REMOTE VITAL SIGNS MONITORING

Monitorização Remota de Sinais Vitais

Project Report
Version 1.0

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REVISIONS

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0.1	Creation of the document structure	**26/07/2007**
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ABSTRACT

One of today's most pressing dilemmas in medical care is the reduction of errors and costs while improving the quality of care. Many researches in both industry and academia, attempted to combine new wireless technologies with the advances in the medical field, to develop mobile care systems to remotely monitor the vital status of patients.

This project focuses the development of a system for the remote monitoring of a variety of vital signs that may promote the mobility and flexibility for both patients and medical personnel. The system includes two principal modules: a wireless portable multi-parameter device named acquisition module was designated to acquire physiological signals and transmit them to a second module using wireless technologies for short-range data transmission such as Bluetooth or ZigBee. Data are then wirelessly relayed from the transmission module to a web-based server or nursing central. Wi-Fi and GSM GPRS technologies allow the implementation of the system in both hospital and home scenarios.

The topic of this project report is the description of the architecture, schematic and PCB design, of all the modules involved in the new mobile-care system.

RESUMO

Hoje em dia, um dos dilemas mais críticos relativamente aos cuidados médicos consiste na redução de erros e custos e simultaneamente o melhorar da qualidade dos cuidados de saúde. Várias pesquisas têm vindo a ser realizadas não só a nível académico como na indústria, no âmbito de combinar as vantagens oferecidas pelas tecnologias sem fios com os avanços realizados no sector médico, de forma a projectar e desenvolver novos sistemas portáteis que monitorizam de forma remota os sinais vitais de pacientes.

Este projecto tem por objectivo o desenvolvimento de um sistema para a monitorização remota de uma variedade de sinais vitais, com o qual poderá ser conferida uma maior mobilidade e flexibilidade não só aos pacientes mas também aos profissionais de saúde. Este sistema é constituído por dois módulos principais: um módulo de aquisição, que consiste num aparelho portátil com capacidade de comunicação sem fios, tem como função a aquisição de sinais fisiológicos e sua subsequente transmissão para um segundo módulo recorrendo ao uso de tecnologias sem fios para a transmissão de curta distância de dados, tal como as tecnologias Bluetooth ou ZigBee. Os dados recolhidos são posteriormente reencaminhados via wireless desde o módulo de transmissão para um servidor web ou para uma central de enfermagem. As tecnologias Wi-Fi e GSM GPRS envolvidas na retransmissão dos dados permitem a implementação do sistema tanto em ambiente hospitalar como no domiciliário.

Através deste relatório de projecto, pretende-se fornecer uma descrição da arquitectura do novo sistema e dos esquemáticos e PCB layouts de todos os módulos nele envolvidos.

ACKNOWLEDGMENTS

First and foremost, I would like to thank my supervisor, Engineer Paulo Santos for having been the one that enabled the project progress. I would like to thank him not only for his guidance and friendship throughout the course of the project but also for having opened a new door for me in the field of electronics.

I also want to thank Engineers Artur Vieira and Pedro Monteiro for having shared their knowledge with me and especially for their patience.

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ACRONYMS AND DEFINITIONS

Abbreviation	Definition
AC	Alternate Current
AES	Advanced Encryption Algorithm
BAN	Body Area Network
BP	Blood Pressure
b.p.m	Beats Per Minute
CCC	*Centro Cirúrgico de Coimbra*
CDMA	Code Division Multiple Access
CEI	Electronics and Instrumentation Centre
CMOS	Complementary Metal Oxide Semiconductor
CMRR	Common Mode Rejection Ratio
CO_2	Carbon Dioxide
CPOD	Crew Physiological Observation Device
CPU	Central Processing Unit
DC	Direct Current
DFN	Dual Flat No-Lead
DSSS	Direct-sequence spread-spectrum
ECG	Electrocardiogram
EDGE	Enhanced Data rates for Global Evolution
EEG	Electroencephalogram
EEPROM	Electrically-Erasable Programmable Read-Only Memory
EIA/TIA	Electronic Industries Association/Telecommunications Industries Association
EMG	Electromyogram
EMI	Electromagnetic Interference
EMR	Electronic Medical Record
EMT	Emergency Medical Technician
ESR	Equivalent Series Resistance
EUSART	Enhanced Universal Asynchronous Receiver Transmitter
FHSS	Frequency Hop Spread Spectrum
FRAM	Ferroelectric Random Access Memory
FSK	Frequency Shift Keying
G	Generation
GGSN	Gateway GPRS Support Node
GHz	Gigahertz
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communications
IC	Integrated Circuit
ICT	Information and Communication Technology
ICU	Intensive Care Unit
IEEE	Institute of Electrical and Electronics Engineers<<<
IEETA	Institute of Electronics and Telematics Engineering
INE	*Instituto Nacional de Estatística*
IP	Internet Protocol
ISA	Intelligent Sensing Anywhere
ISM	Industrial, Scientific and Medical
I^2C	Inter-Integrated Circuit
LAN	Local Area Network
LED	Light Emitting Diode
Li-Ion	Lithium-Ion
MBU	Mobile Base Unit

MIPS	Millions of Instructions Per Second
MOSFET	Metal Oxide Semiconductor Field Effect Transistor
MSOP	Mini Small Outline Package
MSSP	Master Synchronous Serial Port
NiMH	Nickel Metal Hydride
OEM	Original Equipment Manufacturer
PC	Personal Computer
PCB	Printed Circuit Board
PCU	Personal Communication Unit
PDA	Personal Digital Assistant
PDS	Packet Driver Specification
PHS	Personal Handyphone System
PIN	Personal Identification Number
PWM	Pulse Width Modulation
QFN	Quad Flat pack No lead
QoS	Quality of Service
RAM	Random Access Memory
RC	Resistor-Capacitor
RF	Radio Frequency
RTC	Real Time Clock
SAM	Sensitron application modules
SD	Secure Digital
SDIO	Secure Digital I/O
SGSN	Service GPRS Support Node
SIM	Subscriber Identity Module
SMD	Surface Mount Device
SOIC	Small Outline Integrated Circuit
SPI	Serial Peripheral Interface
SpO_2	Saturation of Peripheral Oxygen
SSOP	Shrink Small Outline Package
SUIC	*Agência para a Sociedade do Conhecimento*
TDMA	Time Division Multiple Access
TFQP	Thin Quad Flat Package
TSSOP	Thin Shrink Small Outline Package
TTL	Transistor-Transistor Logic
UART	Universal Asynchronous Receiver Transmitter
UMTS	Universal Mobile Telecommunications System
USART	Universal Synchronous/Asynchronous Receiver/Transmitter
USB	Universal Serial Bus
Wi-Fi	Wireless Fidelity
WLAN	Wireless Local Area Network
WMAN	Wireless Metropolitan Area Network
WPAN	Wireless Personal Area Network
WWAN	Wireless Wide Area Network

CHAPTER I: INTRODUCTION

1.1 Domain and Motivation

The actual expansion and availability of wireless technologies for the general public combined with the advancing in medical solutions can give rise to new services and applications in the healthcare area. New telemedicine technologies based upon wireless techniques for short and long range data transmission to web-based applications are set to enable medical devices mobility and interconnectivity, anytime and anywhere. Face to the pressing dilemma of reducing errors and costs while improving the quality of care, tele-homecare and wireless monitoring appear to be attractive solutions.

Remote monitoring of patients has the potential to provide full, detailed and accurate vital signs measurements, without the need of constant displacements of patients to the healthcare unit. It may allow the patient to be fully mobile, pursuing daily life activities whilst undergoing health monitoring. The rapid transmission and management of clinical data benefit all the features offered with digital information, such as search and transfer facilities. Data may be easily accessed and consulted by authorized personnel when abnormalities in a patient vital signs data are detected leading to the alarm sound or simply for routine diagnostic purposes.

1.2 Objectives

This project aims at developing a system for the measurement, processing and remote transmission of vital signs data. Patients' data should be collected using a Body Area Network (BAN) that integrates wearable sensors distributed over the patient and that sense the physiological signals. An extra-BAN communication, that is external communication of the BAN, is required for the remote monitoring application. This communication should be handled using Wi-Fi, UMTS, GPRS or GSM technologies. The module responsible for the data acquisition should have reduced dimensions and low-battery consumption, be ergonomic, comfortable and easy to use. Its portability may satisfy the simultaneous patients' need for mobility and healthcare.

The acquisition module must accurately measure the vital signs of the patient and wirelessly send them to a second module, the transmission module, which is responsible for the transfer of the received physiological data to a web-based server. The transmission module should be able to receive, temporarily store and re-transmit data coming from the acquisition module. This last transmission to a web based server should be accomplished in real-time using the previously referred technologies that support the exit gateway of the BAN.

The system should be able to send alerts to the healthcare provider via GSM whenever abnormal situations in the patient's condition are detected. After receiving the alarm, the healthcare provider may visualize the patient's data in real-time using a PDA, a smartphone or simply a PC. Data must then be stored in a database in such a way that electronic medical records will be accessible from any browser. A user interface must be created allowing a fast and secure way for consultation or updating of the patient medical records. Additional subjective information about the patient health condition may also be provided.

1.3 Audience

The audience for this project report is composed by the jury members and supervisors of the project course. This document has the purpose to introduce the scope and objectives of the project, provide background knowledge and describe the research, process and decisions that were made throughout the duration of the project. The document elaboration were focused on the contextualization of the work done, allowing its analysis and evaluation. It may also represent a good tool to contextualize other students that may continue the project development in the future, regard the work that have already been done.

1.4 Document Structure and Organization

The present chapter, the introduction, aims to introduce the reader the project domain and motivation, its objectives and the audience to which this report is destined.

The rest of the document is organized as following. Chapter II refers to the project management. The project team members and supervisors and the way how the project was organized, in particular, the tasks assignment and the timetable definition, are presented.

Chapter III contains the problem analysis and enumeration of some relevant works that attempted to solve it. The final section of the chapter reassumes the advantages that the pretended solution may offer when compared with the already existing.

In Chapter IV, the reader is provided with background information related with the project requirements, more specifically, the vital signs monitoring scenarios, the medical monitoring equipment indispensable for the pretended application and the communication technologies involved in the system. The description of the system architecture and functioning is then made. This description is organized into two sections: the acquisition module and the transmission module.

Chapter V refers to the hardware design. It is subdivided into two sections: the schematics design and the PCB layout design. In each section, after a brief introduction to the software used for the purpose, the description of the design process is made. The schematic designs of the parts which compound the entire system are described. The referred parts are: the acquisition module, the transmission module, the Bluetooth module, the ZigBee module, the

GSM GPRS module and the Wi-Fi module. The chapter is concluded with a brief approach to the basic rules on which the PCB design of all the system modules has been based.

The last chapter concluded the present project report. The summary of what have been done since the project development has started is presented. An analysis of possible future developments is then presented and finally, the student gives a final appreciation regarding the project and its benefits.

CHAPTER II: PROJECT MANAGEMENT

2.1 Project Team Members

The project team was comprised of three Biomedical Engineering students of the Faculty of Sciences and Technology, University of Coimbra and the project supervisors.

The students were responsible for the projection and development of the vital signs monitoring system. The supervisors accompanied the project evolution and individual development of the students, being responsible for the orientation and coordination of their work.

The elements that composed the team are presented in table 1.

Name	Contribute	Email Contact
Emeline Gonçalves	Student	emeline.alves@gmail.com
Ricardo Martins	Student	ricardomartins112@gmail.com
Tiago Marçal	Student	silvamarcal@gmail.com
Engineer Paulo Santos	Supervisor	psantos@isa.pt
Professor José Basílio Simões	Supervisor	jbasilio@lei.fis.uc.pt
Professor Carlos Correia	Supervisor	correia@lei.fis.uc.pt

Table 1 - Project team

2.2 Project Supervising

2.2.1 Supervising at CEI

The Electronics and Instrumentation Centre (CEI) has been created in the Physics Department of the University of Coimbra. Schoolmasters, researchers and technicians members of the CEI work on a wide range of research areas including Atomic and Nuclear Instrumentation, Biomedical Instrumentation, Plasma Physics Instrumentation, Microelectronics, Optical Signal Processing and Telemetry and Industrial Control.

The supervision at CEI was conducted by the Professor Carlos Correia and prevailed in the first stage of the project, at multidisciplinary levels. The student acquired theoretical background through literature review benefiting the supervisor's assistance in case of interpretation difficulties or resources problems.

Meetings organized by the supervisor were held at the CCC in the initial stage of the project with the purpose of establish the clinical parameters of interest that the system should monitor and allow the student contact with the monitoring equipment actually used in the referred healthcare unit.

Informal meetings were held throughout all the duration of the project development in order to inform the supervisor about the work progress. Additionally, a session was organized to introduce the student to the basic guidelines for writing the present report.

2.2.2 Supervising at ISA

ISA (Intelligent Sensing Anywhere) is a spin-off company of the University of Coimbra that was founded in 1990. The technology based company integrates a R&D unit that works on the development of complete solutions, which include hardware, firmware and software, for a wide range of application areas: telemetry solutions for the utilities, industrial telemetry and logistics, building management systems, environmental monitoring and control and more recently, in the healthcare and medical field.

Two elements of ISA supervised the project: Professor José Basílio Simões as the project coordinator and Engineer Paulo Santos as the technical supervisor.

The supervising at ISA initially consisted of periodic meetings that involved the supervisors of both ISA and CEI and that took place in the ISA's installations. The project evolution at short and long term was discussed during the meetings, as well as the system's requirements and architecture.

Once the individual tasks of the student were defined, informal and periodic sessions of clarification with the technical supervisor were held. The supervisor gave the student practice explaining regarding the project evolution and clarified the doubts that arose during the work progress.

In the final stage of the project, the student continued his work in the company installations, benefiting of a closer accompaniment of his work by the technical supervisor. The last stages of progress the student were expected to complete were agreed and planned. The supervisor also guides the student in the preparation of the final report writing and defence.

2.3 Tasks Assignment

The idealization of a system for the remote monitoring of vital signs required the acquisition of theoretical basis through literature study and the analysis of the sate of the art. During this initial stage of the project, the students discussed together the system architecture and the functionalities it will be expected to support. This evolution has been continuously followed and oriented by the supervisors during the meetings. Once the general structure of the system has been agreed, the students wrote together the project documentation that describes the functional requirements analysis and the state of the art of the project. The first oral project presentation marked the end of the first phase of the project progress.

The work has then been divided and tasks had been assigned to each student. Emeline Gonçalves were responsible for the acquisition module development while Tiago Marçal should develop the transmission module. The creation of a user interface to visualize the measured data was under Ricardo Martins responsibility.

Afterwards, a redefinition of the individual tasks assignment has been accorded. Emeline Gonçalves remained responsible for the system hardware design while Tiago Marçal started to work on the embedded firmware that, together with the hardware, should support the system's functionalities that were pretended.

2.4 Tasks Timetable

The project execution required the planning of the diverse stages and activities that the students had to carry on. This implied the identification of all the things that need to be done in order to reach the fixed objectives.

2.4.1 Initial planning

An over-ambitious time-scale has initially been proposed during the meetings at CCC, which consisted of the presentation of a first prototype solution to be tested in the referred healthcare unit, in January 2007. This idea has then been put aside when the group of students started to work on the project and realized the unfeasibility of the previous suggestion.

Initially, the tasks of the students had not been strictly planned. They opted for the non-division of the group while they still were studying the project background and related theory, as well as during the system definition. The individual knowledge deepening, for example software learning and individual tasks were conducted according to the necessities that arose during the work progress.

2.4.2 Final Planning

The tasks carried out until the first oral presentation which took place on 23 February 2007 are presented in a Gantt-chart in table 2. This planning has been created by the three students of the project team as the tasks until this date have been carried by the entire group.

ID	Task Name	Start	Duration
1	1.Integration in the CEI Investigation Group	11-09-2006	1d
2	2. Definition of the System Features and architecture	11-09-2006	13w 4d
3	3. Contact with the CCC Healthcare Unit	18-09-2006	2w 1d
4	4. Construction of an ECG circuit	03-10-2006	10w 3d
5	4.1 Theoretical Fundaments	02-10-2006	1w 4d
6	4.2 Circuit Projection and Construction	13-10-2006	6w 3d
7	4.3 Processing Software - MATLAB	29-11-2006	2w 1d
8	Scholar Pause – Exams and Works	15-12-2006	6w 1d
9	5. Documentation Elaboration – Vision and Objectives	29-01-2007	1w 2d
10	6. Creation of the Project Website	07-02-2007	2d
11	7. Documentation Elaboration – Project Requirements Analysis	07-02-2007	1w 3d
12	8. First Oral Project Presentation Preparation	19-02-2007	4d
13	9. First Oral Project Presentation	23-02-2007	1d

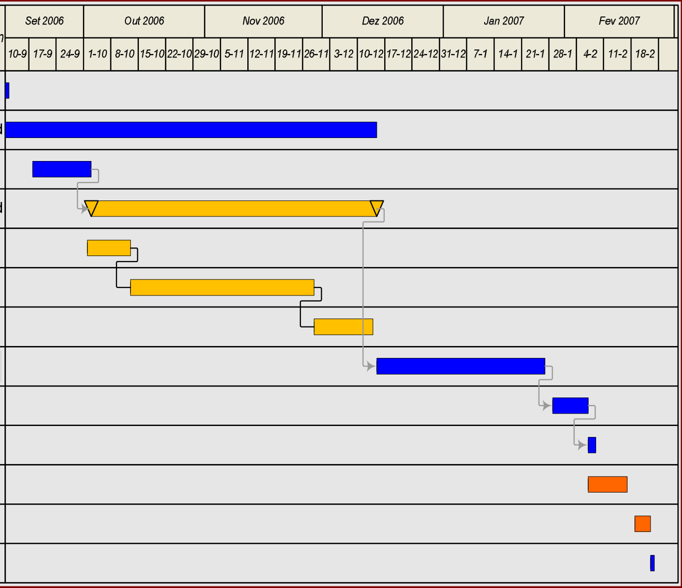


Table 2 - Tasks concluded until February 23, 2007: Gantt chart

- Blue: Tasks carried out by the three students
- Yellow: Tasks carried out by Emeline Gonçalves
- Orange: Tasks carried out by Emeline Gonçalves and Ricardo Martins

Once the individual responsibilities were specifically attributed to each student, the project planning was made and used as a guide for both work evolution and control. The project didn't exactly follow the planned schedule but the last one helped things happen logically. This planning has been thought and elaborated by the student and its technical supervisor from ISA. Some tasks revealed to be more laborious than others and consequently obliged the student to dedicate more time to their realization. As a result, the project planning has been constantly actualized according to the progress being made. Two Gantt Charts are presented below on table 3 and table 4: one referring to the planning before moving to the ISA's installations and the second refers to the planning after that, respectively. They describe the project evolution since the first oral presentation until the conclusion of the project discipline, which is marked by the report delivery.

ID	Task Name	Start	Duration
1	**10. Global Architecture Definition**	26-02-2007	3w 1d
2	10.1 Transmission Module	26-02-2007	1w 3d
3	10.2 Acquisition Module	08-03-2007	1w 3d
4	**11. Study of Electronic devices**	20-03-2007	2w 1d
5	**Scholar Pause**	04-04-2007	1w
6	**12. Orcad: Schematics Design**	11-04-2007	13w
7	12.1 Transmission Module	11-04-2007	6w
8	12.1.1 Power Supply	11-04-2007	2w
9	12.1.2 Central Processing Unit	23-04-2007	1w 3d
10	12.1.3 RTC and Memories	02-05-2007	1w
11	12.1.4 USB Interface	09-05-2007	1w
12	12.1.5 Input/Output	18-05-2007	1d
13	12.2 Acquisition Module	23-05-2007	4w 1d
14	12.2.1 ECG Front-End	21-05-2007	1w
15	12.2.2 Central Processing Unit	28-05-2007	1w
16	12.2.3 RTC and Memory	04-06-2007	1w
17	12.2.4 Sensors	11-06-2007	1w
18	12.2.5 Input/Output	18-06-2007	1d
19	12.3 ZigBee Module	21-06-2007	3d
20	12.4 Bluetooth Module	26-06-2007	2d
21	12.5 GSM GPRS Module	04-07-2007	3d
22	12.6 Wi-Fi Module	09-07-2007	2d
23	Scholar Pause	25-06-2007	1w 2d

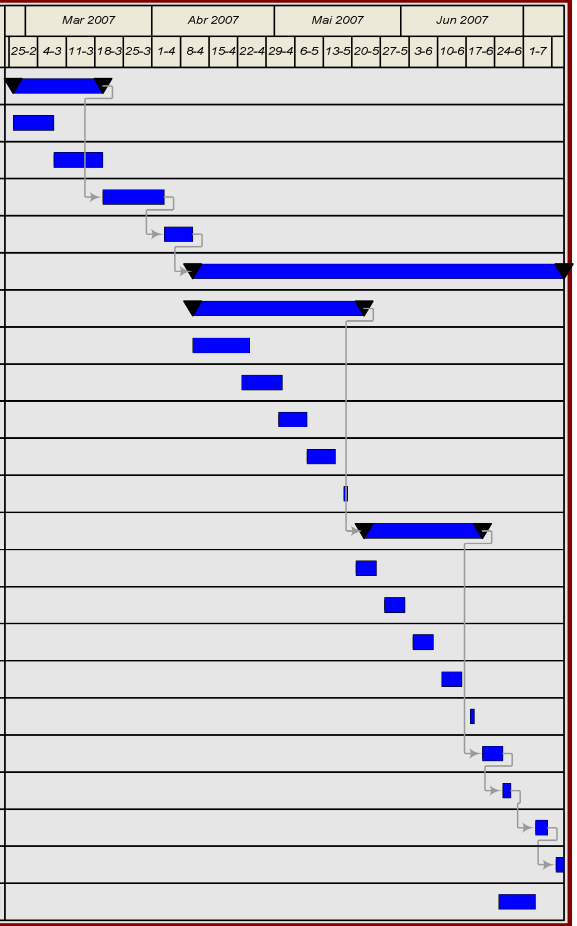


Table 3 - Tasks concluded since February 23 until July 10, 2007: Gantt chart

ID	Task Name	Start	Duration
1	**13. Bills of Materials Construction**	10-07-2007	1w 1d
2	**14. Enclosures Selection**	18-07-2007	1d
3	**15. PCB design – Transmission Module**	19-07-2007	1w 3d
4	15.1 PCB Design - Main	19-07-2007	1w 1d
5	15.2 PCB Design - GSM	27-07-2007	,5d
6	15.3 PCB Design - Wi-Fi	27-07-2007	,5d
7	15.4 PCB Design - Bluetooth	30-07-2007	,5d
8	15.5 PCB Design - ZigBee	30-07-2007	,5d
9	**16. PCB Design – Acquisition Module**	31-07-2007	3d
10	**17. Orders – Components and PCB**	03-08-2007	1d
11	**18. Project Report Elaboration**	06-08-2007	5w
12	**19. Construction of 2 prototype**	27-08-2007	3d
13	**20. Test and Validation**	30-08-2007	1w 1d
14	20.1 Electrical Testing	30-08-2007	2d
15	20.2 Functional Verification	03-09-2007	4d
16	**21. Project Report Delivery**	10-09-2007	1d

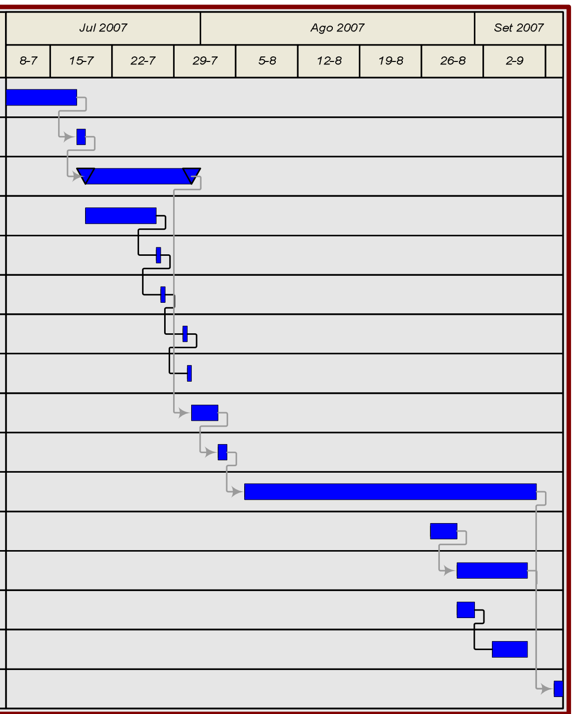


Table 4 - Tasks concluded since July 10 until September 10, 2007: Gantt chart

CHAPTER III: RELATED WORKS

In this chapter, it is pretended to give the reader an overview about the problems that gave rise to this project development and benefits that its solution will bring. The State of the Art analysis and the verification of what is lacking in the same are then made. Finally, a brief summary of what it is pretended to be done and how the new system will differ from the remaining is presented.

