 0;
            if (prev == 0x30 || prev == 0x31 ||
                 prev == 0x33 || prev == 0x35)
            {sanitized = false;}
          if (prev == 0x32)
            {sanitized = true;}
            break;}

          case 0x35://toilet
          {
            snt = 0;
```

```
          if (prev == 0x30  || prev == 0x34 ||
               prev == 0x31 || prev == 0x33)
          {sanitized = false;}
        if (prev == 0x32)
          {sanitized = true;}
          break;}
    }

//show the alarm by properly set the led collor
    if (sanitized == false)
    {
      if (cnt<21)
      {
      cnt+=1;
      digitalWrite(6, HIGH);
      digitalWrite(5, HIGH);
      digitalWrite(4, HIGH);
      delay (200);
      digitalWrite(5, LOW);
      digitalWrite(6, LOW);
      digitalWrite(4, LOW);
      alert = 0x31;
      }
      else
      {
        digitalWrite(5, LOW);
        digitalWrite(6, HIGH);
        digitalWrite(4, HIGH);
        alert = 0x32;
      }
      }
    else
    {
      cnt=0;
      if (id == 0x32)// if it is at the sink
      {
        if (snt<81)
        {
          digitalWrite(6, HIGH);
          digitalWrite(5, HIGH);
          digitalWrite(4, HIGH);
          delay (200);
          digitalWrite(5, LOW);
          digitalWrite(6, LOW);
          digitalWrite(4, LOW);
```

```
              alert = 0x31;
            }
            else
            {
              sanitized = false;
              digitalWrite(5, HIGH);
              digitalWrite(6, LOW);
              digitalWrite(4, LOW);
              alert = 0x30;
            }
          }
          else // if it is at the same place and it is sanitized ->
remain sanitized
          {
            if (prev == id)
            {
            digitalWrite(5, HIGH);
            digitalWrite(6, LOW);
            digitalWrite(4, LOW);
            alert = 0x30;
            }
            else
            {
              if ((prev == 0x32) && (alert == 0x31))
              {
                  digitalWrite(5, LOW);
                  digitalWrite(6, HIGH);
                  digitalWrite(4, HIGH);
                  alert = 0x32;
                  sanitized = false;
              }
            }
          }
        }
          if (prev != id)
          {
            prev = id;
          }
      //attach the accelerometer values to the data packet
        packet[13] = ax;
        packet[12] = (ax >> 8);
        packet[15] = ay;
        packet[14] = (ay >> 8);
        packet[17] = az;
        packet[16] = (az >> 8);
```

```
packet[19] = gx;
packet[18] = (gx >> 8);
packet[21] = gy;
packet[20] = (gy >> 8);
packet[23] = gz;
packet[22] = (gz >> 8);
packet[24] = alert;//attach the alert to the data packet

xbee.send(TxPacket);//send data packet at each half a second
delay (300);
i=0;
}
```