3.1 Problem Analysis

Europe's population is getting older. From 2005 to 2030, the number of people over 65 years of age will rise by 52.3% while the age group of 15-64 years old will decrease by 6.8% [1]. A continuing increase in average life expectancy is evident. An INE study reveals that the average life expectancy of Portuguese's men has increased 11 years between 1960 and 2001, and 13 years for women [2]. Medical cares for senior population is consequently becoming progressively more important as the incidence of chronic diseases becomes higher with age. This patient's conditions must continuously be observed for a long term by caregivers.

Another problematic situation takes place at disaster's scenes. Generally, in these situations, the initial treatment is handled by paramedical personnel arriving at the site of the accident with the ambulance. The improvement of coordination and communication between the on-site and on-base medical teams may certainly contribute for better patient outcomes. If the medical personnel at the hospital can access the patient vital signs data before its arrival at the healthcare unit, they may be able to respond more speedily and efficiently to the situation, taking the appropriate decisions for the patient treatment as soon as the ambulance arrives.

These two situations are only two examples of the many cases in which people need to be continuously submit to biomedical monitoring of their health conditions.

Nowadays, there is an urgent need to increase the quality of care while reducing errors and costs. The number of people requiring healthcare is increasing while the number of healthcare providers is diminishing. This progressive reduction of the medical personnel may be due to budgetary restrictions in the healthcare units or simply due to geographic factors that contribute to the limited number of healthcare providers especially in the rural zones. As a consequence, the total number of patients under the care of each medical professional is becoming larger and they can spend less time caring for each patient. Additionally, with increasing ICU occupancy, prolonged average length of stay, and costly patient transport between units, hospitals are quickly getting congested. Face to the space limitations, healthcare organizations and institutions are encouraged to reduce the length of patient's stay in the healthcare unit and minimizing unnecessary transfers thus enabling costs reduction and overcrowding diminution.

Wireless solutions that combine remote monitoring equipment with communication technologies appear to be suitable for the simultaneous reduction of the waste of medical resources and real-time care service achievement. Thus, continuous vital signs monitoring of patients not only may be more revealing as the patient can be assessed under active conditions but also enables the medical personnel to remotely and accurately monitor the patient status without the need of room visits, within the healthcare unit.

With tele-homecare, the health care can be delivered while the patient proceeds as usual with his life. After-treatment at home can accelerate recovery and there is no need of constant dislocations to the healthcare unit. The patient's vital signs data are constantly being measured and send to the caregiver. In case of critical events detection, a warning in real-time may be emitted and communicated to the proper caregiver. This solution will enable the mobility of patients and medical personnel but also improve the quality of healthcare.

Finally, wireless advances in tele-homecare and telemetry help eliminate inefficiencies and time delays in the patient management process. Computer distortions or human errors may produce difficulty of processing the data and can be avoid through automatic electronic-based data input. Patient's history can thus be retrieved and remotely updated.

3.2 State of the Art

Trough the following State of the Art, it is pretended to summarize what solutions others have developed for solving the above referred problematic situations.

All the systems presented in this section were created with the objective of remotely monitor patients vital signs. The systems differ according to the type of applications to which they are destined or for example because of the different vital signs they must monitor.

3.2.1 CodeBlue

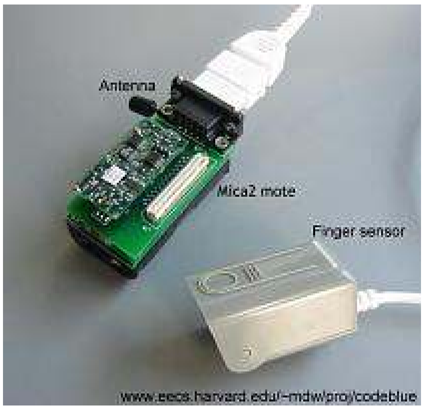
The CodeBlue project has been developed by the School of Engineering and Applied Sciences of the Harvard University in collaboration with the Boston Medical Center, the Spaulding Rehabilitation Hospital, 10Blade, Inc., Boston University School of Management, the AID-N, Johns Hopkins Applied Physics Laboratory and the Intel Digital Health Advanced Technology Group.

This project aims to explore applications of wireless sensor network technology to a range of medical applications that include the real-time, continuous patient monitoring in pre-hospital, in-hospital emergency care, disaster response and stroke patient rehabilitation. In this kind of scenarios, it turns possible the replacement of expensive and cumbersome wired telemetry systems. In a home monitoring scenario, for chronic and elderly patients, data are periodically or continuously collected and sent to physicians. The records of the biosensors readings are then associated with other information regarding the patient, and properly organized in a database which can be assessed by the healthcare professionals at any time.

The CodeBlue project emerges with the objective of develop small, battery-powered wireless sensors organized in a network that permits the physiological data gathering and computation. The data are then submitted to real-time electronic triage before being stored. Immediate alerts of changes in patient status can be emitted based on the patient records. The system is particularly useful when mass casualty events happen with a large number of patients needing care delivery from the emergency personnel.

Architecture

The CodeBlue system includes a wearable wireless pulse oxymeter and a 2-lead ECG based on the Mica2, MicaZ and Telos sensor nodes platforms and a specialized motion analysis sensor board [3]. The pulse oxymeter measures the heart rate and blood oxygen saturation. The ECG continuous monitoring is performed by measuring the differential signal across a single pair of electrodes. The ECG signal is typically sampled at a frequency of 120 kHz. The Mercury motion analysis sensor board incorporates a 2g/6g 3 axis accelerometer, a single axis gyroscope and one EMG unit. The accelerometer and gyroscope are sampled at a frequency of 100 Hz while the EMG is sampled at 1 kHz. In addition to monitoring patient's vital signs, CodeBlue also integrates an RF-based localization system, called Mote-Track, to track the location of patients and caregivers.



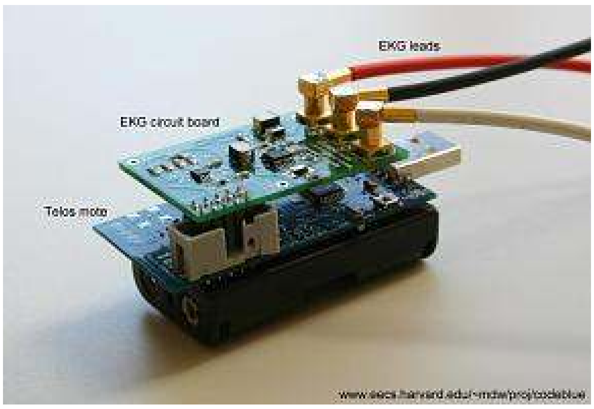


Figure 1 - Wireless pulse oxymeter sensor (left image) and wireless 2-lead ECG (right image) - The pulse oxymeter is based on the Mica2 platform, a mote module used for enabling low-power, wireless sensor networks. The wireless ECG, on the other hand is based on the Telos platform, an ultra-low power wireless module for use in sensor networks. [3]

The vital signs sensors consist of a low-power microcontroller and low-power digital spread spectrum radio. They communicate over IEEE 802.15.4/ZigBee in a short-range wireless network (approximately 100m) to any number of receiving devices that can be PDA's of the EMTs, computers or ambulance-based terminals in which the information is integrated through the *iRevive* technology. The devices have a RAM memory of 4-10KB and can be programmed with the TinyOS operating system to perform the sampling, transmission, filtering or processing of the vital signs data.

The system starts to make the measurements once the motes are attached to the patient for collect the vital signs data. The sensors have the capability of locally filter, compress or analyze data to reduce radio congestion. The data are sent to the final receiver through multicast routing. The transmission of critical data is made according to a prioritization based on the information content. CodeBlue is based on a publish/subscribe model for data delivery. The sensor nodes publish the vital signs measurements while the EMT subscribe to access data of interest. CodeBlue supports a flexible security model which guarantees a proper authentication of the EMTs when trying to access the patients' data.

Limitations

A number of limitations have been identified in the CodeBlue project. Related with the computational power of the sensors nodes, the current mote processors run with a processing speed lower than 10 MIPS so the processing of information can't be made in real-time. Furthermore, the small amount of memory (4-10kB) of the devices isn't enough to store significant data.

Additionally, communication problems have been reported. The 802.15.4/ZigBee radios are now available at 250Kbps but, as a matter of fact, it is not clear how much bandwidth is available to applications and the maximum transmission rate obtained is 80kB. This value conditions the communication leading to the congestion of the data traffic. At last, the existing wireless networks doesn't provide for prioritized traffic of information, which is critical for the pretended application.

Finally, the patients' mobility is conferred by the system powering with 2AA batteries. The maximum battery lifetime obtained is of 5-6 days when the system was continuously running [4].

3.2.2 Lifeguard

The Lifeguard system has been developed by the NASA Amestrobionics and the Standford National Biocomputation Center for monitoring the health of astronauts during space flight and extravehicular activities but also to monitor their performance and physical conditions during exercise routines.

The Lifeguard system, that initially has been created for the specific explorers' safety monitoring, has reveal itself to be very suitable for other applications that include the vital signs monitoring of patients during transfer to the hospital and data transmission from the accident scene to an emergency room physician. The patient status can already be known by the doctor at the time of the patient arrival at the healthcare unit. Another useful application of the Lifeguard system consists of the vital signs monitoring of fire-fighters and hazardous material workers. In the case of some abnormal physiological condition being detected during their activity, the subject may be substituted. The system can even be used for sleep disorders, heart diseases or other unsteady conditions diagnosis of patients at home or in a healthcare unit.

Architecture

Lifeguard is a wearable wireless physiological monitoring system that consists of a small unit called the Crew Physiological Observation Device (CPOD) [5] responsible for the collection and storage or wireless transmission of the gathered data. The biosensors that achieve the measurements are attached to the CPOD.

The biosensors are disposed on the body and the following physiological signs are tracked: a two-channel ECG, the diastolic and systolic blood pressure, the temperature of the patient skin but also the surrounding temperature. The system also monitors the blood oxygen saturation with a pulse oxymeter and using three tiny accelerometers, it tracks the 3-axis acceleration activity of the patient.

The CPOD unit is a compact, portable, wearable device that the subject must wear around the waist. The device is responsible for the signal acquisition with the sensors attached to it, conditioning and storage of the collected data. The CPOD can record the physiological parameters up to 9 hours in a flash memory after the device has been turned on and can download saved or real-time data to a computer based station through a standard RS232 connection. Alternatively, the CPOD can send data wirelessly, in real-time to some other device. The transmission is effectuated via one of the two following wireless technologies: Bluetooth or the 916 MHz FSK.

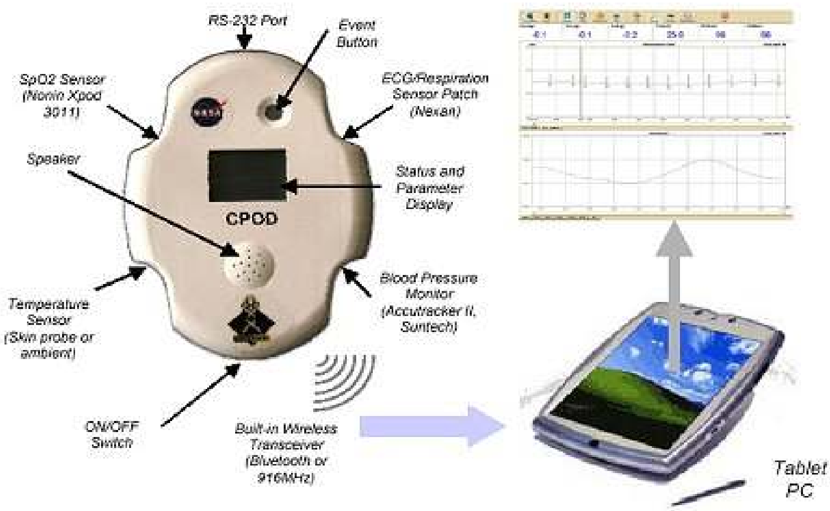


Figure 2 - Basic features of the CPOD - The sites of attachment of the sensors with the device are represented. The gathered data are then sent wirelessly or through the RS232 port to a tablet PC where all the information can be visualized. [6]

The access to the CPOD required the previous installation of the Lifeguard System software on a Tablet PC and the wired or wireless connection of this unit with the CPOD. The

Lifeguard System can only accept one connection at a time so the device can't be accessed by multiple people at the same time.

Limitations

With respect to the wireless communications, the Bluetooth and 916 MHz FSK wireless technologies do not provide the quick transfer of data to doctors. The farthest distance of wireless connection to the CPOD is 33 meters and need to be increased for the remote transfer of information.

In addition, there is a lack of security measures when trying to consult data. An authentication mechanism has not yet been implemented. Furthermore, there is a lack of protection against the possibility of data interception. A secure encrypted connection will at least prevent the data reading even in the case of their illegal interception.

The system is also being review in order to turn it much smaller and more rugged for its wearability and reliability improvement.

3.2.3 Mobihealth

The Mobihealth project has been started on May 2002 at the University of Twente where it has been concluded on February 2004 [7]. The project has been funded by the European Commission and regroups 14 partners that represent all the relevant disciplines. The project has been developed under Mr Rainer Herzog coordination and Dr. Val Jones and Prof. Dr. Ing. Dimitri Konstantas scientific supervision [8].

Mobihealth aims at developing and trialing a system that allows patients to be fully mobile whilst undergoing health monitoring. It responds to the growing patients' need for mobility and personalized care [9]. The potential areas of application are the remote assistance and monitoring of patients in a home-care setting, the monitoring of chronically ill patients, the remote assistance in case of accidents and emergencies, the remote physical state monitoring in sports and even the remote management of clinical trials.

Architecture

The Mobihealth System consists of a wireless BAN [10] that allows the simple connection of different vital sign sensors that continuously measure the patient's physiological data. The devices that compose the BAN also perform communication via a central controlling device, the Mobile Base Unit (MBU) through which the vital signs measurements along with audio and video are sent to a remote healthcare location over wireless telephony services.

Communication between sensors, actuators and other multimedia devices integrated in the BAN and the MBU are referred as intra-BAN communication. It can be made wirelessly or through wires. Extra-BAN communications happens when the BAN communicates with other networks. For intra-BAN communications, the system uses the Bluetooth technology (IEEE

802.15) but also allows ZigBee (IEEE 802.15.4). For extra-BAN communications, the system is equipped with GPRS and/or UMTS communication capabilities.

The BAN enables a high degree of personalization with respect to the vital signs being measured. Sensors that can be connected to the Mobihealth system are the ECG, the EMG, a respiration sensor, an activity/movement/position sensor, a pulse-oxymeter that gives the blood oxygen saturation value, plethysmographic waveform and heart rate, a temperature sensor, blood glucose and cholesterol sensors or even a skin-pigmentation sensor.

A generic BAN software platform that provides functionality for plug-and-play sensor connectivity and that handles all issues related to security, Quality of Service (QoS) and handover has been developed. The *BANware* can be supported by hardware platforms such as programmable mobile phones and PDAs.

Physical measurements of the patient are obtained by the sensors and transmitted wirelessly from the central unit of the BAN to the healthcare unit or directly to his doctor.

Limitations

The main objective of the Mobihealth project is to test the ability of 2.5 and 3G communications technologies to support innovative mobile health services [10]. Trials were conducted in 4 European countries and were finalized in March 2004. Some issues and problems were identified for example in the areas of communications and technology infrastructures.

The 2.5 and 3G technologies suffer from limited bandwidth for applications that serves multiple users. The UMTS network does not enable the establishment of high uplinks and downlinks for variable and fixed data rate transmissions. When a user is silent for a couple of seconds and then requests the transmission or reception of a high volume of data, his request is not immediately satisfied. The data are buffered and the system risks their loss due to buffer overflow. The uplinks delays in the UMTS network increase linearly with the size of data packets. This delay - jitter - leads to the data buffering in order to compensate the jitter. Once again, the system risks the data loss.

The trials showed that continuous monitoring of vital signs generates approximately 10MB of data per day per user. This fact is at the origin of some preoccupation related to the actual communication costs.

With regard to the ambulatory monitoring scenario, some biosignals appear to be severely affected by movement artefacts and the system is still too cumbersome principally because of its power requirements.

Finally, the bandwidth limitation for the intra-BAN communication that arises from the limited bandwidth of the Bluetooth interface is also a relevant concern [11].

3.2.4 Cardguard

Cardguard is a Swiss company that works on the development of healthcare technologies and solutions. Cardguard specialize in the telehealth systems and monitoring services for high risk and chronically ill patients.

The newest wireless healthcare system developed by the company, the PMP4, makes possible the screening, monitoring and the management of general consumer health, disease management and fitness [12]. It enables the patient to monitor health parameters of interest and to interact with physicians by utilizing cellular and broad-band TV technologies, dedicated web-based software and medical monitors [13].

Architecture

The PMP4 system includes multiple handheld clients, medical monitors and a central server. Each monitor measures and wirelessly sends the results to a handheld device where they can be visualized. The information is sent in real-time to the central server via a wireless network, including cellular (SDIO, GSM-GPRS, CDMA, PDS-PHS) or Wi-Fi [12]. This transmission is made via secure transmission protocols. Once at the web-based medical centre, data are submitted to analysis, follow-up and storing in the physicians' database. The electronic medical records are accessible from any browser. The stored information includes tests results, patient's symptoms and notes, and physicians' notes and diagnosis.

The medical monitoring equipment is composed by a 1 and 12-Lead ECG, a spirometer, blood glucose meter, blood pressure monitor, pulse oxymeter, weighing scales and a body fat analyser.

The PMP4 medical line of monitors is described below and shown in figure 3.

- **SelfCheck ECG** – Cardiac symptoms and pathologies monitoring. Auto-diagnosis. Data transmission is realized via Bluetooth.
- **SelfCheck BP** – Wireless non-invasive blood pressure and pulse rate measurement system. Auto-diagnosis. Data transmission is realized via Bluetooth.
- **BP Pro** - Wireless non-invasive blood pressure and pulse rate measurement system. Same features as the SelfCheck BP but not destined to the auto-diagnosis.
- **SelfCheck Gluco** – Blood glucose meter housed in a miniature SDIO component. Blood samples of 1.5 - 3μL.
- **Oxy Pro** – Real-time measurement of the oxygen saturation levels in the blood and pulse rate. Continuous monitoring. Data transmission is realized via Bluetooth.
- **Spiro Pro** – Wireless spirometer for Asthma monitoring, pulmonary and chronic obstructive pulmonary disease symptoms. Volume vs. Time and Flow vs. Volume curves obtainment. Continuous data transmission is realized via Bluetooth.

- **SelfCheck Scale** – Automatic turn on when stepping on the scale. Self calibration. Data transmission is realized via Bluetooth.

Figure 3 - The Card Guard's PMP4 wireless medical monitors - Each monitor accurately measures and wirelessly sends the results to a handheld device. The results are sent in real-time to the PMP4 web-based medical centre. [12]

Both physicians and patients benefits from the PMP4 system. The patient's health status can be monitored anywhere he is and at anytime. He can have an immediate contact with his medical caregiver whenever he needs it. A personal web page is attributed to the patient so he can view his physiological measurements and introduce other subjective information or symptoms that may be relevant for his doctor.

Physicians, on the other hand, receive a secure patient data base with all the medical files and tests results. The access to patients' data is immediate and all information transactions are paperless.

The patient-physicians communication is obviously enhanced so do the patient involvement in his own health management.

Limitations

The PMP4 system developed by the Cardguard Company presents some inconvenient.

The system is not portable. In fact, it does not enable the continuous assessment to the patient under active conditions that is, while he proceeds with its usual daily life. The system appears to be more oriented to the remote medical consultation than to the continuous monitoring of physiological parameters.

3.2.5 Ericsson Mobile Health

Ericsson Mobile Health is a mobile service developed by Ericsson in order to be use in a wide range of medical situations like the remote monitoring of chronically ill patients. In that way, prolonged stay in the healthcare unit and constants displacements to the last one becomes unnecessary. In fact, the Ericsson Mobile Health system propitiates the direct contact between patients and caregivers, maintained at all times. The patients' quality-of-life is considerably improved and at the same time, the care organizations benefits of care costs reduction. Another medical situation for which the referred solution appears to be very suitable is for example after the patient internment in the hospital, for the remote assistance and monitoring in a home-care environment. It also enables an increased efficiency through remote diagnosis and assistance when accidents or emergencies occur. At last, the Ericsson Mobile Health may also be used for the remote management of clinical trials of medicines for example. The evolution of the trials and obtained results can then be submitted to a massive and rapid analysis.

Architecture

The Ericsson Mobile Health architecture can be described as a BAN that integrates the sensors chose according to the patient's particular needs. The sensors available are the ECG 1 or 3 lead, the pulse oxymeter and capnography, body weight scales, the blood pressure meter, the Peak Expiratory Flow (PEF) meter, a coagulation monitor and finally, the glucometer for diabetic patients monitoring. Sets of sensors are regrouped forming different units that are released according to the targeted diseases and monitoring scenarios. Each sensor transmits information wirelessly to a communication module, making use of the Bluetooth technology.

The communication module, Ericsson Ellen or Ericsson P910 receives data that have been measured by the sensors and send them over GPRS/UMTS to a central server. Additional subjective diary data that the patient may consider important can also be sent together with the physiologic measurements.

Once the patients' data have been collected, they can be consulted by the authorized medical personnel through a web server. All the information is treated with security and confidentiality. Ericsson developed an application to visualize the patients' vital signs record as graphic representations, the physiologic parameters evolution, the patient history and other subjective information that could have been previously introduced. The healthcare providers may use the information to provide real-time care, define different alarm levels and even intervene in potentially critical situations.

Limitations

The Ericsson Mobile Health however evidences a few limitations. First of all, continuous communications can't be supported for a long time due to the limited battery supply of the communication module that must support two different kinds of communication technologies. The patient's mobility is consequently restricted by the limited power supply of the system. Furthermore, there is a time delay between the signals acquisition and visualization. In fact, the data visualization isn't really made in real-time.

3.2.6 Care Trends Wireless Bridge

The care Trends Wireless Bridge system has been developed by Sensitron, a wireless healthcare innovations company.

The care Trends system is used to collect vital signs data at the point of care and wirelessly transfer them together with other clinical data to the medical record. It enables the immediate access to the patient's vital signs data from the medical staff. The automated data capture permits avoiding possible errors in data transcription and transmission and the reduction in paperwork.

The care Trends system supports various applications for hospitals, clinics, nursing facilities and long term care home [14]. It allows the patient care improvement while reducing the staggering cost of healthcare.

Architecture

The present system includes 3 main units. The first reunites the wirelessly-enabled vital signs monitoring devices. The second one is a PCU and an access point represents the third one.

The manual and automatic vital signs being measured are the blood pressure, the temperature, the weight, the pulse, the SpO_2, the respiration rate, the glucose levels and the pain. The Sensitron application modules (SAMs) are equipped with a Bluetooth card, which uses the IEEE 802.15.1 protocol, embedded software and the appropriate hardware for the measured data transfer. Moreover, the 802.11b communication protocol can also be used for data transmission. Vital sign monitors are enabled with SAMs.

The PCU manages the test sequence and communications. The caregiver can through it select patients that need to be monitored and manually selects the vital signs he wants to monitor and consequently decides the sensors that must be disposed on the patient. The patients' results can then be viewed in real-time on the PCU. By combining the vital signs data with other clinical records, the healthcare provider can respond more quickly to abnormal situations that may occur related to the physiological condition of the patient. Data are collected by the Sensitron's enterprise software in the server where they are recorded in the patient clinical history. All data are transmitted via secure encryption. The healthcare provider can consult data simply resorting to a PDA.

Limitations

The care Trends wireless bridge system is more convenient for the vital signs monitoring in a hospital scenario. The caregiver selects the vital signs to monitor and data are captured at the patient bedside. Although it can be used for the long term care home, it has not been created with the purpose of enhance the patient mobility that is the patient can't proceed with its usual daily activity whilst undergoing health monitoring.

3.2.7 Sensium

Toumaz Technology Limited is a spin-off from Imperial College London that invests in the development of ultra-low power wireless infrastructures for body monitoring solutions.

The Toumaz Sensium is an ultra-low power sensor interface and transceiver platform that enables the connection between the mobile individual and the healthcare providers. It is very suitable for a wide range of applications in healthcare and lifestyle management. The physiological parameters monitoring of patients can be done at their own home, at the hospital or at the ICU. It also can be used for the physical activity monitoring.

The objective of the Sensium technology was the creation of a system that enables sensors' data collection, intelligent local processing and wireless transmission of vital signs and other health status information. The relevant information is reported to a base-station Sensium plugged into a PDA or Smartphone and then submitted to filtering and processing by application software.

Architecture

The Sensium system is based on the AMX™ (Advanced Mixed Signal Silicon Devices) technology that emerges from the development of signal processing techniques and wireless systems with ultra-low power consumption.

The system architecture can be split into 3 units. The first unit is composed by the target stations, which are the wearable sensor nodes that support the sensors (digital plasters disposed on the patient) that monitor the physiological signals of interest. Data can be generated at rates up to 50kbps. The Sensium enables the monitoring of the following physiological parameters: ECG, temperature, blood glucose and oxygen levels. Other sensors also are integrated in the system namely 3-axis accelerometers, pressure sensors and on-chip or on an external sensor temperature monitor.

A mixture of analogue and digital processing embedded on the chip to select the more relevant data and send them via Bluetooth to the base station, the second unit of the system, is integrated on the device. Before being transmitted, the gathered signals are submitted to local processing enabled by an on-chip program and data memory integration. Once the relevant information has been isolated, it is sent resorting to the RF transceiver included on the device.

As referred above, the base-station constitutes the second unit of the Sensium system. It can link up to 8 target stations. Data are transmitted to a SD card or a USB module. The SD card is used together with a PDA or smartphone running Windows Mobile 5. Received data are processed and displayed on the device screen. Critical events occurrence are detected by specific algorithms.

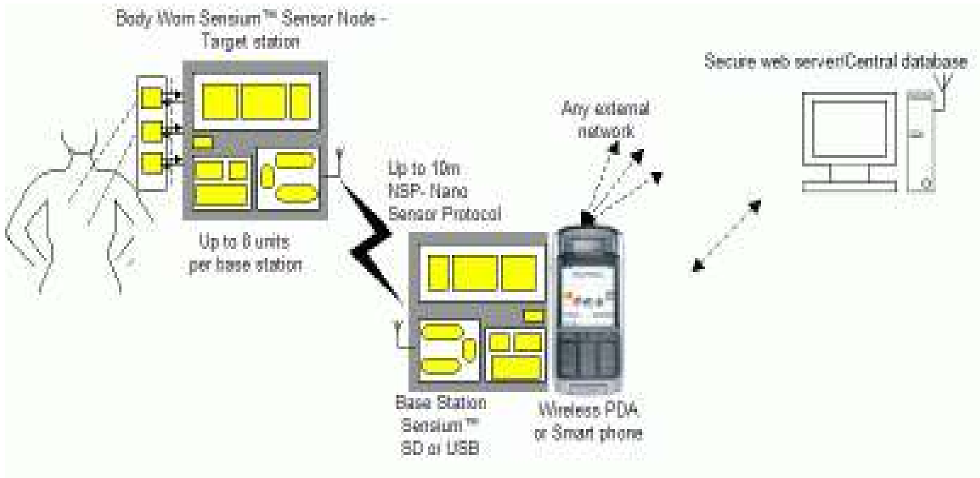


Figure 4 - Sensium system architecture for wireless body monitoring - The system can be represent split into 3 units: the target station, the base station to which measured data are sent and a central database where data are organized and stored. [15]

Once the patient's data become available on a secure web server, the third unit, the healthcare providers can consult them and focus on the important issues. Real-time feedback can be provided to the patient. The Sensium technology thus enables non-intrusive continuous monitoring of the health status of patients without conditioning their freedom of movement.

3.2.8 Lifeshirt

The Vivometrics company is composed by a team of biomedical and software engineers that worked on the biosensors adaptation for ambulatory use until the creation of the Lifeshirt system.

The Lifeshirt system is an ambulatory vest, lightweight, machine washable with embedded sensors to continuously monitor the patient vital signs. The physiological data are provided in real-time to commanders that can then make proper decisions concerning the subject being monitored. Vivometrics Lifeshirt technology enables to monitor more physiologic data in more scenarios. These scenarios allows for example the monitoring of an athlete physical condition during practice, pharmaceutical researchers to monitor the effect of drugs on subjects or even to prevent the exhaustion conditions of first responders and biohazard workers.

Architecture

The Lifeshirt system is used to collect and store cardiac, respiratory, posture, activity and emotional measures. The data collection is made with a shirt that integrates a set of sensors:

- Inductive plesthymography sensors to accurately measure the ambulatory respiratory volume. This technology is the more efficient for the detection of both obstructive sleep apnoea and central sleep apnoea;
- Accelerometer placed on the abdomen to record body posture and physical activity of the subject;
- 3 electrodes directly placed onto the subject's skin record the ECG and pulse rate;

- Other peripheral diagnostic devices may be optionally integrated in the system: pulse oxymeter for the SpO_2 measurement, temperature sensor that records the skin and internal temperatures, blood pressure meter and capnometer. Subject weight, EEG, cough, end tidal CO_2 and periodic leg movement also may be monitored.

All sensors are attached trough wires to a battery-powered module, a PDA. The PDA, worn on the patient belt or carried in a pocket, contains a flash memory card where data are stored after being encrypted. They can be processed locally using VivoLogic Software on a desktop PC or be sent to the VivoMetrics data centre. The Lifeshirt software enables thresholds establishment for each physiologic parameter. Every time a threshold is read, an alert is emitted. The system also offers the advantage of correlating the objective data with subjective ones including symptoms, types of activities and medications that may have been introduced by the patient or its health caregiver. Data accumulated on the flash memory are wirelessly transmitted to the remote monitoring station via a RAELink2 Modem and AreaRAE Network or can be sent by post directly to the Vivometrics centre. The information quality is then reviewed by physiologists and physicians prior to its distribution to clinical investigators or to the patient's physicians.

Limitations

Although the Lifeshirt system seems to be very complete, a few points of its architecture can be ameliorated. For example, as referred above, the system has all the sensors connected to the PDA via wires. This fact can become cumbersome for the patient depending on the kind of activity he is maintaining.

Data can be stored in the flash memory and are not read until it is sent to Vivometrics base-station. The communication with the physicians in this case is not made in real-time.

3.2.9 Vital Jacket

Developed by the Institute of Electronics and Telematics Engineering (IEETA) of the University of Aveiro, The Vital Jacket is a waistcoat that brings together textile technology and microelectronics [16].

A set of sensors are integrated in the waistcoat to monitor some physiologic parameters of interest. The system may be used in different kind of scenarios:

- **Telecardio** – monitoring of hypertension patients or with cardiac problems;
- **Telecover** – monitoring of patients which have been submitted to surgical intervention.

In both situations, the vital signs monitoring can be achieved at the hospital or at home. Benefits for both patients and medical staff are evident regarding to their mobility but also for the patient monitoring comfort. Furthermore, it enables the healthcare organizations to free human and physical resources.

Architecture

The vital signs that can be monitor with the Vital Jacket are the cardiac signals, the temperature, oxygen saturation in the blood and the physical activity. Some sensors have been entirely developed by the IEETA while others have been adapted to the system exigencies and purpose from sensors already available on the market.

The available documentation regard the system does not clearly explain the technical details of its functioning. Basically, the gathered data are wirelessly transmitted to a PDA incorporated in the waistcoat and are continuously being analysed trough electronic and computer systems also developed by the IEETA. The information after being placed on Internet can be accessed by healthcare professionals responsible for the patient health management.

The Vital Jacket was conceived with the paradigm of the “House of the Future” in a way that it may be complemented with other “home monitoring” systems that may be interconnected. This system can be used together with an arterial blood pressure meter, a scale or even an automatic supplier of medicines, for example.

Figure 5 - The Vital Jacket - The system consists of a waistcoat in which the biosensors are integrated (left image). Data are wirelessly sent to a PDA for visualization and analysis (centre and right images). [17]

3.3 Advantages of the pretended solution

Almost all the systems above described present some limitations. As the objective of the project is the development of a remotely vital signs monitoring system, features lacking in the other systems should be identified in order to turn possible the emerging of a new advantageous telemedicine solution.

Many systems are not sufficiently ergonomic to provide the patient the desired mobility. The excessive quantity of wires doesn’t enable the total freedom of movement that will be expected. The ideal solution would present a reduced quantity of wires where each sensor would have a transceiver for data transmission via wireless.

In addition, many systems still need to be review in order to improve their portability. The concept of portability implies the use of batteries to supply the devices that monitor the patient's vital signs. The batteries actually available on the market don't enable the development of miniaturized devices. The power supply requirements namely for a system that must continuously be reading data and wirelessly sending them to other devices, implies the use of batteries that still are too large. New advantageous solutions are emerging in the field of energy storage. The Lithium-ion batteries for example can bring some advantages to the monitoring system compared to the common rechargeable batteries (AA, AAA types for example). In summary, the lithium batteries can be smaller, have a higher voltage and hold a charge much longer than other types of batteries. Progressive advances in the referred field are expected to improve considerably the portability of systems for the remotely vital signs monitoring.

As referred above, some solutions for the pretended application have their functioning based on the continuous monitoring of the vital signs. However, despite the fact that physiologic measurements are continuously being done, data often are stored in a memory integrated in the device instead of being immediately sent to a database centre from which their access should be enabled in a secure way. As a consequence, the real-time concept is not preserved. The patient's health status can't be known at every time by the healthcare provider. Instead, the system becomes more like a "black box" where the patient's data are recorded. Another similar situation where the real-time continuous monitoring concept is not preserved happens with systems that are more adapted for medical consultation. The measurements are made and visualized at the same time but only during appointments with the healthcare professional. The patient does not benefit of the continuous control of his health condition.

The remote transfer of data suffers from communication limitations. Almost all the described solutions presented in the State of the Art make use of the Bluetooth technology. This technology is evidently advantageous but can restrict the speed of data transfer depending mainly on the data packets size. Furthermore, the wireless technology used in the various systems has considerable power consumptions which report us again to the portability and power requirements issues previously considered.

Finally, security mechanisms for the data access are sometimes lacking. Data must properly be encrypted before being sent. Illegal interception of the data packets is possible and the encryption may impede the interceptor to read the message. Once they are received, data should be decrypted and after being available on a web based server, their access must be restricted. Only the patient's caregiver can be authorized to access them and modify or add information to the patient report. This condition can be guarantee by the simple attribution of usernames and passwords to the healthcare professionals.

This project aims the development of a system for the remote monitoring of patients' vital signs. It seems obvious that the described limitations must be exceeded in order to create a new valid solution for the pretended applications that include the continuous health monitoring at hospital and also in a home scenario, that is, for tele-homecare.

The monitoring system will include a set of sensors attached to the patient that will continuously read his physiologic signals. The sensors' readings will be immediately sent to an acquisition module to which they are connected through wires or in which they are integrated depending on the type of sensor. The acquisition module will be attached to the patient's belt so the wires' extension will not be cumbersome for the subject. The collected data will then be sent to a second module, the transmission module via Bluetooth or ZigBee. The use of the ZigBee technology is doubtless advantageous. ZigBee was created to address the market need for a cost-effective, standards-based wireless networking solutions that supports low data-rates, low-power consumption, security and reliability. The data transmission can be made using this new technology that will increase the autonomy of the system which is indispensable for the subject's mobility. The acquisition module is equipped with a RAM memory that will impede the loss of information in case of no network coverage.

The transmission module, on the other hand, must also support the same communication technology as the acquisition module in order to establish the connection for data transfer. It must be placed in proximity to the patient bearing in mind the Bluetooth and ZigBee range but doesn't need to be attached to the patient. He can thus move freely while data are being acquired and transmitted via wireless. The transmission module will then send the measurements via GSM/GPRS or Wi-Fi to a web-based server. Data can also be downloaded from the transmission module to a PC through a standard USB connection. Thus the system can incorporate a wide variety of communication technologies. In every way, data are transferred and processed in real-time. All the information must then be available to the healthcare provider that only needs a PC and an Internet connection to see the data. Introducing the correct username and password, his access will be accepted and he may consult his patient's vital signs data for diagnosis or other purposes.

Regarding the system's hardware development, it consisted on the projection of both the acquisition and transmission modules. The above specified communication technologies had to be implemented to guarantee the correct data transfer. The devices' design was made bearing in mind the power consumption requirements but also the necessary requisites to obtain a system sufficiently ergonomic and portable to enable the mobility of the patient whilst undergoing healthcare monitoring.

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CHAPTER IV: SYSTEM ARCHITECTURE

4.1 Project Requirements

In this chapter, the definition of the monitoring system architecture is made. Initially, the project requirements are specified. The two main monitoring scenarios are described in detail for the better definition of the requirements the new system must complete. The set of sensors chosen for the vital signs monitoring is described, so are the communication technologies that it will support as it has been explained in the previous chapter.

Finally, the present chapter is concluded with the full description of both the acquisition and transmission modules, i.e. the way how they are internally organized and what are the operations they must perform that lead to this organization.

4.1.1 Vital Signs Monitoring Scenarios

The vital signs monitoring system to be developed has been thought for two application scenarios: at hospital and for home monitoring.

The first objective pretended to be reached was the system implementation in the healthcare unit. During the course of the project progress, the system has been submitted to many changes regard its architecture. The actual system architecture can be implemented in both hospital and home ambient.

4.1.1.1 At Hospital

The implementation of the remotely vital signs monitoring system in the healthcare unit was the first objective pretended to be reached.

Many medical actions in the healthcare unit like surgical operations, anaesthesia or patients transfer are conditioned by the excessive presence of cables that attach the patient to the monitoring equipment [18]. The high cost of this same monitoring equipment goes against the global healthcare organization need for reducing costs. Healthcare providers required frequent access to relevant information about their patients' status. This few examples of the healthcare issues together with those already mentioned in the project problem analysis can be eliminated with the new monitoring system.

During the first phase of definition of the system architecture, the hospital scenario was considered as a set of rooms in which each patient would be continuously submitted to his vital signs monitoring. In each room the patients' sensors would be endowed with the Wi-Fi or ZigBee technology and making use of one of the two solutions, they would send the gathered data to a concentrator module placed at the corridor extremity. The selected technology has to be extremely reliable and the sensors' power consumption should be low. Because data transmission via Wi-Fi or ZigBee can only span a limited distance before the quality of the signal degrades, various repeaters should be placed along the corridor to preserve the signal integrity and extend the distance over which data safely travel, that is until they reach the concentrator module. Each transceiver that emits the patient vital signs data would represent a node of a mesh network that would include all the active nodes present in the floor. A mesh network is a LAN in which if one node can no longer operate, all the others can still communicate with each other, directly or through one or more intermediate nodes.

The system architecture and implementation in the hospital has then been reviewed and it was opted for the proximity between the patient and the concentrator module, now called the transmission module. This option was based on the project team decision to create a unique solution compatible for both hospital and home monitoring scenarios.

The patient is submitted to his signs monitoring. Measured data are collected in the acquisition module. This same one sends data to the patient's transmission module via Bluetooth or ZigBee. The transmission module must enable the information transmission to a terminal unit localized in the hospital installations. So, data gathered from each transmission module are concentrated in the nursing central responsible for a particular unit in which patients are interned. Patient's mobility is thus improved. He benefits of continuous biomedical monitoring regardless of his location in the hospital, including while he is reposing in his room and while he is moving in the rest of the hospital installations.

A study realized by the INE and the *Agência para a Sociedade do Conhecimento* (UMIC) regard the use of Information and Communication Technologies (ICTs) in the officials and particular hospitals of Portugal in 2006 reveals that 33.8% of them have the Wireless LAN solution implemented in their installations [19]. In order to verify the technology used in the Portuguese's healthcare units, a large number of public and private hospitals have been contacted by the project team students. The results of this research are presented in appendix A. Analysing the received answers it was clear that hospitals in which any type of wireless network is supported have the Wi-Fi technology implemented in it. Some healthcare units are entirely covered while others only have the referred technology integrated in some sections of the unit. In many of them, the integration covers the internment services and the perspective of the expansion of the network coverage to larger areas of the unit seems eminent. This data support the idea of the transmission module communication via Wi-Fi. In this manner, the system can be integrated in the Wi-Fi networks already existents in the healthcare units. In the contrary case, the system also supports transmission via GSM/GPRS even if it is not the more indicated for the present scenario.

As already mentioned data are sent to and concentrated in the nursing central where they can be visualized. With one monitor and the appropriate software, the healthcare professional should be able of sequentially see every patient's received data. Alerts will be generated whenever a critical situation is detected or even due to a simple abnormality in some patient record. Different levels of alarms can be defined depending on the seriousness of the events. The alarm levels must be defined by the healthcare professionals. Whenever an alarm occurs, the patient's caregiver will be immediately informed and can then take the appropriate measures regard the patient's care delivery.

4.1.1.2 At Home

The fusion of technology with telecommunications in a new wireless vital signs monitoring system can support the cost-effective delivery of healthcare and promote health maintenance at the patients' home. The tele-homecare appears as the new solution for quick patients' physiologic data diagnosis. It offers many advantages such as the vital signs data quantity and quality improvement but also the use of diagnosis software that can automatically analyse the patients' collected data. This form of remote treatment implies the beneficial diminution of displacements to the healthcare unit and above all, considerably increases the patients' mobility and autonomy. On the other hand, it implies some alterations in the healthcare organizations. Healthcare providers may have a heavier workload during the initial phase of the tele-homecare solution implementation [20].

The wireless monitoring system developed for the present project will enable the patient's monitoring at his own home. The acquisition module works as for the hospital scenario. Sensors attached to the patient measure the signals that are directed to the acquisition module. It may then send data to the transmission module that must enable their transfer to a remote data centre. The transmission module does not need to be constantly carried by the patient, but only must be sufficiently close to the acquisition module in order to enable the Bluetooth or ZigBee connection. Data must be available in healthcare units that can be located many kilometres away from the patient's home. The physiological signals must be sent whether the patient is at home or in displacement during his normal daily routine, for example on his way to his workplace. This implies the use of a wireless technology with a wide range and a large territorial coverage extension for data transfer. Data rate supported by the selected communication technology must be sufficient for the pretended application. Three communication technologies have been initially considered in order to be implemented in the monitoring system: GSM GPRS, GSM EDGE and UMTS.

Based on these requirements but above all, on the network coverage available in the Portuguese territory, the GSM GPRS technology was the preferred for data transmission. Many zones of the country have no UMTS network coverage especially rural regions. The EDGE technology as a GSM network enhancement that provides up to three times the data capacity of GPRS, can be overlaid directly onto an existing GSM network. As the GPRS data rate seems to be adequate for the monitoring solution, there is no need to appeal for the EDGE technology. The gathered vital signs data are emitted by the transmission module via GSM GPRS to the database centre where they will be processed and analysed for any anomalous event immediate detection.

Referring again to the INE and UMIC study regard the use of ICTs in the hospitals of Portugal in 2006, 97.5% of the inquired hospitals appear to have recourse to internet connections. Among them, 22.8% support at least one telemedicine activity. Tele-diagnosis and tele-consultation seems to be the most carried-out in this domain. In fact, 20.7% and 15% of the inquired hospitals have adopted one of the two solutions, respectively [19]. Those data came as a support for the development of the pretended tele-homecare solution.

Returning back to the system functioning in a home scenario, the information after being sent to the data centre, being processed and analysed by appropriate softwares for signals irregularities detection, is placed in the patient's history and can be consulted by his respective health caregiver. The patient can thus proceed as usual with his life while critical events and life threatening variations are ensured to be detected in time and communicated to his healthcare provider.

4.1.2 Medical Monitoring Equipment

This section introduces the vital signs that the system will monitor. Because they are the indicators of the general physical conditions of the human being, it may be interesting to understand the relevance of the physiological parameters that will be measured.

Initially, only the ECG, the blood oxygen saturation and the temperature where considered to be read by the monitoring solution. Later, it was decided to also integrate a 3-axis accelerometer in the system so the patient's movements and posture could be known too.

4.1.2.1 ECG

The ECG consists of a representation of the heart's electrical activity recorded from electrodes on the body surface. It is produced by the electrocardiograph and used for the evaluation of whether the heart is functioning properly or suffering from any abnormality that may be associated to a cardiovascular disease. Nowadays, 40% of the Portuguese die because of cardiovascular diseases [21].

The heart function of pumping blood through the circulatory system is the result of a sequence of electrical events that origins the action potentials responsible for the mechanical heart movements. Electrodes disposed on the patient skin at specific positions (chest, arms and legs) work as transducers converting ionic flow from the body through an electrolyte into electron current that is, to an electric potential that will then be measured by the ECG system front-end [22].

The 12-lead ECG record can be obtained using as many as 12 electrodes. The term lead refers to the positioning of the two electrodes being used to detect the electrical activity of the heart. The third electrode is use as a neutral. Each lead serves to see a part of the heart in more detail. The 12-lead ECG is obtained through the positioning of the electrodes on the limbs of the patient and across his chest and enable the detection of a wide range of abnormalities including arrhythmias, myocardial ischemia, left ventricular hypertrophy and pericarditis. The unipolar leads refer to the augmented and chest leads that have a single recording electrode and make use of a combination of the other to obtain the cardiac signal. On the other hand, the standard limb leads refer to bipolar leads that are obtained measuring the electrical potential between a single positive and a single negative electrode. There are three bipolar leads that together form the so-called Einthoven triangle (Left side of figure 6) in honour of Willem Einthoven who developed ECG in 1901. Lead II is the most commonly used providing a significant rhythm problem diagnosis tool.

The typical ECG tracing is represented on the right side of figure 6.

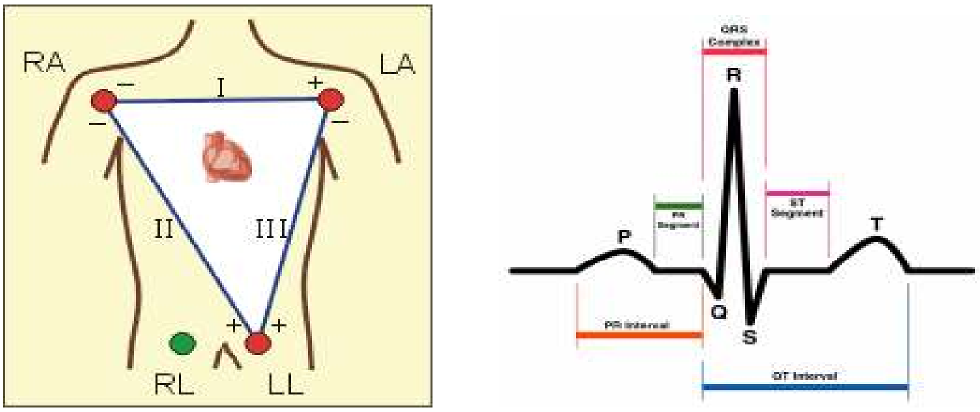

Figure 6 - Einthoven's triangle (left).Typical ECG tracing with waves, segments and intervals labelled (right) -The P wave represents the wave of depolarization that spreads from the sinoatrial node throughout the atria that contracts to pump out the blood. The QRS complex represents the right and left ventricular depolarization. The ST segment is the isoelectric period during which the entire ventricle is depolarized and corresponds to the plateau phase of the ventricular action potential. The T wave indicates the resting period of the ventricles, during their repolarization. [23]

The ECG is also one of the most precise methods of heart rate measurement that normally is about 70b.p.m. in human adults' males.

The lead to be used in the first prototype of the monitoring system is the lead I in which the potential difference between the positive electrode on the left arm and the negative one on the right arm is measured. The signal coming from the right leg is used as the reference electrode.

4.1.2.2 Pulse Oxymeter

The pulse oximetry is a useful method for the non-invasive indication of a patient's cardio-respiratory status. It serves to determine the arterial blood oxygen saturation of the haemoglobin molecule that is the amount of oxygen bound to each haemoglobin molecule. This measurement is made with recourse to a pulse oxymeter whose operation is based on two principles [24].

The first principle state that the absorption of light at two different wavelengths by haemoglobin differs depending on the haemoglobin degree of oxygenation. For the pulse oximetry measurement, red and infra-red light absorption characteristics of oxygenated and deoxygenated haemoglobin are analysed. The red light is in the 600-750nm wavelength band while the infrared light is in the 850-1000nm wavelength band. Using a light emitter with red and infrared LEDs and a photodetector that receives the transmitted light, the blood oxygen saturation can be determined. The light emitter is placed on a side of the tissue and shines the two beams of light through it. The transmitted light is then collected by the photodetector that must be placed on the opposite side of the same tissue. The measured site must be translucent enough to let the beam pass through it and also needs to have a good blood flow. The most common sites used are the fingers, toe and lobe of the ear. Once the photoreceptor has received the red (R) and infrared (IR) signals, the ratio R/IR is calculated and then converted to a SpO_2 value. Healthy young persons have a SpO_2 value of approximately 95-99% [24].

The second principle on which this physiological parameter measurement is based is the pulsatile component of the light signal following the transmission of the beams through the measuring site, which arises from the changing volume of arterial blood with each pulse beat. As a consequence, the pulse oximetry also enables the determination of the patient's pulse rate in b.p.m. averaged over 5 to 20 seconds.

Some limitations can affect the measurements like for example the light ambient, movements like the patient's shivering, abnormal haemoglobins or vasoconstriction and cardiac functions [24].

4.1.2.3 Temperature probe

The temperature is considered a vital sign because it reflects the condition of the internal physiological processes of the human body. The normal body temperature ranges from 36.5ºC to 37.2ºC. The body temperature is taken with a thermometer or temperature probe. It can be obtained in four ways: orally, rectally, axillary or by ear. When taken by ear, a special thermometer quickly measures the temperature of the ear drum. The measured value reflects the body's core temperature that is, the temperature of the internal organs.

The human's body temperature can be affected by many factors that include illness, hydration, infection but also the environment or even the different phases of the menstrual cycle for women. The age of a person may also affect the results. In fact, age alters the body's ability to regulate temperature and as a consequence the older adults may not have a fever with infection. These are only a few examples of what can condition the temperature measurement.

An elevated temperature is known as fever or hyperthermia. Fever generally indicates that some process is happening abnormally within the body. This condition can be due to infection or hyperglycaemia for example. On the other hand, a low temperature is known as hypothermia and may suggest the occurrence of blood loss, anaemia, narcotic use or hypovolemia that is, an abnormally decreased volume of blood circulating in the body.

In the case of the pretended vital signs monitoring system, the temperature is included in the set of vital parameters to be measured. The continuous monitoring will be done having recourse to a skin temperature probe that uses the skin as an indicator of body temperature.

4.1.2.4 Accelerometer

Falls in the aged community is one of the reasons that support the integration of an accelerometer in the system in order to monitor patient movements and possibly prevent falls. The sensor can be used to directly measure gait patterns, fall characteristics, the level of general activity and postural sway. The daily activity profile of the patient can be obtained indicating when lying, sitting, standing and walking.

The 3-axis accelerometer has the ability of simultaneously detect acceleration in three axial directions: X, Y, Z. This kind of sensors are employed to measure accelerations, vibrations and the inclination that is, the acceleration due to gravity. By sensing the amount of dynamic acceleration, one can analyse the way the device is moving. In the present case of the vital signs monitoring system implementation, as the 3-axis accelerometer is integrated on the acquisition module board, attaching the module to the patient's chest, the patient respiration rate and body posture can be known.

4.1.3 Communication Technologies

Nowadays, the fast development of wireless technologies and the increase in communication bandwidth enable the development of new telemedical solutions that may give the patient an increased autonomy.

The choice of the communication technologies to be used for data transfer had to be done keeping in mind some key considerations as the amount of data to be transfer, the security requirements, power consumption, radio frequency, interference and the distance over which data must be transmitted. The amount of data the system needs to send can be evaluated considering the frequency range of each of the physiologic signals and is presented in table 5.

Physiological parameter	Number of samples per second (samples/s)	Nº of bits per sample (bit/sample)	Bit rate
ECG	100	8	**800 bit/s**
SpO_2	0.2	8	**1.6 bit/s**
Temperature	0.2	10	**2 bit/s**
Movement, posture	20 (per axis)	8	**480 bit/s**
		Total bit rate	**1283.6 bit/s** (160.45 B/s)

Table 5 - Determination of the physiological signals bit rates - Bit rates are calculated using the sampling frequency of each signal and the quantity of bits generated for each sample.

Actually, four categories of wireless networks can be defined according to the distance over which data can be transmitted:

- **Wireless personal area network**, **WPAN –** Personal network with short range of approximately ten meters that enables wireless ad-hoc communication between devices centered on an individual person's workspace.
- **Wireless Local Area Network, WLAN –** Network in which a mobile user can connect to a local area network through a wireless connection. The WLAN are similar to the WPAN but enable medium range communications.
- **Wireless Metropolitan Area Network, WMAN –** This type of network enables users to establish wireless connections between various locations in a same metropolitan area.
- **Wireless Wide Area Network, WWAN** – Geographically dispersed telecommunication network used for communication over an entire city, country or even over the all world.

Among the wireless technologies actually available, the Bluetooth and ZigBee technologies has been selected to establish the connection between the acquisition and transmission modules, the Wi-Fi technology in a local WLAN network within the healthcare unit and GSM GPRS connection for the data transfer over large WWAN networks. Even if the selected technologies are satisfactory regard the key considerations above mentioned, some particular limitations can appear like intermittent connectivity, communication interruptions and inherent delay of the information transfer and data rates variations which may result in the data packets accumulation with buffering. Data loss because of the overflow must be avoided.

In the next section, the referred technologies will be introduced to the reader.

4.1.3.1 Bluetooth

Bluetooth is likely to be one of the most popular technologies for WPANs [25] typically used in handheld battery-powered devices enabling short-range, low-power connectivity for the transfer of voice, images and data. This communication technology was intended to replace the cables connecting portable and/or fixed devices while keeping high security levels.

The Bluetooth technology enables electronic devices to connect and communicate wirelessly, establishing ad-hoc networks known as piconets which are formed automatically and dynamically as soon as Bluetooth devices have radio proximity. The sensor network can only start to transfer data after a self assembly phase during which the connections are established. Each piconet formed is composed of one master and up to seven slaves that only can start transmission after being contacted by the master.

Bluetooth is a communication technology based on spread spectrum transmission [26]. It operates in the unlicensed industrial, Scientific and Medical band at 2.4 to 2.485 GHz. Its spread spectrum operation implies that sensors nodes within communication range use separate channels to transmit data. The communication is based on adaptive frequency hopping that takes advantage of the available frequency. The device ready to send data detects other devices in the spectrum and avoids the frequency they are using. It may then choose another channel to transmit its own data packets. This operation mode confers Bluetooth based sensor networks resilience to interference. In fact, one of the advantages this technology offers is a high degree of interference immunity thus enabling greater performances when transmitting data. Bluetooth technology also has built-in security such as 128 bit encryption and PIN code authentication.

Three classes have been defined according to the signal power and range:

- Class 1 radios – Up to one meter range;
- Class 2 radios – Up to ten meters range. Commonly used with mobile devices;
- Class 3 radios – Up to one hundred meters range. More required for industrial cases.

The power consumption of the Bluetooth technology also appears to be advantageous, being very low. Devices using class 2 radios require 2.5mW of power. When the communication mode is inactive, the transceiver chip integrated in the device can be powered down thus enabling an enhanced reduction of power consumption. Otherwise, this solution allows the transmission of moderate amounts of data. Versions 1.1 and 1.2 enable data rates up to 723.1Kbps while version 2.0 as an enhanced data rate version, have data rates up to 2.1 Mbps.

All the referred features are today available on small size and low cost chipset solutions that once implemented in handheld devices enable the data transfer through Bluetooth connection without the need of line of sight positioning of the interconnected devices.

4.1.3.2 ZigBee

The ZigBee technology appears to be very suitable for applications where low power and low cost are major concerns. Its development started in 2001 and has been promoted by the ZigBee Alliance. The initial targeted markets areas were the residential home control, commercial building control and industrial plant management. Progressively, many other areas of application have been explored by ZigBee companies like personal healthcare, telecom services and consumer electronics or simply for PCs and peripherals.

ZigBee is a wireless standard based on 802.15.4 that incorporates the network, security and application layers for low data rate WPAN standard. According to the frequency band that best fits a certain application, the designer can choose between the 2.4 GHz and sub-GHz frequency bands. The frequency bands used by the ZigBee technology are depicted together with their corresponding geographic areas of operation and data rates for data transmission, in table 6.

Frequency Band	Geographic Region	Data Rate	Channel Number(s)
868.3 MHz	Europe	20kbps	0
902-928 MHz	Americas	40kbps	1-10
2405-2480 MHz	Worldwide	250kbps	11-26

Table 6 - Characteristics of the ZigBee technology - The focused characteristics are the frequency band and geographic region of operation, data rates for data transmission and the number of channels enabled.

Depending on the frequency band being used, data rates change. The ZigBee solution is more directed to applications that are typically low duty cycle and low data rate.

Some key features must be considered when viewing the ZigBee technology. The first one is its robustness. Like the Bluetooth technology, ZigBee uses spread spectrum technologies to avoid multipath fading which improves signal immunity in the case of radio interferences presence. The device that communicates via ZigBee pick the best channel for transferring data, avoiding other wireless networks such as Wi-Fi. It thus ensures a reliable solution in noisy environments. The second particularity of this technology that should be referred is the secure way it enables data transfer. It disposes of multiple levels of security to ensure that data and network remain intact and secure. At the lower level, it provides Advanced Encryption Standard. On the top of that, ZigBee defines a security toolbox for key generation and distribution. Acknowledgements messages are sent whenever a communication has been established to guarantee that messages have been received at their final destination.

Another feature characteristic of the ZigBee technology is its ability to provide several networks topologies that include star, cluster and mesh networks. The networks form by themselves and can integrate up to 65535 nodes and continue to operate with relatively low latencies. This technology is a short range solution that enables communications range from 10 up to 75 meters. Mesh networking can extend the range of the network through routing.

The most important feature that distinguishes this recent technology from others is its low power consumption requirements. Furthermore, 802.15.4 radios have the capability to turn-off and power-on whenever ZigBee connections need to be established. In this manner, its power consumption is even more reduced. Devices only need 30 ms to return to their active status, ready to transmit data.

Some limitations may affect the communications via ZigBee and still need to be avoided like the presence of interferences due to its coexistence with other 2.4 GHz systems or the decrease range especially for indoor applications.

Bluetooth and ZigBee technologies present a set of common characteristics. However, some particular features may turn one of the two more suitable depending on the application in which short range communication is required. For example, Bluetooth technology uses the 2.4 GHz frequency band while the ZigBee technology uses 2.4 GHz and sub-GHz frequency bands so ZigBee offers a major flexibility in the choice of the frequency band that best fits some application. Additionally, Bluetooth operation is based on point-to-point connectivity and consequently doesn't provide a robust networking solution for many targeted applications. In rebuttal, ZigBee technology offers a variety of routing algorithms: hierarchical tree, neighbour and table-based routing, and a high degree of network flexibility and stability. Both the technologies provide full security approaches as it has already been referred in the previous sections of the present document.

The more important difference between them is power consumption. Even if both are considered low power consumption technologies, ZigBee power consumption is considerably lower than that of Bluetooth [18]. The integration of ZigBee technology in the vital signs monitoring system thus turns it advantageous when compared with the already existent that are almost exclusively based on Bluetooth technology. As the devices are battery-powered, the recourse to ZigBee technology may enable a longer autonomy.

4.1.3.3 Wi-Fi

The IEEE802.11 is an international standard that has been developed for WLANs and WWANs. The Wi-Fi term is derived from the term Wireless Fidelity. A Wi-Fi network is a network that responds to the 802.11 standard. This kind of network enables to connect any type of peripherals on a WLAN. The range in a Wi-Fi network can vary depending on the type of Radio being used, the type of antennas and whether the network is in a building or office with lots of walls, where the range can vary between 25 and 50 meters approximately or in open environment where it can have a range up to 305 meters.

As a matter of fact, the IEEE802.11 is the initial standard that provides data rates up to 1 or 2 Mbps. It has been submitted to successive revisions in order to optimized data rates, improve security and ameliorate interoperability. From the revisions, the following set of standards was created (only the most relevant are listed):

- **802.11.a** – Enables high data rates up to 54 Mbps (effective speed: 30 Mbps). Up to eight communication channels can be used in the 5 GHz frequency band.
- **802.11.b** – This is the actually more used. Data rates can reach 11 Mbps (effective speed: 6 Mbps). Considering an open environment, its range can be of up to 300 meters. Three communications channels are provided over the 2.4 GHz frequency band.
- **802.11.d** – Internationalization. It enables the connection to WLANs at the international level.
- **802.11.e** – Service quality enhancement regarding the data link layer. This standard aims the definition of the packets needs regarding bandwidth and transmission delays in order to improve voice and video transmission.
- **802.11.f** – Roaming. It proposes the Inter-Access-Point Roaming Protocol to enable users to change their access point in a transparent manner when travelling.

- **802.11.g** – Uses the 2.4 GHz frequency band and offers data rates up to 54 Mbps (effective speed: 30 Mbps).
- **802.11.h** – It appears for the purpose of turning the 802.11 standard conform to European Standard (HiperLAN2). The conformity regards frequency and energy savings concerns.
- **802.11.i** – It comes to improve the transmission security. It is based on the AES encryption.

In order to enable the establishment of a Wi-Fi wireless network, equipments such as wireless adapters or access points are necessary. If the network operates in infrastructure mode, the wireless clients connect to an access point. On the other hand, if operating in Ad-Hoc mode, the wireless clients connect one to each other without the need of access points.

Regarding the transmission techniques, the 802.11 standard have defined the following ones to limit problems related to interferences: the Frequency Hopping Spread Spectrum, the Direct Sequence Spread Spectrum and the use of infrared light. For the first one, the frequency bandwidth is divided into 75 channels. The transmission is made through successive emissions on a channel and then on another one during a short time interval. The second technique, the DSSS, basically consists of the transmission of a Baker sequence to spread the data before it is transmitted. Each bit is modulated by an eleven bit sequence (pseudo-random noise).

At a security level, it is hard to confine the transmission waves into a restricted perimeter. This behaviour may make easy the intrusion in the network and confidential data interception by non authorized persons. Whoever is under the network coverage area may be able to access all the communications being held on the network.

To face these security levels limitations, namely regard the confidentiality of the transmitted information on wireless networks, the 802.11 standard integrates a simple mechanism to cipher data, the Wired Equivalent Privacy. Unfortunately, it is not sufficient to guarantee data confidentiality. If a very high level of security is necessary, it is preferable to install a virtual private network in which data ciphering is higher.

4.1.3.4 GSM/GPRS

The GPRS standard appears from the evolution of the GSM standard and is also referred as the 2.5G technology as it has been designed to move 2G (GSM standard) networks closer to the performance of 3G (UMTS standard) networks. It has been developed to be implemented in WWAN networks.

The 2.5G technology is a mobile data standard available to users of the GSM communication. Data are sent by packets with data rates up to 171.2 Kbit/s (effective speed up to 114 Kbit/s). The transmission is made with multiple users sharing the same transmission channel and only transmitting when they have data packets to send. Using GPRS, the network connection is always in an active state. Unlike data communication via traditional circuit switching that is billed per minute of connection time, with GPRS, the bill is made according to the quantity of data packets that has been transferred.

The GPRS proposes to access data networks making use of the IP but also supports X.25, a packet-based protocol that is used mainly in Europe.

With the GPRS standard, GSM data services have been upgraded and many new services became available:

- Multimedia Messaging Service (MMS);
- Point-to-point service: any person can connect in a client/server mode to a device that makes part of an IP network;
- Point-to-Multipoint service: it enables to send a data packet to multiple receivers (Multicast);
- Short Message Services (SMS);
- Wireless Application Protocol (WAP) access: intranet applications for smart devices;
- Internet communication services such as email and World Wide Web access.

It may be important to refer that the GPRS standard has not been projected to be used exclusively on mobile networks based on the GSM standard but also those which are based on the IS-136 TDMA (Time Division Multiple Access).

The GPRS architecture simply consists of the GPRS integration in the GSM architecture and requires new GPRS support nodes to be added on the backbone. The Serving GPRS Support Node (SGSN) is a router that enables the management of all the surrounding terminals coordinates and makes the interface between the packets traffic and the gateway GPRS Support Node (GGSN). The GGSN must furnish an IP address to each mobile terminal during all its connection to the GPRS network.

Regarding the security of the GPRS standard, four channels encoding schemas are defined and each one stated the level of the packet protection against interferences. Depending on the channel encoding schema being used, transfer speed varies. The higher is the packets protection, the slower is the data rate of the packets transfer. The four channel encoding schemas are presented in table 7.

Encoding Schemas	Data Rate	Protection
CS-1	9.05 Kbit/s	Normal
CS-2	13.4 Kbit/s	Lightly lower
CS-3	15.6 Kbit/s	Low
CS-4	21.4 Kbit/s	No error correction

Table 7 - Data rates and protection level of each of the four GPRS encoding schemas

The GPRS standard integrates the Quality of Service (QoS) notion which means that it is able to adapt the service to the particular needs of an application. The QoS criteria are the priority, reliability, the delay and throughput.

4.2 Acquisition Module

The acquisition module is responsible for the vital signs data collection. Sensors attached via wire to the acquisition module are placed directly over the patient and continuously measure his physiologic parameters and transmit them to the acquisition module to which they are attached. The vital signs of interest are the ECG, the pulse oximetry, the temperature and the movements/posture of the patient. For this purpose, the acquisition module has been organized as shown in figure 7.

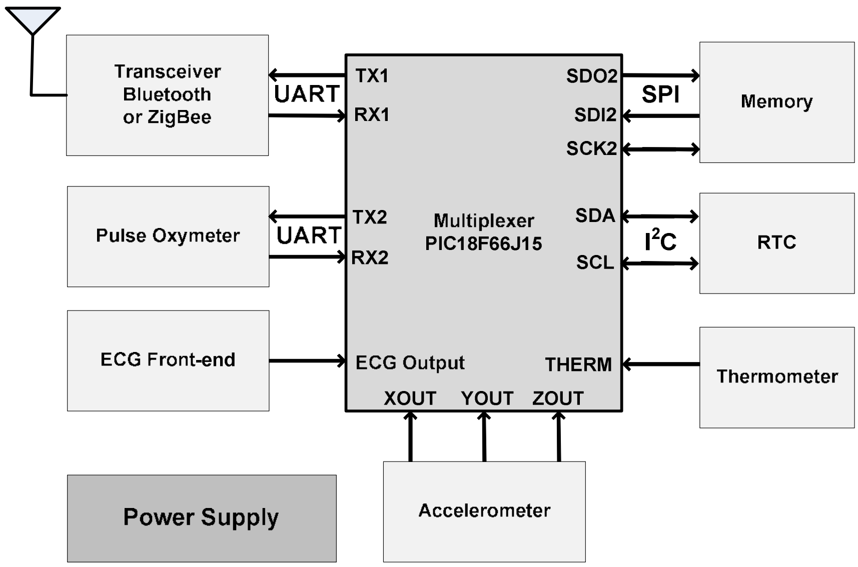

Figure 7 - Block diagram of the acquisition module - The sensors blocks are presented so do the memory and RTC. The communication modes between the microcontroller and surrounding devices are evidenced. Data transfer implicates the integration of a transceiver on the module.

The acquisition module comprises an embedded microcontroller, a transceiver to enable communication with the transmission module to which the gathered data must be sent, a 64 Kbit ferroelectric non volatile RAM memory for data retention in the case of no network coverage for example, a RTC and the front-ends of each physiologic sensor. Both the memory and RTC use one of the two MSSP modules supported by the microcontroller to exchange data with it. The memory communicates using the Serial Peripheral Interface (SPI). On the other hand, the RTC communicates via the Inter Integrated Circuit (I^2C) mode.

The ECG sensor consists of 3 electrodes disposed on the patient: one on each shoulder and the third one is the reference signal obtained on its right leg. The measured signals are treated on the ECG front-end integrated on the acquisition module board. The resulting signal is directed to one of the microcontroller's analog input.

The pulse oxymeter is used on the patient's finger, and like the ECG sensor, it is attached to the acquisition module through a wire. They are tied through a standard RS232. The acquired signal reaches the acquisition module already in a digital format. Data enters the microcontroller resorting to one of the two Enhanced Universal Synchronous Asynchronous Receiver Transmitter (EUSART) serial modules.

The temperature probe is attached to the patient's skin whose temperature is then continuously measured and sent to the module through a unique wire. Like the ECG, the signal is directed to an analog input of the microcontroller.

At last, the accelerometer consists of a device directly integrated on the acquisition module board, from where all its measurements are made. The 3 analogue signals obtained that correspond to the acceleration in the 3 axial directions X, Y, Z, also need to entry the microcontroller through analog inputs to be processed soon after.

The most important particularity of the acquisition module is its flexibility regarding the way data are transferred to the transmission module. On the board, 2 connectors enable the integration of one of two communication modules: Bluetooth module or ZigBee module. Depending on the type of application, the more convenient communication technology is chosen and the corresponding module is plugged-in on the principal board to enable data transfer. Independently of the selected technology for data transmission, the transceiver communication with the microcontroller is made via the second enhanced USART serial module available on the latter.

As this module must be continuously carried by the patient, it must be battery-powered to respect one of the principal purposes of this project development that is, to enable the patient's mobility. The first version of the acquisition module has thus been thought to be powered with two generic AA batteries.

4.3 Transmission Module

The transmission module is responsible for the reception of data coming from the acquisition module and their re-transmission to the proper destination. This proper destination can refer to a Web Based Server from which data can be easily consulted by healthcare professionals, to the nursing central of a section in a healthcare unit when the monitoring scenario is at hospital or even the simply data download to a PC. This module must consequently support two different kinds of communication technologies. The transmission module architecture is outlined in figure 8.

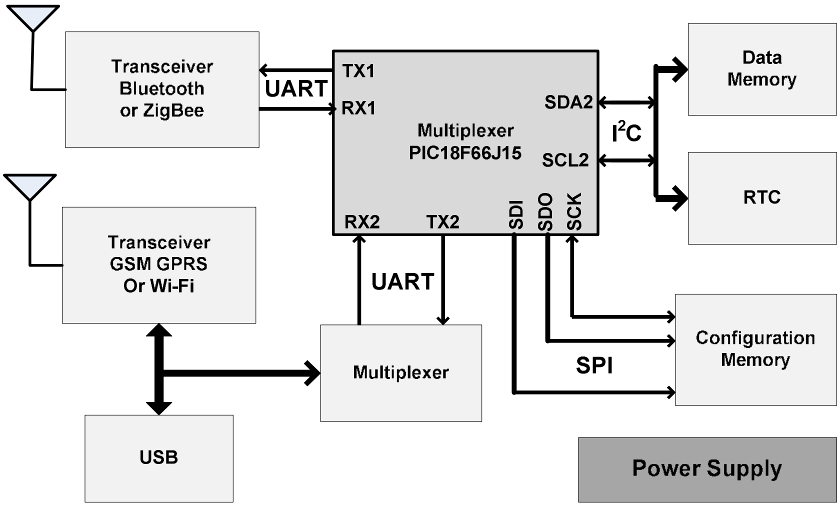

Figure 8 - Block diagram of the transmission module - The transmission module operation is enabled by the integration of transceivers, a RTC and memories surrounding the microcontroller. Data download can be made via wireless or through a standard USB connection. This alternative is enabled by the use of a multiplexer. Other devices with secondary functions also are present on the module but are not represented here.

The transmission module receives data coming from the acquisition module. For this purpose, logically, he must support the same communication technology as the acquisition module. The transmission module possesses 2 connectors on which one of the two communication modules referred in the previous section can be fitted. This mechanism of changing the communication technology module, in the present case choosing between the ZigBee and Bluetooth modules, is referred as plug-and-play. The transceiver communication with the microcontroller is made using one of the two enhanced USART serial modules of which the PIC18F66J15 disposes.

Once data have been integrated into the microcontroller, they must be sent once more to become available to healthcare professionals. Data can be downloaded whether via wireless or through a standard USB connection. In both cases, the communication with the microcontroller is made through its second enhanced USART serial module. The multiplexer makes the connection between the microcontroller, the wireless transceiver and the USB interface. As the transmission module has been created to be continuously sending data via wireless, the system has been organized in a way that this wireless communication suspension happens only if the establishment of a USB connection has been detected. In the contrary case, wireless data transmission is made whether via Wi-Fi (more probable in the hospital scenario) or via GSM GPRS in a home monitoring scenario for example. Once again, the plug-and-play mechanism has been adopted and the user can thus choose between two communication modules: the GSM GPRS module and the Wi-Fi module.

Concerning the memories integrated on the transmission module board, a 64 Kbit ferroelectric non-volatile memory is used for the storage of configuration instructions.It communicates with the microcontroller through I^2C interface that it shares with the RTC. On the other hand, data storage is enabled by the integration of a serial-interface Flash memory endowed of 4 Mbits of memory capacity. This last memory communicates with the microcontroller through SPI interface. As referred in the section regard the acquisition module, the data memory can be extremely useful above all if there is no net coverage. Data can thus be stored in the memory, and as soon as the connection becomes available again, data accumulated are sent to their final destination.

Regarding the power supply of the present module, once it has not been conceived to be continuously carried by the patient but rather should be disposed anywhere in his proximity, it can be directly tied to the domestic current. The module comes equipped with a rechargeable Li-ion battery. In that way, whenever the patient wants to go out, he only needs to carry the transmission module with him during its outing and beneficiates of the autonomy that the battery confers to him.

Both the acquisition and transmission module have been briefly presented in the previous sections. On both the boards that have been created for these two modules, other peripheral devices have been integrated. For instance a temperature sensor can monitor the internal temperature of the module or even LEDs that are used to signal the acquisition or transmission module status.

The terminal unit is not explored in this document. As the student had the responsibility to develop the system at a hardware level, that only regards the acquisition and transmission module. He chose not to focus on this part of the system and only briefly remember the basic operations that may be carried after data re-transmission from the transmission module. As it has already been told, data are subsequently processed, alarms can be generated according to the seriousness of some abnormal situation regarding some patient. Database histories relative to each patient are automatically created and the information after being received and processed is placed in the proper file. It becomes then available to the healthcare provider that can alter patient's history for example if he considers some kind of subjective information potentially relevant regards the patient health status.

CHAPTER V: HARDWARE DESIGN

This chapter provides an overview of the hardware as well as a description of the circuits designed for the project. It describes the practical work that has been developed by the student during the project progress. The student task was the development of the transmission and acquisition modules as well as those that enable the wireless communications of the entire system, at a hardware level. All parts of each module are described with the objective of elucidate the reader regard the decisions that have been took and the arguments on which the work evolution has been founded.

The chapter is organized in two major sections: one referring to the modules schematics design and the second one describes the printed circuits board layout design.

For the complete schematics and PCB Layout designs, please refer to Appendix B.

5.1 Schematics Design

The system schematics have been designed having recourse to the Orcad Capture software. The ORCAD Capture is a software tool part of the ORCAD circuit design suite that enables designers to create and manage circuit schematics. The student initially had to learn how to use this software and what features are available in it. The technical supervisor gave the student explanations and instructions for common tasks fulfilling using ORCAD Capture and conducted the discussions that lead to the definition of the final circuits that should support all the pretended features of the monitoring system.

5.1.1 Acquisition Module

The acquisition module project design is organized into 6 schematic design documents: the power supply schematic, the vital signs sensors front-ends organized into 2 schematic documents, the central processing unit schematic which central component is the microcontroller, a schematic document which include the RTC and memory circuits design and the sixth one called input/output in which the connectors that are the point of connection with the communication modules are represented.

Each schematic design document is next described in detail.

5.1.1.1 Power Supply

The acquisition module must be battery-powered to confer mobility to the patient being monitored.

Initially, it has been decided to use 2 AAA batteries in series to power the module. A search of boxes available on the market and which features satisfied the requirements which have been proposed for the acquisition module leads to the rethinking of which batteries should be more appropriate. The pretended box should have dimensions acceptable for such a system and above all, integrates a battery compartment. The search reveals that most of the enclosures are not fit for the use of AAA batteries. As strict limitations regard the module size and weight were not imposed for the first prototype, the option of use 2 AA batteries instead of 2 AAA batteries was considered and later approved.

The acquisition module is powered with two typical rechargeable NiMH type AA batteries. Each battery has a nominal voltage of 1.2V and a capacity of 2000mAh. If the two batteries are joined together in series, the resultant battery presents a capacity still of 2000mAh and as the voltage is additive, the resulting voltage is 2.4V. The series connection simply consists in connecting the positive lead from one battery holder to the negative lead of the second holder.

All devices that are included in the acquisition module operate at 3.3V. A step-up converter that develops 3.3V from the two AA batteries is thus needed. The requirements that seem essentials when choosing a convenient step-up for the application were:

- Low power consumption: logically, less power consumption leads to longer battery life-time;
- Low noise: eliminate disturbances will make the physiological measured signals more reliable;
- Pulse Width Modulation (PWM): this method works with a fixed frequency so it is easy to filter the signal. On the contrary, FPM (Frequency Pulse Modulation) is a method of pulse modulation based on the variation of the frequency which turns its filtering more difficult;
- Good efficiency.

The LTC3526B-2 step-up from Linear Technology was chosen as it completes all the previously referred requirements. A switching step-up regulator (boost regulator) is used to convert a lower voltage to a higher voltage. The basic components of the boost switching circuit are shown in figure 9.

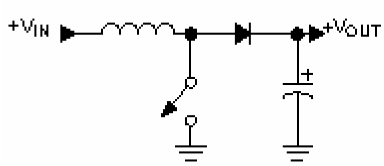

Figure 9 - Simple boost converter. [27]

When the switch is closed, the input voltage $+V_{IN}$ is applied to the inductor. The current through the inductor rises linearly as the magnetic field builds-up according to the equation:

$$\frac{dI}{dt} = \frac{V_{IN}}{L}$$

Where I is the current across the inductor, V_{IN} is the input voltage, L the inductance value and t is the time. During the time the switch remains closed, energy is being stored in the inductor. The basic concept on which the step-up operation is based consists in transferring the stored energy into the output capacitor once the switch has been opened. In fact, once the switch is open again, the discharge phase begins. The energy is no longer transferred to the inductor which leads to the magnetic field collapse forcing the inductor current to charge the output capacitor and thus the output voltage rises. The diode presence prevents the capacitor from discharging to ground when the switch is closed again. For applications where the output voltage is below 10V, manufacturers recommend the use of Schottky diodes for their minimum forward voltage drop and fast recovery time characteristics.

Now regarding the step-up used for the power-circuit of the acquisition module, the LTC3526B-2/LTC3526-2 has the ability to star-up and operate from inputs less than 1V and up to 5V and presents an output voltage range of 1.6V to 5.25V. The LTC3526-2 features burst mode operation at light-load conditions while the LTC3526B-2 features continuous switching. The LTC3526B-2 has been selected because it performs low-noise PWM operation and its continuous switching is made with a fixed frequency which turns easier the filtering of the signal. It has a good efficiency of up to 94%, is housed is a 6-pin DFN package and appears to be well suited for medical instruments applications. The high efficiency here means less power drain on the input source and less heat build-up around the regulator.

Typical applications are described in the LTC3526B-2 datasheet. One of them corresponds exactly to the present situation: the use of the step-up to convert the two cells powering to 3.3V voltage. The power supply schematic design has been almost completely based on the example that is presented in figure 10. The component connections and values have been chosen according to the standard proposed by Linear Technology.

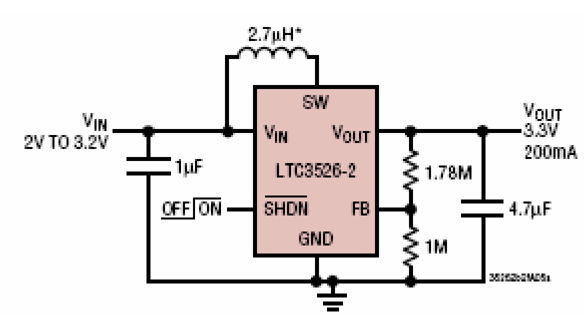

Figure 10 - LTC3526B-2 typical application: 2-cell to 3.3V. [28]

The two resistors control the feedback loop, setting the output voltage. At the V_{OUT} pin of the step-up, the 3.3V voltage becomes available for the powering of the entire acquisition module and communication modules fitted on it.

The power-supply schematic design also includes a power LED that is used to indicate the power supply status of the system board. The LED is connected to and controlled by the microcontroller that after receiving power, acts on the power LED to turn it on. A red LED has been chosen to indicate the power supply status.

5.1.1.2 Central Processing Unit

The Microchip PIC18F66J15 microcontroller has been selected to be employed as the coordinator of all different parts of the acquisition module. It belongs to a low voltage devices family that enables high computational performance and a rich feature set suitable for applications in which high performance and costs are relevant concerns.

The PIC18F66J15 microcontroller has be chosen because of its core features that make it suitable for the pretended application:

- NanoWatt Technology - power consumption during operation can be significantly reduced for example using power managed modes such as Alternate Run Modes in which the controller can be clocked by either timer1 or by the internal RC oscillator enabling power consumption reduction during code execution, Multiple Idle Modes in which peripherals can be maintained active while the CPU core is disabled or also the On-the-Fly Mode Switching for power managed mode evocation by the user code during operation;
- Flexible oscillator structure – five different oscillator modes;
- Program memory – PIC18F66J15 provides 96KB of readable, writable and erasable flash program memory;
- Data memory – Implemented as static RAM, allowing up to 3936 bytes of data;
- Communications – The device incorporates a range of serial communication peripherals, including 2 independent Enhanced USARTs modules that supports RS-485, RS-232 and LIN1.2 and 2 MSSP modules, capable of both 3-wire SPI and I^2C Master and Slave modes;
- 10-bit, 11 input channels Analog-to-Digital Converter module;
- 7 bidirectional ports;
- 11 analog inputs;
- 64-pin TFQP package.

PIC18F66J15 supports an operating voltage range of 2.0V to 3.6V which enables its operation at 3.3V in the present circuit. The use of bypass capacitors helps filter the electrical noise out of the circuit. In this design, a pair of filter capacitors, one of 1uF and the other of 100nF, disposed in parallel is used for each power supply pin of the microcontroller. As no separate supply is used, the analogue and digital supplies must be connected through an RC filter to improve noise filtering. All the decoupling capacitors used are depicted in figure 11.

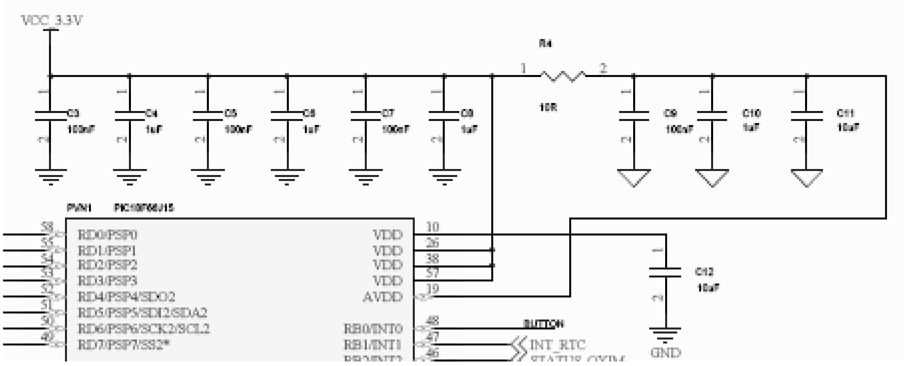

Figure 11 - Decoupling capacitors associated to the microcontroller power supply pins - A pair of capacitors is used for each V_{DD} and AV_{DD} pin. To make the connection between the analogue and the digital power supplies, an RC filter has been applied.

An important feature of the PIC18F66J15 is that it powers its core digital logic at a nominal 2.5V. In the present case, the device operates at a higher voltage, more precisely 3.3V but has the advantage of incorporate an on-chip regulator that allows it to run its core logic from V_{DD}. To enable the regulator, the configuration of pins ENVREG and V_{DDCORE}/V_{CAP} shown in figure 12 has to be adopted.

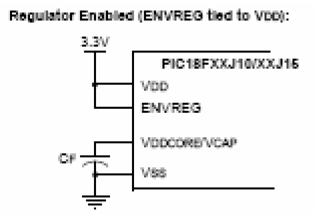

Figure 12 - Connections for the on-chip regulator enabled. [29]

The ENVREG pin controls the regulator and should be tied to V_{DD}. This connection provides power to the core from the other V_{DD} pins. Additionally, a low ESR filter capacitor of 10uF has been connected to the V_{DDCORE} / V_{CAP} pin helping to maintain the stability of the regulator.

Regarding the oscillator configurations, 2 external oscillators have been selected to be associated to the microcontroller. In High-Speed Oscillator mode, a 7.3728MHz crystal is connected to the OSC1 and OSC2 pins to establish oscillation and is used together with 2 capacitors of 22pF, each tied to one of the referred pin. The second crystal is a 32.768 KHz watch crystal and is connected between T1OSO and T1OSI (pins 29 and 30). Loading capacitors of 33pF are also connected from each pin to ground. This oscillator is a low-power circuit that continues to run during all power-managed modes.

A reset circuit had to be introduced in the schematic to guarantee that the PIC18F66J15 remains in a reset status whenever V_{DD} is below a certain value. For this purpose, the external power-on-reset circuit showed in figure 13 has been tied to the MCLR pin of the microcontroller. Reset is generated by holding the MCLR low.

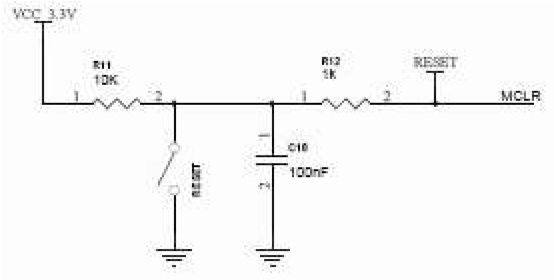

Figure 13 - External power-on-reset circuit
The circuit tied to the PIC through a 1KΩ resistor that will limit any current flowing into MCLR from the capacitor in the case of MCLR/V_{PP} breakdown.

Peripheral parts have also been integrated in this central processing unit schematic. First of all, a 6-pins connector is used to enable the user to program the microcontroller. A button has been placed so that the patient can directly reset the acquisition module pressing the button. Two LEDs are used: one to signal the communication status and the second can be used for other purposes that the user may consider relevant for example, as a battery-low indicator. At last, a temperature sensor also makes part of the circuit: the LM19. It senses the circuit temperature and directs the measured analogue signal to one of the analog inputs of the microcontroller.

5.1.1.3 Vital Signs Sensors

The circuit parts that enable the physiological signals capture are described below. All signals are connected to the microcontroller through analog inputs except the pulse oxymeter measurements which already arrive in a digital format.

5.1.1.3.1 ECG Front-end

The ECG signals are very small and are obtained in the presence of much larger common mode voltages and noise. The electrical potential to be measured is an AC signal with bandwidth of 0.05Hz to 100Hz. The pretended signal is generally around 1mV peak-to-peak and is affected by external high frequency noise and common mode voltages. The common mode voltages include the 50Hz power-line frequency interferences and DC electrode offset potential. This last one is the result of the electrode contact with skin, giving rise to a potential difference of up to ±300mV [22]. Noise filtering is thus required and can be performed either using analogue circuitry or digital signal processing. The ECG front-end integrated on the acquisition module is based on a design provided in Texas Instruments' datasheet for the INA321 component and incorporates design elements from a four-lead ECG system built by researchers at MIT's Media Lab as part of the Every Sign of Life project [30].

The INA321 have been selected for the ECG front-end because of its particular features that makes him very suitable for the present application. First of all, the INA321 offers single supply operation in a supply range of 2.7V to 5.5V which turns it very convenient for its integration in the acquisition module circuitry powered at 3.3V. It is a rail-to-rail output CMOS instrumentation amplifier that provides low-cost, low-noise amplification of differential signals with micro-power current consumption of 4μA per channel. It is internally configured for 5V/V gain but external gain resistors permit the user to set the desired gain depending on the application. It presents a high CMRR of 94dB and high input impedance. It comes in an 8-pin MSOP package and is considered optimal for low-power battery applications. The circuit diagram for the INA321 can be seen below in figure 14.

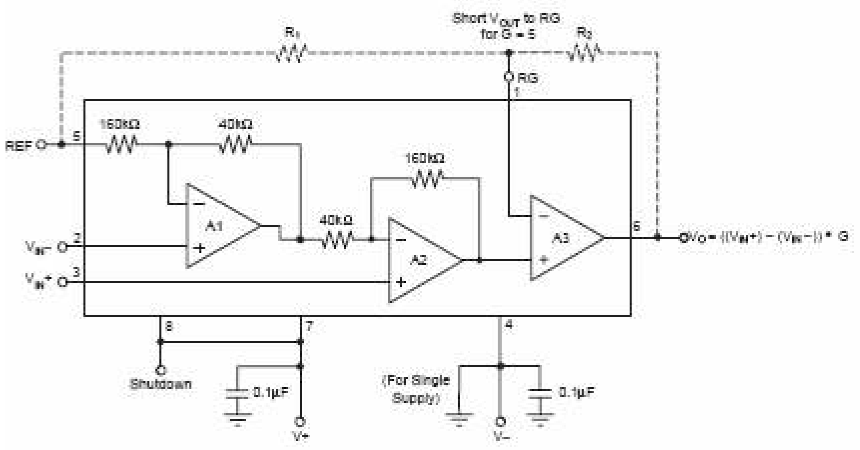

Figure 14 - INA321 circuit diagram and basic connections. [31]

The ratio of R_2 to R_1 determines the resultant gain. As those resistors had not been used for this application, the resulting gain is the internally set, that is G=5. The instrumentation amplifier removes the AC line noise common to both inputs V_{IN}^- and V_{IN}^+, and amplifies the differential signal present on the inputs. An ECG right leg driver is further implemented in order to eliminate 50Hz noise, feeding back the input common mode voltage to the right leg of the patient.

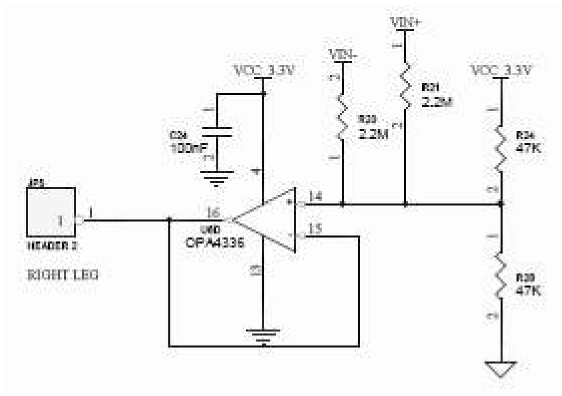

Figure 15 - ECG right leg circuitry

The common-mode signal is drove back to the patient through the amplifier represented in figure 15. A high-pass feedback filter (left side of figure 16) is connected to the INA321 to correct any DC shift that may occur over time. The INA321 output is then passed through an operational amplifier (right side of figure 16) that allows the signal amplification with any desired gain value and simultaneously performs filtering of high frequency noise.

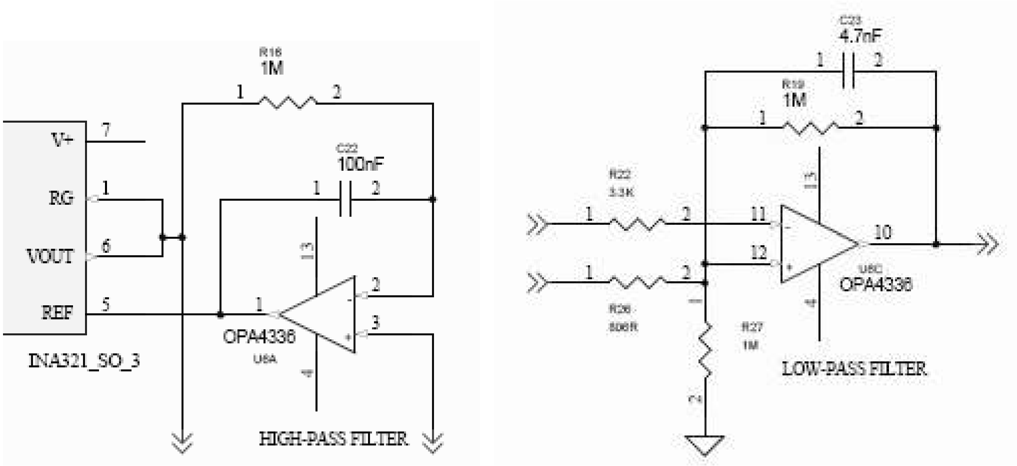

Figure 16 - High-pass feedback filter (left) and final operational amplifier for signal amplifying and high frequency noise filtering (right)

The final ECG output is then passed through a buffer. A last stage of filtering can be applied to the signal if its quality isn't satisfactory enough. According to the placement of the 0Ω resistor, the signal may be submitted or not to low pass filtering, as evidenced in figure 17.

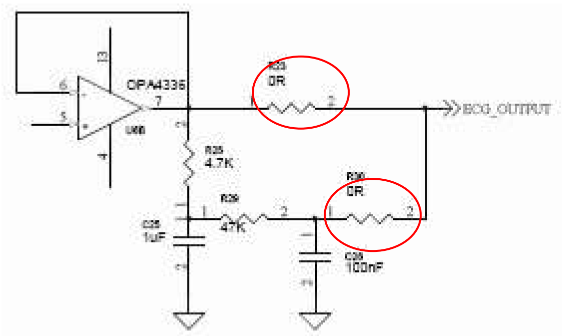

Figure 17 - Facultative final stage of signal filtering - The 0Ω resistor can be collocated in one of the two places evidenced in the figure. Placing it immediately at the buffer output, the low pass filtering will not be performed.

4 amplifiers were required for the ECG front-end design. For this purpose, the quad version of the OPA336 series was selected to be implemented in the circuit. It includes 4 micro-power CMOS operational amplifiers designed for battery-powered applications. The main features considered when choosing the device were its bandwidth, the input offset voltage, the input bias current and power consumption. The OPA4336 operates on a single supply with a voltage range of 2.3V to 5.5V. The output is rail-to-rail and in addition to its small size (SSOP-16 package), it presents the following advantageous features: low quiescent current of 20µA per amplifier, low offset voltage of 125µV, low input bias current of 1pA and a gain-bandwidth product of 100KHz. The quiescent current is the current that flows through the pin tied to ground. Wherever is the value of the current entering the device, a little part is always discharged to ground. The current that gets out of the device on its output is equal to the input current minus the quiescent current.

The ECG output is then directed to an analog input of the microcontroller where it may then be converted in a digital format to be wirelessly transferred.

5.1.1.3.2 Other sensors

The schematic document named "Sensors" aggregates the circuits for the accelerometer, the skin temperature sensor and the pulse oxymeter connection with the microcontroller.

Beginning with the accelerometer circuit analysis, the MMA7260QT accelerometer was chosen for the patient's movements and posture sensing. The device makes the measurements directly from its location on the acquisition module circuit board. The MMA7260QT comes in a 16-pins QFN package. It features signal conditioning, a 1-pole low pass filter, temperature compensation and allows the selection of one of 4 sensitivities: 1.5g, 2g, 4g or 6g. It has a sensitivity of 800mV/g at 1.5g and presents low current consumption which makes it a good option for the pretended application.

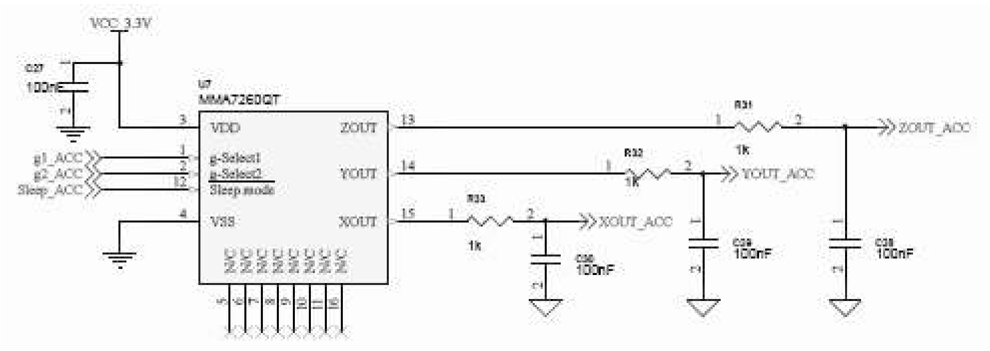

Figure 18 - MMA7260QT circuit diagram and connections

The accelerometer implementation has been made according to the recommended connection diagram provided in the device's datasheet and is shown in figure 18. A 100nF capacitor is used to decouple the power source. Pin 1 and 2 named g-select1 and g-select2 respectively, are logic inputs controlled by the microcontroller to which they are directly tied. The g-select features allow for the sensitivity selection. The sleep mode pin is also controlled by the PIC18F66j15 and when receiving a low input signal, the device is placed in sleep mode reducing the current to 3μA typically. Finally, the X, Y and Z direction output voltages are connected to analog inputs of the microcontroller with an RC filter on each output of the accelerometer to minimize clock noise from the switched capacitor filter circuit.

Now referring to the skin temperature sensor, a search of the medical temperature probes available to be implemented in the monitoring system have been held in order to understand how the connection of the sensor with the acquisition module would be made. In most of the cases, the sensor's connector terminal was a 6.25mm jack plug whether of mono or stereo type. The circuit and connector to be integrated on the module were designed thinking about both the hypothesis and is represented in figure 19.

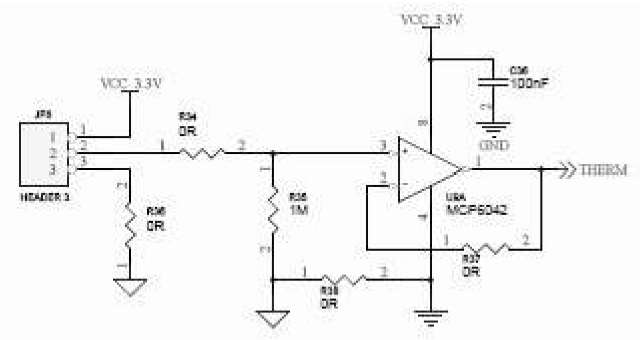

Figure 19 - Temperature sensor circuit diagram and connections

On figure 20, mono and stereo plug are depicted. As it can be seen, signals carried by each differ. Depending on the type of plug used, mono or stereo, the connector on the module must present either 2 or 3 pins, respectively.

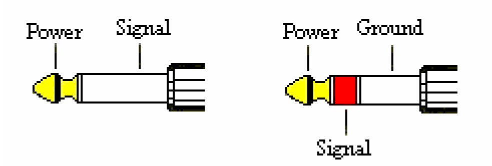

Figure 20 - Mono plug (Left) and stereo plug (Right) pin assignment

When using the mono version, no 0Ω resistor must be placed tied to the third pin of the connector. This last one must be used for stereo plugs giving the ground signal. Regarding the second pin of the connector, the first resistor of 0Ω serves as prevention in the case of a resistor divider being needed if the sensor operates with higher voltages than the 3.3V used for the circuit operation. The input impedance that is seen at the circuit input by the second pin of the connector, results from both the 1MΩ resistor impedance and the operational amplifier internal impedance. The input impedance should be high to ensure that the input will not overload the source of the signal and reduce the voltage of the signal by a substantial amount. An amplifier is used serving as a buffer when the OΩ resistor is placed on its negative feedback. If the signal obtained is too weak, the resistor can be substituted by another one with higher value which will confer the desired gain to the signal before it is directed to an analog input of the microcontroller.

The last sensor circuit enables pulse oximetry measurements. The pulse oxymeter connects to the acquisition module through a standard RS-232 connection. The sensor attachment to the module is made using a DB-9 connector. In order to establish the communication with the microcontroller, it is necessary to convert the RS-232 levels down to TTL or CMOS levels. The SP3238E device has been selected for this purpose and implemented as shown in figure 21. It is an RS-232 transceiver solution suitable for portable applications. SP3238E is a 5 drivers/ 3 receivers device that operates with power supplies ranging from 3.0V to 5.5V. The drivers are inverting level transmitters that convert TTL or CMOS logic levels to 5.0V EIA/TIA-232 levels while receivers convert ±5.0V EIA/TIA – 232 levels to TTL or CMOS logic output levels. It possesses an Auto-On-Line feature that allows its automatic wake-up during a shutdown state when the RS-232 cable is connected. It integrates an on-board charge-pump circuitry that generates ±5.5V RS-232 voltage levels from the single power supply, in the present circuit 3.3V, and guarantees a data rate of 250 Kbps fully loaded. The SP3238E device comes in a 28-pin SSOP package.

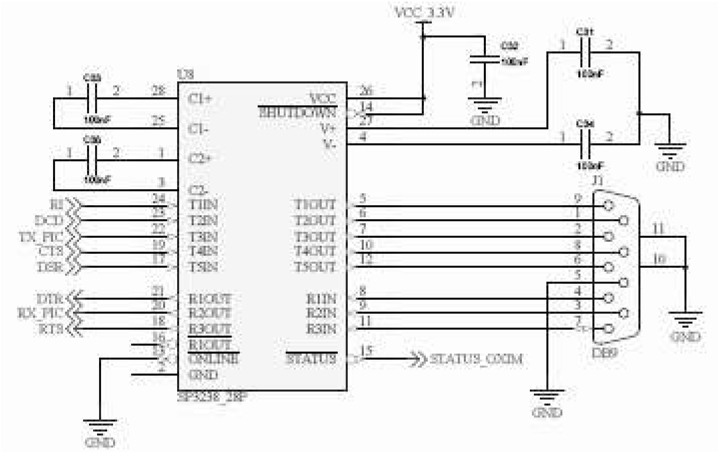

Figure 21 - Pulse oxymeter circuit diagram - Connections between the DB9 connector and the microcontroller (not represented) are mediated by the SP3238E RS-232 transceiver.

The connection establishment between the SP3238E device and DB-9 connector is based on a circuit diagram for the two components connectivity provided in the RS-232 transceiver datasheet, and is made via the UART interface. The communication lines are depicted in table 8.

RI	Ring Indicator – used by modems to signal an incoming call on the telephone line (not used)
DCD	Data Carrier Detected - remains ON as long as a suitable carrier signal can be detected (not used)
TX_PIC	Communication line for data transmission from the microcontroller to the sensor device
CTS	Clear to Send – turned on when the microcontroller is ready to begin communication
DSR	Data Set Ready – Asserted by the microcontroller to indicate an active connection (not used)
DTR	Data Terminal Ready – when turned on, it indicates that the DTE is ready to transmit data to or receive data from the DCE (not used)
RX_PIC	Communication line for data transmission from the sensor device to the microcontroller
RTS	Request to send - Asserted by DTE to prepare the microcontroller to receive data
STATUS_OXIM	TTL/CMOS Output indicating to the microcontroller if a RS-232 signal is present on any receiver input

Table 8 - Communication lines between PIC18F66J15 and the SP3238E RS-232 transceiver

The Shutdown pin tied to V_{CC} and on the other hand, the Online pin tied to ground are conditions mandatory to maintain the Auto-On-Line function active.

5.1.1.4 RTC and Memory

The RTC and Memory schematic design comprises these two devices circuits.

The Ramtron FM25CL64 memory has been selected for 2 main reasons: the first is that it is a ferroelectric non-volatile RAM memory and the second is that it communicates through SPI interface. The first feature guarantees that even when power is removed, the information it contains will not be lost. The FM25CL64 is a 64Kbit random access memory that can perform unlimited read and write cycles. It provides reliable data retention for 45 years. The FM25CL64 presents more advantages like no write delays incurred, unlimited write endurance and much lower power during writes. The device will work as a memory buffer and thus will require the high speed SPI bus to communicate. This communication interface enhances the high-speed write capability of FRAM technology. The FM25CL64 has low voltage operation (2.7V to 3.65V), low current consumption and for the present circuit, has been selected in the 8-pin SOIC package. The device circuit diagram is represented in figure 22.

FM25CL64 and PIC18F66J15 communicate via the SPI interface sing clock and data pins. The chip select pin enables the microcontroller to activate the FM25CL64. At that moment it will start to monitor the clock and data lines. The SCK pin gives the memory the clock frequency to which all its input/output activities are synchronized. SI and SO pins are the data input and output pins respectively that enable data transfer between the FM25CL64 and PIC18F66J15.

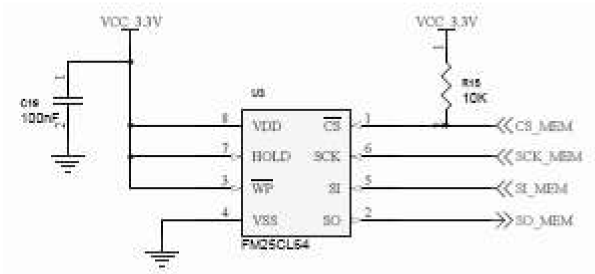

Figure 22 - Circuit diagram of the FM25CL64 ferroelectric RAM memory

A pull-up resistor of 10 KΩ is used on the Chip Select connection between the FM25CL64 and the microcontroller. The connection between the two devices is direct so when the microcontroller isn't stable, as he controls the memory through this Chip Select line, the pull-up resistor will insure that given the unstable input, the Chip Select pin of the memory assumes the default value provided by the resistor tied to V_{CC} until the microcontroller reaches a stable condition.

Now regarding the RTC choice for the acquisition module circuit, the Intersil ISL1208 has been considered suitable. It is a low power RTC with timing and crystal compensation, clock/calendar tracking time with registers for hours, minutes and seconds, and calendar registers for days of the week, day, month and year. It incorporates a power fail indicator, enables periodic or polled alarms and provides automatic backup to battery. The ISL1208 RTC operates with a power supply range of 2.7V to 5.5V and requires a 400nA battery supply current. SOIC package have been considered satisfactory for this application. ISL1208 circuit diagram is depicted in figure 23.

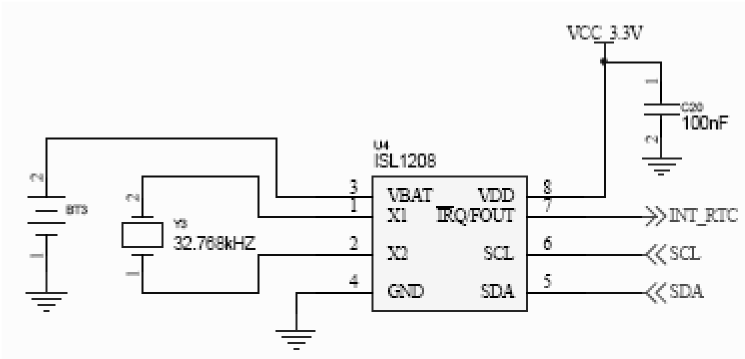

Figure 23 - Real time clock circuit diagram and connections

X1 and X2 pins are connected to an external 32.768 KHz quartz crystal which function is to supply a timebase for the RTC. V_{BAT} input pin provides backup supply voltage to the device. In the event that V_{DD} supply fails, this battery will powered the device. For the purpose, a lithium coin battery is used supplying a nominal voltage of 3V and presenting a nominal capacity of 225mAh.

The ISL1208 communicates with the microcontroller via the I^2C interface supporting a data transfer rate up to 400 KHz. Three pins are involved in the communication. The IRQ/F_{OUT}, when used in the interrupt mode, provides an interrupt signal output to the microcontroller when some action is required whenever an alarm has occurred. In the frequency output mode, the pin outputs a clock signal related to the crystal frequency. The serial data pin is a bidirectional pin used to transfer data into and out the device while the SCL is the clock line that is used to synchronize all data transfers over the I^2C bus. A 2.2KΩ pull-up resistor is tied to each of these two connections between the microcontroller and the RTC device. When the PIC18F66J15 needs to put information on the I^2C bus, it pulls it to a low level. The pull-up resistors are then utilized to pull the bus lines back to a logic high state when released by the microcontroller.

5.1.1.5 Input/Output

The Input/Output schematic only includes the connector parts that will enable the connection of either the Bluetooth or ZigBee module to the acquisition module. The use of two connectors was decided in order to provide mechanical stability to the communication module that will fit on them. One 8-pin connector integrates all the power lines. 4 pins will provide the 3.3V power supply to the communication module while the others are tied to ground. The second 8-pin connector is used for signals transfer between the microcontroller and the communication module. TX_BT/ZB and RX_BT/ZB pins are used for UART communication between the devices. CTS_BT/ZB and RTS_BT/ZB pins are also involved in the referred communication. The RTS_BT/ZB pin is used for the transfer of a request from the communication module being used to the microcontroller that through the CTS_BT/ZB pin may authorize data transfer. The fifth pin connects the communication module to a LED integrated on the acquisition module and that is used to indicate the wireless communication status, which can be interrupted for example in case of no network coverage. The last 3 pins are standard input/outputs that may be used for general purposes that the user may require in the future.

5.1.2 Transmission Module

The transmission module schematic design includes 5 schematic documents; each of them is described below. Some devices used in the transmission module are the same as those used in the acquisition module. As they have already been described in the previous sections, they will not be analysed in detail in this section.

5.1.2.1 Power Supply

The transmission module can be powered either by a Li-Ion battery integrated on it or by direct power line supply making use of a voltage transformer to take incoming voltages of 220V, 50Hz and converting it to lower voltages. The devices included on this module operate either at 3.3V or 3.8V. This two voltage values have to been obtained from the voltage provided by the transformer having recourse to voltage regulators.

The first voltage regulator used in the transmission module power supply circuitry is the step-down regulator LM25576 from National Semiconductor. Step-down regulators, also called buck regulators, are used for converting large input voltages into a smaller output voltage. The basic components of a switching circuit rearranged to form a buck regulator are shown in figure 24.

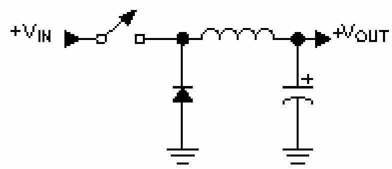

Figure 24 – Buck converter topology. [27]

An integrated controller (not represented in figure 24) senses the output voltage $+V_{OUT}$ and in the case of being too low, closes the switch so current starts to flow from the input through the inductor, which also starts to recharge the capacitor. Once a predetermined value of V_{OUT} has been reached, the switch is open so the current is forced to move around the path comprised by the inductor, capacitor and the diode. The inductor transferred the energy stored in it to the output circuit and/or to the capacitor. Current flows from the inductor and capacitor to the output. When the integrated controller senses the output voltage too low, the cycle is repeated.

The LM25576 regulator operates within an input voltage range of 6 to 42V and delivers an adjustable output voltage as low as 1.225V. Before reading the LM25576, the incoming current passes through a protection circuit that is comprised by a 3A fuse, a 30V varistor and a Schottky diode as shown in figure 25.

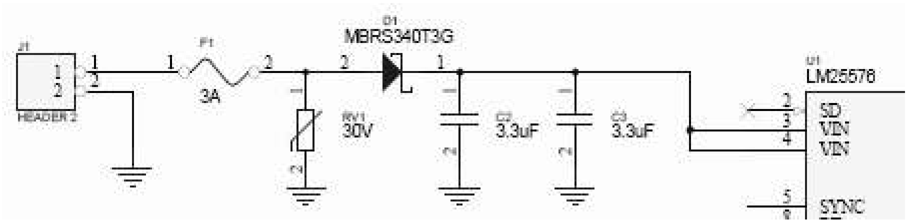

Figure 25 - Protection circuit at the LM25576 entry

The varistor acts as an over-voltage limiter. When a power surge or voltage spike is sensed, the varistor resistance rapidly decreases, creating an instant shunt path for the over-voltage. The fuse, as an over-current protection device, contains a metal wire in it that, in the referred conditions, melts breaking the connection between the transformer and the LM25576. The Schottky diode is used because it has a lower turn-on voltage because of the lower barrier height of the rectifying metal-to-semiconductor junction and has faster switching speeds.

The LM25576 is available in power enhanced TSSOP-20 package. It has been selected because it can efficiently step-down high unregulated voltages and only requires a minimum of external components to do it. The device includes a set of protection features namely current limiting, thermal shutdown and remote shutdown capability. The LM25576 circuit diagram is represented in figure 26.

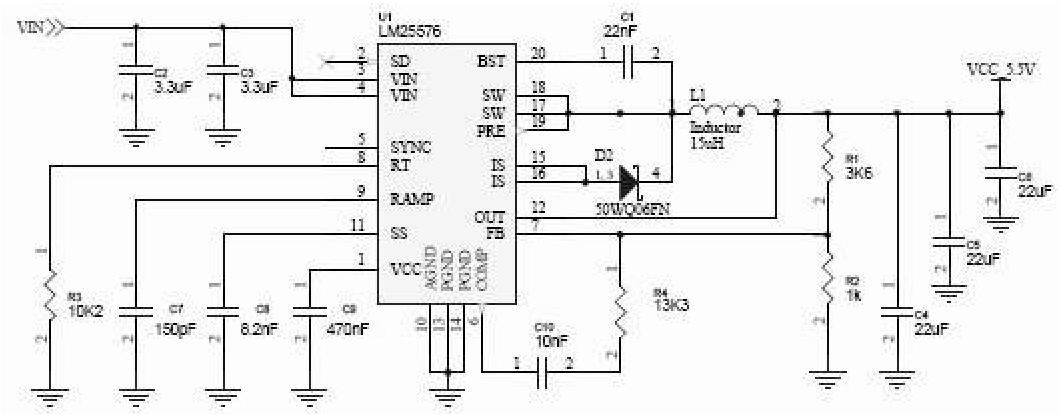

Figure 26 - LM25576 circuit diagram and connections

In figure 26, the 2 capacitors tied to the V_{IN} pins are used to limit the ripple voltage while supplying most of the switch current during the on-time. Through the RT pin, the single 10.2KΩ resistor (R_3) connected to it sets the internal oscillator frequency that is given by:

$$F = \frac{1}{R_3 \times 135 \times 10^{-12} + 580 \times 10^{-9}} \cong 511KHz$$

The RAMP pin have an external capacitor of 150pF tied to it that sets the ramp slope used for current mode control in the pulse width modulator. The capacitor (C_8=8.2nF) at the SS pin, on its hand, determines the soft-start time which is the time for the reference voltage and the output voltage to reach the final regulated value:

$$t_{SS} = \frac{C_8 \times V_{OUT(MIN)}}{I_{SS}} = \frac{C_8 \times 1.225V}{10\mu A} \cong 1ms$$

Where $V_{OUT(MIN)}$ corresponds to the minimum output voltage value and I_{SS} corresponds to the soft-start current source. The capacitor at the V_{CC} pin provides noise filtering and stability for the V_{CC} regulator. The bootstrap capacitor between the BST and the SW pins supplies the gate current to charge the buck switch gate at turn-on.

The inductor value determination was based on the operating frequency (F), ripple current (I_{RIPPLE}), maximum input voltage $(V_{IN(MAX)})$ and the desired output voltage (V_{OUT}). It can be calculated as follow:

$$L = \frac{V_{OUT} \times (V_{IN(MAX)} - V_{OUT})}{I_{RIPPLE} \times F \times V_{IN(MAX)}} = \frac{5.5V \times (42V - 5.5V)}{0.5A \times 511KHz \times 42} \cong 18.7\mu H$$

Regarding the two feedback components closed in the loop between COMP and FB pins, these components configure the error amplifier gain characteristics to accomplish a stable overall loop gain. The output voltage is set by the two resistors R_1 and R_2.Their values have been chosen to provide an output voltage of 5.5V as it can be verified as follow:

$$V_{OUT} = \left(\frac{R_1}{R_2} + 1\right) \times 1.225V = \left(\frac{3.6}{1} + 1\right) \times 1.225V \cong 5.6V$$

All the components values have been obtained using a simulator available on the National Semiconductor website. Introducing the minimum and maximum input voltage values, the desired output voltage value and the output current, the simulator automatically creates the schematic design that includes the LM25576 and external components required for the pretended solution.

When tied to the power line, the transmission module is powered by the 5.5V voltage furnished at the LM25576 output and simultaneously, a battery charger included in the power supply circuitry charges the Li-Ion battery. The use of a Li-Ion battery has been decided because of the following advantages inherent to this kind of batteries:

- They are lighter than other equivalent rechargeable batteries, which is convenient for systems that must be ergonomic;
- They do not suffer from the memory effect;
- Higher power capacity per a given weight or volume.

The Microchip MCP73826 device is a linear charge management controller for single Lithium-Ion cells. The device operates in a supply voltage range of 4.5V up to 5.5V and power down automatically when input power is missing. The battery charge controller circuit has been implemented as recommended in a typical application circuit provided in its datasheet and is shown in figure 27.

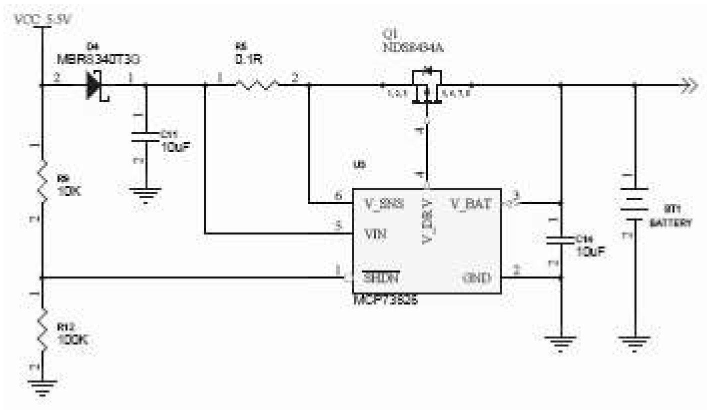

Figure 27 - MCP73826 charge controller circuit diagram and connections

The MCP73826 charges the battery in three phases: preconditioning, controlled current and constant voltage. During the first phase, the device verifies the state of the SHDN pin which is an input to force charge termination, initiate charge or recharge. If the cell is below the 2.4V preconditioning threshold, the preconditioning replenishes deeply depleted cells and minimizes heat dissipation. Once the preconditioning threshold has been exceeded, the controlled current regulation begins. Fast charge proceeds until the cell voltage reaches the typical regulation voltage of 4.2V. After that, constant voltage regulation begins. The V_{BAT} pin is connected to the positive terminal of the battery sensing the cell voltage. The Lithium-Ion battery has a minimum capacity of 740mAh, nominal voltage of 3.7V and maximum operating voltage range of 2.75V to 4.2V.

In order to achieve a maximum energetic profit of the Li-Ion battery, the following circuit part has been implemented as represented in figure 28.

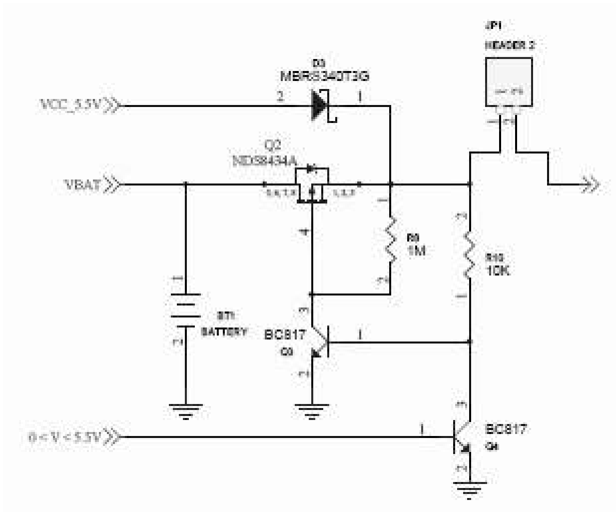

Figure 28 - Diagram of the circuit part for maximum energetic profit of the Li-Ion battery

While the transmission module is tied to the 220V power line network, the 5.5V power is available being used as the power source for all the module devices and is directed to the module power-on interrupter through an MBRS340T3G Schottky power rectifier as shown in figure 28. In the contrary case, the module must be powered by the Li-Ion battery. The circuit part that comprises 2 transistors and the p-channel MOSFET pass transistor acts as an ideal diode, i.e. it operates like a diode enabling the current passage when voltage at the interrupter terminal is inferior to the battery positive terminal voltage, avoiding the inevitable voltage drop that a real diode would introduce. The energy accumulated in the Li-Ion battery is thus maximally used.

The voltage passed by the interrupter is consequently either 5.5V or a value in the full battery discharge voltage range (Li-Ion nominal voltage: 3.7V). The TPS63000 buck-boost converter from Texas Instruments is then used to obtain an output voltage of 3.8V.The device is suitable for products powered by a one cell Li-Ion battery because it can operate efficiently over the full battery discharge voltage range. The converter operates with a peak efficiency of 96, works within an input voltage range of 1.8V up to 5.5V and can provide fixed and adjustable output voltages from 1.2V to 5.5V. It integrates both buck and boost function in a 10-pin QFN package. Only few external components are required for operation as it can be seen in figure 29.

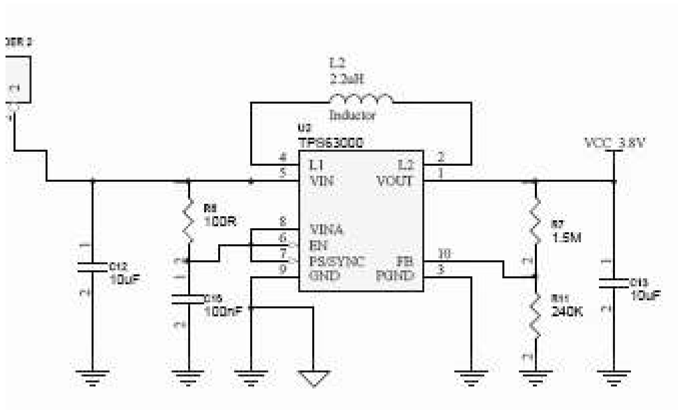

Figure 29 - TPS63000 buck-boost converter circuit diagram and connections

This design corresponds to the typical application circuit for adjustable output voltage option provided in the TPS63000 datasheet. Input and output capacitors values have been set to 10μF. The output voltage is adjusted having recourse to an external resistor divider that must be connected between V_{OUT} and FB pins and GND. The output voltage can be verified using the following expression:

$$V_{OUT} = \left(\frac{R_1}{R_2} + 1 \right) \times V_{FB} \cong \left(\frac{1.5 \times 10^6}{240 \times 10^3} + 1 \right) \times 0.5 = 3.625V$$

Where V_{FB} corresponds to the voltage across the resistor between the FB pin and ground which is typically of 500mV.

The inductance value was chosen based on a recommendation in the device datasheet. A suitable inductor to generate 3.3V from a Li-Ion battery with a battery voltage range from 2.5V up to 4.2V is 2.2uH. To determine the appropriate inductor value, the minimum inductance values for both step-down operation and for boost mode operation must first be calculated. The higher of the two obtained values should be used. The other external components values were chosen according to the manufacturer recommendations.

When the Li-Ion battery is the power source, it discharges down to and below 3.3V so the buck-boost converter must transit from buck mode to boost mode. It works with constant PWM switching over the buck and boost ranges with no overlap or dead time between the two modes.

The final stage of the power supply circuitry consists in the conversion of the 3.8V voltage to 3.3V. This is accomplished by the low dropout voltage regulator MCP1700 from Microchip. The device accepts input voltages in the range from 2.3V to 6.0V and provides on its output voltages ranging from 1.2V to 5.0V. The MCP1700 has a quiescent current of only 1.6μA. Its output is stable when using only 1μF output capacitance as well as on its input. No other external components are required for the device operation. For the present application, the 3-pin SOT-23 package option was preferred.

As for the acquisition module, a red power LED has been integrated to indicate the power supply status of the system board.

5.1.2.2 Central Processing Unit

Like in the acquisition module circuit, the Microchip PIC18F66J15 microcontroller is employed as the coordinator of all the parts of the transmission module. For more details regarding the device, please refer to the central processing unit section of the acquisition module schematic design description.

In the transmission module, the analogue and digital supplies don't need to be separate so no RC filter is needed for their connection. Each power supply pin is decoupled by two capacitors. The same peripheral parts as those integrated in the acquisition module are also used in the present module. 4 LEDs are integrated: 2 of them are employed to signal the communication status of each one of the two communication modules used for wireless data transfer. The other 2 LEDs can be used for other purposes that the user may consider relevant.

Additionally, the Central Processing Unit schematic document includes a multiplexer that is used in order to enable switching between wired and wireless data transfer. Wi-Fi or GSM GPRS modules can be used for data transmission when fitted on the two connectors employed for the purpose. Both of them communicate with the microcontroller via UART interface but only one of them can be used for wireless data transfer. On the other hand, data download through the USB connector implies data transfer from the microcontroller using UART interface. As data download is made using whether wireless or wired transmission, only one of the UART modules of the PIC18F66J15 need to be used, being shared by the two data transfer modes.

This solution is enabled by the SN74LVC125A quadruple bus buffer gate from Texas Instruments. It is designed for 2.7V to 3.6V V_{CC} operation. It features independent line drivers with 3-state outputs.

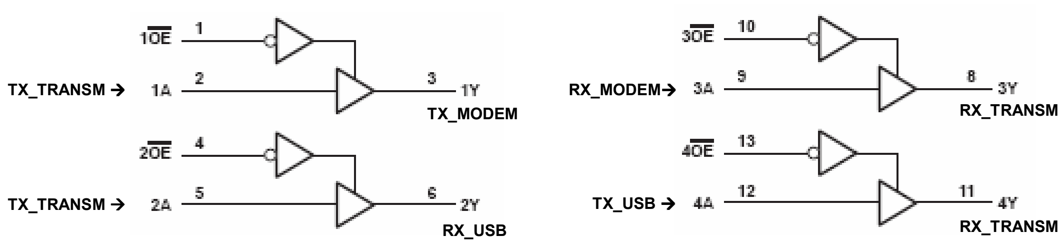

Figure 30 - SN74LVC125A logic diagram. [32]

In figure 30, a logic diagram evidences the connections that enable the partition of the microcontroller UART interface between the selected wireless module and the USB connector. Each output is disabled when the associated output-enable input is high. The OE pins are tied to the microcontroller through pull-up resistors in order to ensure the high impedance state during power-up or power-down, while the PIC is instable. The CBUS0 connection between the microcontroller and the FT232 USB UART device allows it to advice the microcontroller whenever a USB connector have been plugged-in for data download. From this moment, the microcontroller puts the 2OE and 4OE input pins in a high state, data transfer between PIC18F66J15 and the USB device can proceed.

5.1.2.3 RTC and Memories

Once again, the RTC chosen for this design is the same to that implemented in the acquisition module, the ISL1208 RTC. The device features and design are described in the RTC and Memory section of the acquisition module schematic design description. For more details, please refer to this section.

The present schematic design comprises two memories: a data memory, the AT45DB041D and a memory for configurations storage, the FM24CL64. The device offers the advantage of being a ferroelectric non-volatile RAM and thus can retain data stored for 10 years even when it is not powered. This memory is very similar to the FM25CL64 used in the acquisition module. The main difference that can be evidenced between the two devices is the communication interface they use to transfer data to the microcontroller. The FM24CL64 in fact, uses the I^2C bus to communicate with it. The lines used to establish the communication are the same used by the RTC. Here the microcontroller is referred as the master because it is the one that initiates transactions on the I^2C bus and controls the clock signal. The devices being addressed by the master, the RTC ISL1208 and the FM24CL64 memory are called slaves. Both master and slaves can receive and transmit data through the I^2C bus. Each slave comes with a predefined device address. When the master needs to start a transaction, it transmits the device address of the intended slave that only responds to its own address. The I^2C bus configuration is depicted in figure 31.

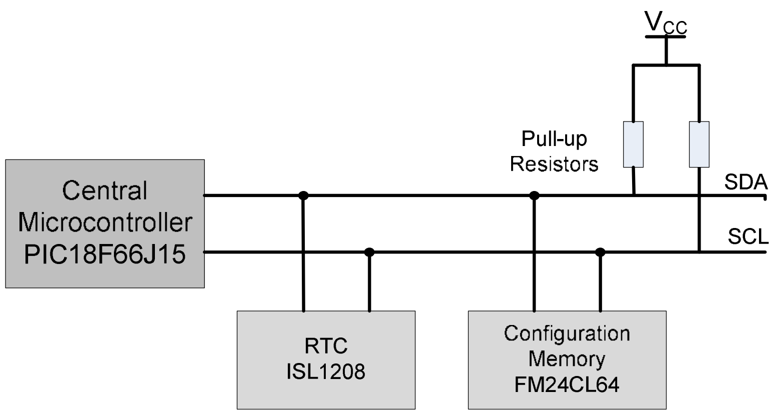

Figure 31 - I^2C bus configuration - I^2C is a two wire serial bus that communicates using two bidirectional open-drain lines, SDA and SCL. The master (PIC18F66J15) can address his slaves when he wants to start a transaction. Only a set of pull-up resistors is needed for the whole I^2C bus, not for each device.

As already referred, the SDA and SCL lines are pulled-up to the supply voltage with pull-up resistors keeping logic high levels on the lines while no transactions are being held.

Referring again to the FM24CL64 memory, it incorporates 64 Kbit of non-volatile memory, can support an unlimited number of read/write cycles and no write delays are incurred. Its operation range (2.7V to 3.6V) and low power consumption make it convenient for the present application. The device comes in an 8-pin SOP package.

The second memory integrated on the transmission circuit board is used for data storage, i.e. physiologic data arriving from the acquisition module that may be stored temporarily before being sent to the final addressee. The AT45DB041D from Atmel is a 4Mbit flash memory that can support very high speed operations. The device was selected because it can further be substituted with other memories with higher capacities that are pin compatible, and also taking in account its communication interface. Incoming data may need to be rapidly stored in the memory so the SPI interface is more indicated for the purpose. The Atmel memory serial interface is SPI compatible for frequencies up to 66MHz. It integrates two buffers that enable data reception even when the main memory is being reprogrammed as well as writing a continuous data stream. Communication with the microcontroller is enabled through the chip select pin. While the referred pin is in a high state, the device is in the standby mode. Once it transits from high to low state, operation can be started via the 3-wire interface that includes the serial input, serial output and the serial clock lines. Through the SI pin, data are shifted into the device while through the SO pin, they are shifted out from it. The SCK pin is used for providing a clock signal. It is the “metronome” of the communication between the microcontroller and the data memory. It is used to control the data flow to and from the memory. The device has an 8-pin SOIC package.

5.1.2.4 USB Interface

The USB UART FT232R from FTDI converts between RS232 serial data and USB. If the device detects a signal on the USB power line, it immediately informs the microcontroller of the USB connection establishment. The microcontroller then acts on the output enable pins of the multiplexer in order to enable data transfer to the USB UART device and consequently, the wireless data transfer via Wi-Fi or GSM GPRS interruption. For the FT232R implementation, no many external components are needed because many of those required for its operation are already integrated in this device version: the clock circuit which exempts the use of an external crystal or ceramic resonator, a pre-programmed EEPROM, USB and pull-up resistors associated to the USBDM and USBDP pins and the RC filter tied to the A_{VCC} pin.

The FT232R device has been implemented in the circuit in its bus powered configuration, i.e. the device gets its power supply from the 5V voltage on the USB bus, once a USB device has been plugged-in. The V_{CCIO} pin on the other hand, is used to supply the UART interface and CBUS group pins so as it is connected to the 3.3V supply, it allows the FT232R to directly interface to the 3.3V lines that connects it to the microcontroller. Additionally, the 3V3OUT pin, when tied to ground through a 100nF capacitor, provides a voltage of 3.3V to the internal USB transceiver cell and to an integrated pull-up resistor tied to the USBDP pin. It may also be used to power the V_{CCIO} pin. Signal transmission from the USB connector to the FT232R device is held by the bidirectional USBDM and USBDP lines. The device converts the USB interface to RS232 acting at 2 levels: a conversion at the physical level and another at a protocol level. The FT232R in its bus-powered configuration connected to the USB connector is represented in figure 32.

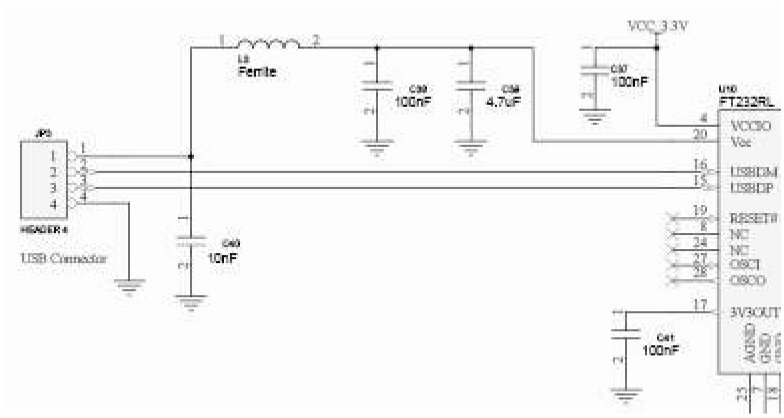

Figure 32 – FT232R circuit diagram and connections with the USB connector

On the other hand, 5 pins are involved in the interfacing of the FT232R to the PIC18F66J15 microcontroller: TXD, RXD, RTS#, CTS# and CBUS0. TXD and RXD pins enable data transfer from and to the FT232R device, respectively. The RTS line is used by the USB UART device to verify if the microcontroller is ready to start transaction. If the transmission can begin, the microcontroller responds to the RTS signal via the CTS line allowing the transfer of data. The last pin involved in the FT232R and PIC18F66J15 interfacing is the I/O CBUS0 that can be used as general purpose I/O, here, to advise the microcontroller whenever the USB connection has been activated.

5.1.2.5 Input/Output

The input/output connectors allow the communication modules attachment to the transmission module circuit board. Two connectors are used for the plug-in of either the Bluetooth module or the ZigBee module to enable the reception of data coming from the acquisition module. These connectors are exactly the same as those used on the acquisition module, already described in the section referring to the Input/Output schematic design of this module.

The other two are used for the plug-in of either the Wi-Fi or GSM GPRS module. Once again, one of the two connectors is used exclusively as the power supply. Two pins provide the 3.3V voltage while two others supply 3.8V required for the GSM GPRS module operation. The other 4 pins are tied to ground. The second connector is comprised by the signal lines. The communication interface used for data transfer with the microcontroller is the UART interface. 4 pins support the lines involved in this type of communication: TX, RX, CTS and RTS pins. Like in the Bluetooth/ZigBee connectors, one line has been reserved to enable a LED control. The LED should be used to indicate the communication status. The sixth line permits the microcontroller to ignite the GSM GPRS modem. Finally, the two other input/output lines are left unused and may be used in the future for general purposes that the designer may want to implement.

5.1.3 Bluetooth Module

The Free2move solution F2M03AC2 module has been selected for the establishment of Bluetooth wireless communications between the acquisition and transmission modules.

The F2M03AC2 is a SMD module that operates in class 2, endowed with an integrated antenna and a transmit power up to +4dBm which confers it a range up to 20 meters in an open environment. Its features make it suitable for voice and data communications. It integrates UART and USB interfaces that can support data transmission at the full Bluetooth data rate, i.e. up to 723.2Kbps (maximum allowed by Bluetooth specification v1.1.). The module offers digital and analog input/outputs and I^2C interface. It operates with a supply voltage in the range from -0.40V up to 3.60V. In the present case, it is supplied with 3.3V and can present low power modes that depend on the range and data rate of transmission and whether it is transmitting data or not.

Figure 33 – Bluetooth module: F2M03AC2 from Free2move. [33]

The communication with the microcontroller is done via the UART interface once the connectors of the module are plugged-in on those of the acquisition or transmission module. Logically the pins used for the data transfer with the microcontroller are the TX, RX, CTS and RTS pins. Two parallel input/output lines are used: one to control the communication status indicator LED and the other remains available for general purposes that may arise in the future. The PIO[3] line is used for the LED control because it indicates if a successful Bluetooth connection with a remote device is established. It is held low as long as there is no Bluetooth connection and goes high once a Bluetooth connection has been established. As it is recommended by Free2move, the reset pin has been connected to the microcontroller through a pull-up resistor that guarantees the high state of the reset pin whenever the microcontroller is unstable. The other signal pins are involved in the pulse code modulation, USB, voice and serial peripheral interfaces and are left unconnected as they are not required for this application.

This Bluetooth module is available with a number of different firmware versions including the wireless UART firmware, used in this application and which key features are robustness, high configurability, high security, low complexity and low power. One of the advantages offered by the module that made it an attractive option for the present application is that using the wireless UART firmware, there is no additional need for drivers or Bluetooth software on the host. The wireless UART offers one asynchronous channel on which all information sent or received is exchanged transparently via Bluetooth with the connected remote device. As soon as a successful connection with the latter has been established, communication via the asynchronous data channel is enabled without the need of sending any configuration commands. The device running the wireless UART firmware can operate either as the master or slave of the piconet to which it belongs.

The F2M03AC2 module is easily available in the market.

5.1.4 ZigBee Module

The XBee OEM RF module is a radio transceiver that meets IEEE 802.15.4 standards to support communication within wireless networks. This module distinguishes itself because it is easy-to-use and cost competitive but also because of its reduced dimensions making it very suitable for a wide range of applications.

Operating within the 2.4GHz frequency band, the XBee module operation is based on the DSSS technology. It is available with a whip antenna or a low-profile chip antenna or a U.FL connector (ultra small mount coaxial connector) to which an external antenna can be connected. For this application, the module version which the chip antenna already integrated in it was selected because of the reduced dimensions of the complete solution. The selected module is represented in figure 34. With the chip antenna, the indoor wireless link range is about 24 meters and 143 meters for outdoor line-of-sight connections.

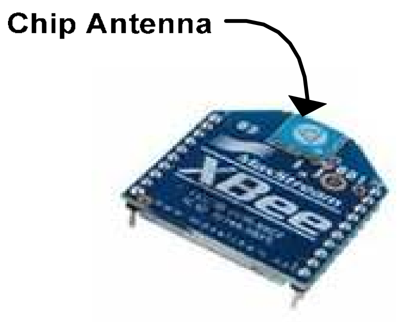

Figure 34 – XBee OEM RF module with chip antenna integrated. [34]

Another feature that needs to be referred bearing in mind that the acquisition and transmission modules are battery-powered, regards the power consumption of the XBee module that requires 45mA when transmitting and 50mA for data reception. Additionally, sleep modes are supported so that when powered-down, the module needs less than 10μA. It operates within a voltage range of 2.8V up to 3.4V.

The XBee OEM RF module interfaces with the microcontroller of the module to which it is coupled through a logic-level asynchronous serial port. The UART interface of the microcontroller can be directly connect to the XBee module. The 4 pins involved in the connection are the DIN pin for data to enter the module, the DOUT pin through which they are sent out of it. The RTS and CTS pins are used for hardware flow control.

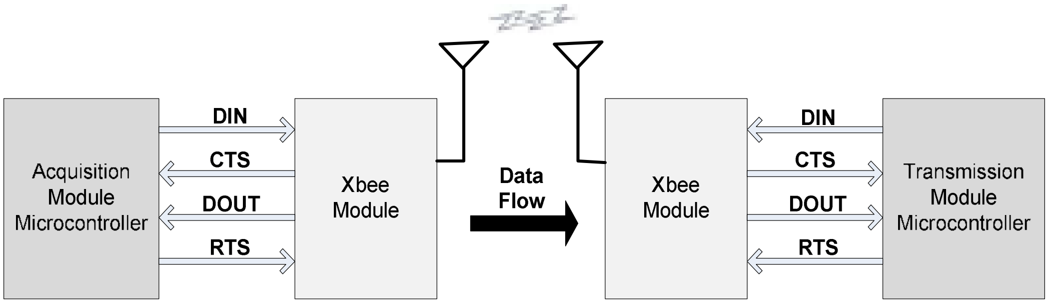

Figure 35 – System data flow diagram in the UART-interfaced environment - The diagram represents the data flow from the acquisition module microcontroller to the transmission module microcontroller via wireless ZigBee connection. XBee transceivers are used for the purpose and interface the microcontroller via UART interface. Pins involved in the connection are depicted.

Data flow inside the module is made in the following way:

- Data entering the RF module via the UART DIN pin are queued up for RF transmission. They are stored in the DIN buffer until being processed. The CTS pin is used to signal the microcontroller whether it can send data or it must stop sending them. Once the packet in the buffer is complete, it is sent. It may also be sent even if it is incomplete if no serial characters are received for a predetermined amount of time or if it has been ordered to do it.
- When RF data are received, they must be sent out the XBee module through the DOUT pin. Once they are received, they are directed to the DOUT buffer where they are accumulated until data flow is enabled by the RTS pin. If the buffer has reached its maximum capacity, all incoming data will be lost.

In addition to the lines used for UART interfacing between the RF module and the microcontroller, other lines are used once the XBee module connectors are plugged-in those of either the acquisition or transmission module. The fifth line of the connector is destined to the communication status indicator LED control by the RF module. The LED will blink when associated. On the other hand, the reset pin is directly tied to the microcontroller. No external pull-up resistor is needed because one of 50kΩ is already included in the XBee module. The seventh line of the connector is used by the RF module to inform the microcontroller about its status (on/sleep). Through the eighth line of the connectors, the microcontroller can acts on pin 9 of the RF module and activate its sleep mode. The RF module will then enter states of low power consumption when it is not being used.

Initially, the Microchip MRF24J40 device has been chosen as the ideal solution for data wireless transfer using ZigBee technology. The device offers good features but requires the use of many external components when comparing with the XBee module that have been integrated with only two external decoupling capacitors tied to its V_{CC} pin. The main disadvantage of the Microchip device for the monitoring system application is that it communicates through SPI interface so an additional microcontroller would be necessary to convert the SPI interface to UART interface in order to turn the ZigBee module compatible with the connectors also used for the Bluetooth module plug-in on the acquisition or transmission module. The XBee module not only enables the bills of materials reduction and the design simplification but also offers all the required features for data transfer via UART interface, a complete solution in a 20-pin module with reduced dimensions.

5.1.5 GSM GPRS Module

The Wireless CPU Q24 Plus from Wavecom can be used for GSM GPRS communication in various types of process applications including telemetry applications such as the pretended wireless vital signs monitoring system. It is represented in figure 36.

Figure 36 – Wireless CPU Q24 Plus. [35]

The device requires a power supply voltage in the range of 3.2V to 4.5V approximately for two different inputs. One, designated V_{BATT} consists of 5 pins that supply directly the RF components of the module. Voltage ripple at these connections must be kept low. V_{BATT} is supplied with a 3.8V voltage. The module works with burst emission (shown in 37) so the power supply must be able to furnish high current peaks in a short time more precisely during approximately 1154μs every 4.615ms for GSM/GPRS class 10.

Figure 37 – Power supply during burst emission. [35]

The current required for the module powering has an average value of 510mA. To provide the current peaks, two capacitors in parallel need to be tied to the 3.8V supply, close to the power supply connector. A unique capacitor with larger capacity could be use but because of its large diameter, it has been decided to use two smaller capacitors placed in parallel. Although during a transmit burst, the Wireless CPU nominal current is 1.4A, to calculate the appropriate capacitor values, a target of 2A has been considered. The capacitors are thus used for charge storage. Anytime a current peak is required, the current arriving at the V_{BATT} is comprised by the input current plus the difference to amount to the 1.4A, provided by the two capacitors.

The second power supply input is the V_{DD} pin, also tied to the 3.8V voltage through a decoupled capacitor that supplies the internal + 2.8V ballast regulators. Regarding power consumption concerns, the Q24 Plus device supports different power consumption modes evolving from the OFF mode to the communication mode when GSM/GPRS communication is established and consequently power consumption is higher.

Now regard to the communication interfaces supported by the Q24 Plus device, SPI and I^2C interfaces can be supported but are not used in the present case. Once again, data transfer is made through UART interface. A 6-wire serial interface is available on the device. The signals supporting the referred interface are the TXD data line for data transfer from the microcontroller to the RF device, the RXD data line as the output line enabling data transfer out of the device, the hardware flow control signals RTS and CTS, and finally DTR and DSR (not used here) signals. The RTS and CTS signals are used to avoid data corruption during transmission. A 0Ω resistor is tied to the CTS pin in case that it doesn't need to be used. Signals on the Q24 Plus device are at 2.75V levels. Before reaching the microcontroller, their voltage level must be converted to the 3.3V level used by the microcontroller and vice-versa, signals coming from the microcontroller must be lowered to 2.75V levels before entering the RF module. For this purpose, the 4-bit dual supply bus transceiver SN74AVC4T245 from Texas Instruments has been implemented on the circuit schematic. The device uses two separate configurable power-supply rails. Port A tracks 3.3V while port B tracks 2.75V. It transmits data from the A bus to the B bus or on the contrary, from the bus B to the bus A. The data transmission direction is controlled through pins DIR and OE. Both are supplied by V_{CCA} which is 3.3V. The DIR pins levels are already defined by the circuit configuration. Data transfer only depends on the OE pins state which is controlled by the microcontroller to which they are directly tied through pull-up resistors.

The Wireless CPU Q24 Plus has been proposed with an additional SIM interface on which 5 signals are available for the SIM CARD control: SIM_CLK (clock for the SIM interface), SIM_RST (to reset the SIM interface), SIM_DATA (data I/O), SIM_VCC (to supply the SIM Card) and SIM_PRES (SIM Card detection) which is tied to 2.75V because it is not used here.

5.1.6 Wi-Fi Module

The Wi-Fi module has not yet been chosen. Many solutions have been analysed.

The ConnectBlue WSPA311g serial wireless LAN module appears to be a good option. The module already provides all the software and hardware required for its implementation. It is available with an internal surface mounted antenna and operates within the 2.402-2.480 GHz ISM frequency band. The power supply voltage range for its operation is of 3.3V up to 5.5V so it is compatible with the voltages supplied through the power connector on which it may be plugged-in, that carries 3.3V and 3.8V. The ConnectBlue module offers low power modes: in the active mode, no power saving is done and the module requires around 165mA, 140mA in the idle mode and in power saves modes during which the device can't neither transmit nor receive data, it has an average current consumption of 400µA.

This module is an attractive solution as it doesn't require the use of external drivers and is a complete solution in a 20-pin module of 36mm x 23mm. The ConnectBlue WSPA311g device can be seen in figure 38.

Figure 38 - ConnectBlue OWSPA311gi-06 OWSPA Serial Wireless LAN module with internal antenna [36]

It integrates UART communication interface as it is required for the present application. Connections between the Wi-Fi module and the microcontroller may be made through the typical 4 pins involved in this kind of connection: RXD, TXD, RTS and CTS pins. All connections to the microcontroller can be established only needing a protective resistor of 100Ω on each signal line.

Even if the ConnectBlue solution seems to be appropriate to be implemented in the monitoring system, it has not been definitively accepted because it is not available in the country. In fact, the search handled to avoid which Wi-Fi solutions can actually been acquired on the market reveals that no suitable solutions are actually available in Portugal. Some Wi-Fi modules are available but present unacceptable features for the pretended monitoring solution as for example large external antennas and cumbersome dimensions.

New solutions that combine both Wi-Fi and Bluetooth technologies on a same module have been developed more recently and are today available on the market. The use of such a module in the vital signs monitoring system has been considered. The idea has then been refuted because both technologies run in the 2.4GHz frequency band and as a consequence, the Bluetooth and Wi-Fi chips are prone to interfere with each other especially because of their proximity on the module.

5.2 PCB Layout Design

The PCB layout design has been carried out using the Altium Designer software. This application incorporates all the technologies and capabilities necessary to develop electronic products. The Altium Designer's board level design capabilities allow the designer to define and implement all the elements of the design. In this section, the steps that conduct to all the monitoring circuit boards design are described. In particular, a set of basic rules for PCB layout creation is listed.

Through the schematic capture process, a database of symbolized parts and a netlist with all connections between the symbols have been created. Once the schematics design has been completed, the bill of materials that contains the list of all the components which make part of the circuit have been created. According as the components where chosen, their footprints were assigned to each corresponding part of the schematic. A device footprint is used to represent the device on the PCB. Almost always the footprints could be found easily in the libraries included with Altium Designer having simply recourse to the library search features available on the program. On the other hand, sometimes they had to be created. Their creation simply consists in arranging a set of pads in the same pattern as the part pins that comes in the component's datasheet, so the part will be soldered on or fit into the board, and assign to each pad the corresponding pin number. Still referring to the components selection, the enclosures to house the circuit boards had to be chosen to define the boards outline. Two enclosures were chosen: one for the transmission module, the other for the acquisition module. After having attributed to each component of the circuit the respective footprint and having outlined the board on which they must be organized, the netlist could be imported. The netlist file contains the device names of the parts used on the board and a list of the interconnections between the pins of those parts.

Now considering the trend to faster, higher integrated, smaller form factors and low power electronic circuits [37], some rules need to be kept in mind when designing the circuit layout. With a good layout, EMI problems can be minimized. The EMI is the frequency energy that interferes with the operation of an electronic device. Some relevant considerations for conductor thickness, component placement, dimensioning and tolerance rules among other things, are analysed in more detail in the next sections.

5.2.1 Parts placement

The parts placement is a major concern when creating the PCB layout. The location of a circuit on a board, the placement of the individual circuit components and what kind of circuits are in the neighbourhood are critical factors that need to be considered. When placing components, their electrical function and physical size, temperature factors and routability are of relevant importance. Some few examples of general guidelines followed when drawing the circuits' board are next described.

- The board layout should be done on a fix grid. Depending on the type of task being carried, the size grid may vary. For finer work, lower snap grid values are recommended.
- The circuit critical components placement must be defined. Generally, the input, output and power placements are first defined.
- One must try to keep together the components belonging to a same functional block avoiding noisy interactions between neighbour blocks. ICs must be functionally grouped and located close to other fixed parts to which they are associated.
- Support part such as resistors and capacitors must be placed in their correct locations like it may be suggested in the component datasheet. For example, when using low value input filter capacitors to ensure low ac impedance to reduce noise and store energy, they must be placed as physically and electrically close as possible to the V_{IN} pin of the IC as exemplified in figure 39.

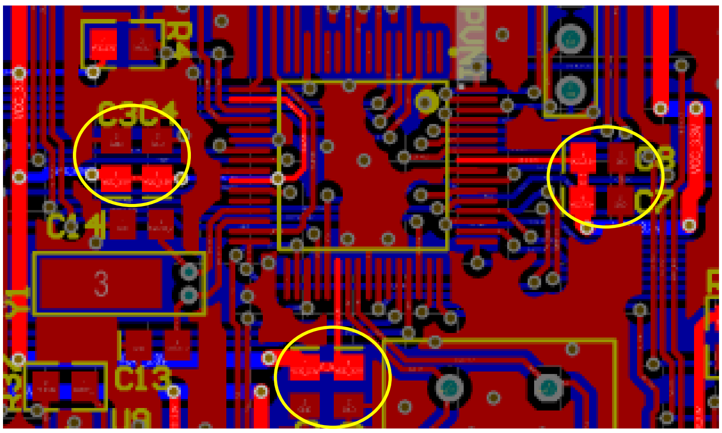

Figure 39 – An example of good bypass capacitors placement - The surrounded decoupling capacitors are directly tied to the power supply pins of the IC (here: PIC18F66J15). The capacitors must be located as close as possible to the device. In the figure, the power supply V_{CC}=3.3V have been brought to light and as it can be seen the V_{IN} pins supply are not coming from the same point.

Another example refers to the LM25576 step-down used in the power-supply circuit of the transmission module in which a typical application board schematic available on the device's datasheet shows that the Schottky diode and the inductor must be placed orthogonally one with regard to the other.

- Crystal track must be kept the shortest possible so crystals must be placed as close as possible to the IC to which they are associated.
- The parts should be arranged evenly spaced guaranteeing that their pads are sufficiently distant to enable interconnecting routing to pass between them.
- Even if the parts can be placed in whichever orientation, it is recommended to use only two orientations: vertical and horizontal for soldering facilities.
- Sufficient diameter around the mounting holes should be allowed in order to avoid the injury of parts placed around it when mounting the board.

5.2.2 Board routing

Once the parts have been conveniently placed, routing can be done. Routing is the process of laying down tracks to connect the components of the board. Each electrical connection between 2 or more pads is known as net. Some basic routing rules are next listed.

- The trace must be done as short and direct as possible. The longer is the net, the greater are the resistance, capacitance and inductance associated to it which are undesired factors.
- The use of right angles must be avoided because they can cause more radiation in the region of the corner. Right angle corners should be substituted by 2 45º corners as shown in figure 40.

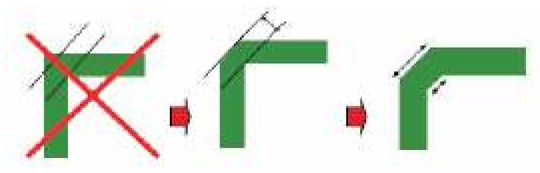

Figure 40 – Poor and good right angle bends - 2 corners of 45º should be used instead of the right angle corner.

- When circuits present many components, it becomes necessary to deal with one or more board layers. The recourse to vias of connection is essential to enable traces distribution among several layers. The use of vias enables the vertical/horizontal strategy: route the traces orthogonally to each other on adjacent layers to avoid coupling.

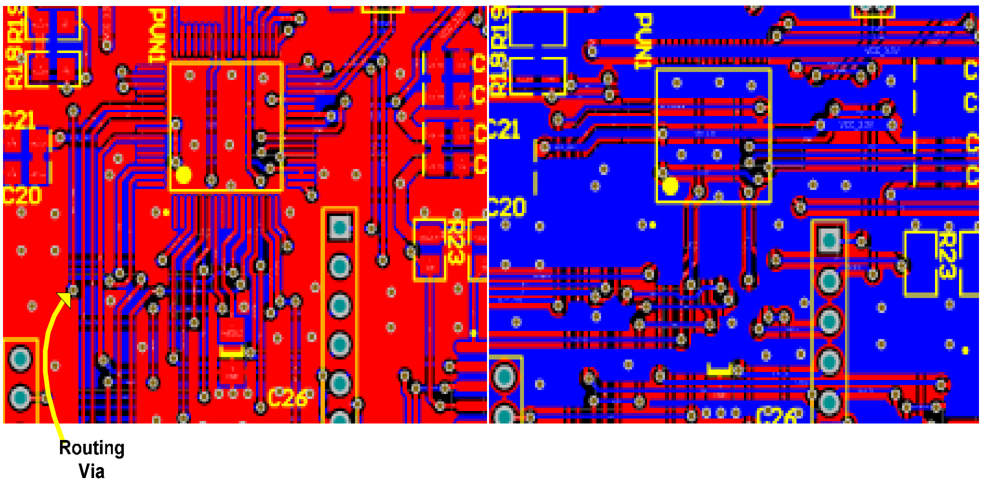

Figure 41 - An example of the vertical/horizontal strategy - The left and right side of the figure represent the top and bottom layers of a same region of the transmission module board. In the figure the vertical routing organization is evident on the top layer while horizontal routing organization has been held on the bottom layer. Transitions between the 2 layers are made through routing vias.

It is important to refer that less vias is better as they bring additional inductance and capacitance and couple noise. The boards design for the vital signs monitoring system only include 2 layers: on one side of the board, routing is made in the horizontal direction while on the other side of the board it is made in the vertical direction as it is shown in figure 41.

- When using a two layer board, it is not convenient to run tracks on top and bottom exactly one over the other. If this situation can't be avoided, at least one must try to reduce to the utmost the extent of the overlapping between top and bottom tracks.
- Polygons can be used to automatically fill large areas with solid copper. Simple or more complex planes can be easily made defining each corner of the polygon. An example of a power plane defined on the transmission module board is shown on figure 42.

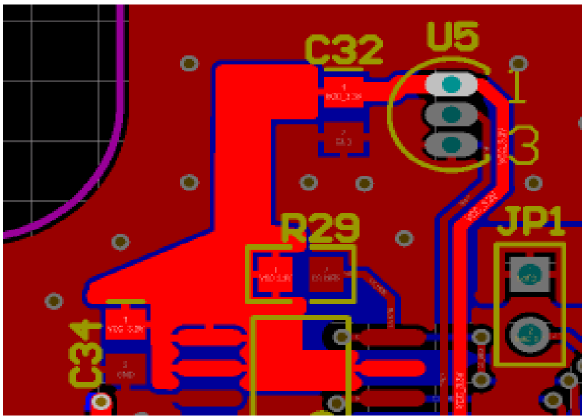

Figure 42 - An example of a solid polygon fill - The evidenced region represents a polygon that connects all pads powered with a voltage of 3.3V in that region.

- The track should always be drawn until the pad centre. Even if the track touches the pad, it may be not enough for the program to detect the electrical connection between them. Also, the track must go right to the pad centre and not off to one side. In that case, the error should be identified when running the Design Rule Check tool of the program.
- If the power and ground tracks are considered critical then it is better to lay them first. As the power tracks must be wide and as it is the supply source for all devices on the board, it need to reach all of them so it appears convenient to first draw all the power tracks thus enabling the use of less blends and vias.
- After having place all components and made the routing, solid ground planes on both sides of the PCB must be routed and lots of vias should be placed between them. It is recommended to split the analogue ground and the digital ground to avoid noise coupling between the digital part and the sensitive analogue part.

Now regarding the track size used when routing the board, no standard are recommended for this concern. As a general rule, the bigger the track width, the lower is the DC resistance and inductance introduced by it and thus the better it is. The track must consequently be kept the wider possible. Sometimes, due to clearance requirements, it may be necessary to reduce the track width. In summary, the track width choice must be based on the electrical requirements of the design, the routing space available and as last resort, on the own personal preferences of the designer. Spacing between tracks is also important. It is recommended to keep the distance between 2 traces at least approximately 2 times the width of the traces [38] to minimize the cross-talk effect. This effect appears when two traces run along each other so that a mutual influence is present. Due to electromagnetic field, the influenced trace is subjected to inductive and capacitive coupling which can lead to the device malfunctioning.

After having concluded the circuit routing, the Design Rules Check tool should be used to automatically check the PCB design for connectivity, clearance between tracks, pads and components and other errors that may exist in the circuit.

In summary, in this section some basic rules for PCB layout design have been presented. The described topics have been followed when creating the transmission, acquisition and communication modules circuit boards. In some situations, those rules have not been strictly respected depending on the part of the circuit being treated or particular recommendations of the components manufacturers.

CHAPTER VI: CONCLUSION AND FUTURE WORKS

The Remote Vital Signs Monitoring project development has been described in the present project report. The projection and design of a system that enables the remote acquisition and wireless transmission of physiological data have been the central objectives of the project and the focus themes of the present report. The document is concluded with a brief summary that reassumes the intended plan of the project, the researches conducted during its progress, what have been done and what future developments can be done. At last, a final appreciation regarding this project benefits in general and especially for the student is made.

6.1 What have been done?

The Remote Vital Signs Monitoring project had the objective of develop a system that will enable patients to be fully mobile while they are submitted to their health condition monitoring, and continuous accompaniment by healthcare professionals. The project emerges from the still and significant gap between the existing solutions and the growing need for health care. The most pressing issues in the medical field are related with the need for more human resources and simultaneous necessity for budgetary restrictions. On the other hand, population requiring healthcare delivery is growing. These issues may represent a threat to the QoS delivered to patients. This project marks an attempt to settle the matter improving the health care quality through the creation of a system that would benefit not only the medical professionals but also the patients to which mobility and care may be offered.

For this purpose, a deep study of the State of the Art helped understanding the main vulnerabilities of the systems already existents. The result of this analysis is of extreme importance as it provides a base for the projection of an innovative system for the physiological parameters monitoring. The solution would combine the use of wireless technologies with the advancing in the medical field to provide accurate measurements of patients' vital signs data in real-time and continuously.

In the report, two monitoring scenarios have been analyzed namely at the hospital and at home. The purpose of the project was the projection of a unique system that would be operational in both scenarios. It consists mainly of two modules: the acquisition module for data capture and wireless transfer to the second one, the transmission module from which after being received, data are wirelessly sent to a final server platform where they may be submitted to processing before becoming available to healthcare professionals. The first prototype has been designed for the monitoring of 4 vital parameters: the ECG, the pulse oximetry, the skin temperature and the posture and movements of patients. The automatism of data capture, transfer and processing appears to be very useful especially for extended recordings of ECG signals where human processing is not only time consuming but also error prone. The entire set of data will provide meaningful information for the diagnosis of abnormal conditions in patients' health status.

Unfortunately, due to many unforeseen problems, the solution is only as a PCB design stage. The first prototype construction has not been achieved because of the lack of time. The planning proposed by the student and its supervisor in the initial phase of the project development has not been strictly respected leading to progressive delays in achieving the tasks agreed. The student started to work on the technical aspects of the system on April 2007. The idealistic time plan scheduled at this juncture did not account for the lack of electronic bases and lack of expertise in circuit design of the student which slowed down the entire process. The fist prototype of the monitoring system is now at a stage ready to be constructed and tested. The system architecture is completely defined so are its schematic and PCB design but there is still a lot of work to be completed in the future.

6.2 What can be done?

In this section, some suggestions regarding future developments that can be studied and applied are explored.

At short term, the first prototype of the system should be constructed and tested for both electric and functional verification. The constructed base platform prototyping boards will serve for the firmware (to be embedded in the hardware devices) development but also as a starting point for future developments for the system optimization. This optimization must be focused on cost savings improvement. The system should also be reviewed in order to attempt to reduce its dimensions, i.e. make it more ergonomic and less cumbersome for the patient. Still thinking about the patient's needs, it is obviously important to enhance the modules autonomy to confer him the maximum mobility.

Long-term objectives can also be defined. The system evolution should be directed to the progressive miniaturization of the sensors placed on the patient. The ideal solution would consist of self-adhesives disposed at predefined locations on the patient to measure the physiological data. Thinking further about the possible evolution of the system, the enhancement of the local processing capability of the sensors would represent a big step ahead for the present application. This last evolution will surely imply the recourse to new solutions to supply the sensors as for example thermal or piezoelectric micro-generators.

Still at a hardware level but now regard to the specific sensors used in this application, it may be interesting to develop and certificate new sensors endowed with wireless technologies such as Bluetooth or ZigBee for direct data transmission. Once again, the cost savings concern must be kept in mind. A good suggestion to reduce the costs inherent to this application is the construction of a new pulse oxymeter and subsequent certification. The device can be easily acquired but presents the disadvantage of being expansive. Once it is not too complex, a new model can be produced without major difficulties.

The system has been designed to make the ECG measurements through the placement of only three electrodes which will provide a one-lead ECG. Some deep research needs to be carried out in order to check the effective usefulness of the one-lead measurement and to verify which improvements should be introduced to optimize the ECG measurements such as the use of more electrodes and their specific placements on the body surface.

This section is concluded with a brief approach to Software developments that have to be conducted. Once the first prototype will be operational, the need for a platform for data gathering and processing becomes indispensable. All gathered data after being processed should be conveniently organized in a database from where they will be easily accessed. Additionally, alarms must be generated whenever an abnormal situation in patients' data is detected and according to the seriousness of the situation. Their visualization implies the development of a user interface not only for data consultation but also for the creation of new configurations for the platform, or the introduction of additional information regarding patients such as personal data and subjective information about its health condition.

As it has already been referred in the initial part of the document, the system was supposed to be tested at the CCC on January, 2007. Now that it is defined, it will be interesting to fix a new date for the first prototype implementation and testing in a real hospital scenario.

6.3 Final appreciation

The final appreciation of the project can be made from 3 different points of view. From an engineering standpoint, this project has defined a new system that combines various technologies to provide a new solution that may enable cost savings and the simultaneous quality of care improvement. From a clinical standpoint, the project will enable early diagnosis, even from sickness prevention to therapy and after-care. Clinical professionals will be able to access accurate data with easier understanding and be alerted whenever critical events occur. They may thus accompany continuously the health status of their patient from a remote location.

Now from a personal standpoint, globally the result of the project is very positive for the student. First, at an academic level, it obliged the remembering of some knowledge previously acquired and above all the deepening of its knowledge of electronics theory. One of the most important aspects of the student participation in the project is the fact that he learns how to work in a team, how to combine the ideas of the elements of the entire project team to give rise to a new valid solution. The student encounters many difficulties that slowed down the project progress, situations that only can have been resolved with his dedication and support of the supervisors. On the last stage of the project development, the student has been integrated in the ISA's installations having the opportunity to contact with all the personnel working in the company, with the enterprise world. It had been given to the student the extremely positive opportunity of being integrated in the R&D unit of the company, to acquire knowledge, to become more independent and to have a first approach of the professional world.

This project has been the bridge between the academic and professional life of the student.

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ATTACHMENTS

APPENDIX A

Inquiry to the Portuguese's Healthcare Units

The following table presents the results of an inquiry made in order to verify the technologies used in the Portuguese's healthcare units. Many units have been contacted via email by the team project students in order to verify if their installations integrate informatics networks and which technologies are used for the establishment of the networks when they are implemented.

Inquired Hospitals	Answers
1. Hospital S. Sebastião - Santa Maria Feira	- Wired and Wireless networks - Star topology with 3Mbit Backbone
2. Hospital Distrital de Águeda	- Wired network - 2 Wi-Fi networks
3. Hospital da Trofa	- Wired network - Wi-Fi network in the internment units
4. Hospital Privado de Santa Maria de Faro-Faro	- Wired network
5. Hospital Infante D Pedro – Aveiro	- Wired network - Wireless network in some units
6. Hospital do Arcebispo João Crisóstomo - Cantanhede	- Wired network - 2 Wireless antennas
7. Hospital Dr. Francisco Zagalo-Ovar	- Wired network - Wi-Fi network in the internment units
8. Hospital São Pedro Gonçalves Telmo-Peniche	- No internal informatics network
9. Hospital Prisional S. João de Deus - Oeiras	- Wired network
10. Hospital Júlio de Matos-Lisboa	- Wired network - Wireless network in the informatics service
11. British Hospital de Campo de Ourique-Lisboa	- Internal informatics network
12. Hospital José Luciano de Castro – Anadia	- Wired network
13. Hospital São João de Deus, S.A.- Vila Nova de Famalicão	- Wired network - Wireless network (not used)
14. Hospital Distrital de Faro	- Wired network - Star topology
15. Hospital Amato Lusitano-Castelo Branco	- Wireless communications with the provisions sector

Inquired Hospitals	Answers
16. Hospital Distrital de Ponta Delgada	- Wired network
17. Hospital Joaquim Urbano - Porto	- Wired network
18. Hospital Distrital da Guarda - Sousa Martins	- Wired network - Wireless communications between the hospital and the psychiatric unit
19. Centro Hospitalar do Baixo Alentejo EPE	- Wired network
20. Hospital de Angra	- Wired network
21. Centro Hospitalar Vila Nova de Gaia	- Wired network in 2 units - Wi-Fi network in the internment units
22. Hospital Padre Américo - Vale do Sousa, EPE	- Wired network - Wi-Fi network in the internment units
23. Hospital Dr. José Maria Grande	- Wired network - Wireless communications between the hospital and the psychiatric unit
Hospital Militar Principal	- Wired network
Hospital Conde de S.Bento - Santo Tirso	- Wired network - Wi-Fi network
Hospital Militar Regional nº 2	- Wired network

APPENDIX B

Schematic Documents and PCB Layout Diagrams

Acquisition Module

Transmission Module

Bluetooth Module

ZigBee Module

GSM GPRS Module