Intelligent Sensing Anywhere

Centro Hospitalar de Coimbra – Hospital Pediátrico de Coimbra

Centro de Electrónica e Instrumentação

Sleep@Home
Remote Monitoring of Sleep Apnea Syndrome Patients

Sleep@Home
Monitorização Remota de Doentes com Síndroma da Apneia do Sono

Final Project Report

Version 1.0

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Abstract

Obstructive Sleep Apnea Syndrome (OSAS) is a dysfunction of the respiratory ways that affects adults and children, but for children consequences are worst and more prejudicial.

Its diagnosis is made commonly using Polysomnography (PSG). However, this technique is very complex and implies that the patient is monitored during a complete night in a hospital. This study is expensive and available in few pediatric Portuguese hospitals. Moreover, it is a harmful technique because children are surrounded by wires and are forced to spend one night in a strange environment. Thus, the possibility of occurrence of the white-coat effect cannot be rejected, as children take longer to adapt to the hospital's environment and to fall asleep, a fact that will affect the results.

In order to avoid these undesirable effects, several devices have been developed to detect OSAS in domiciliary environments. However, as the majority of these devices support its results on the analysis of the oximetry and on the internal parameters of the patient, false negatives are still high.

Therefore, Sleep@Home was developed to make a selection of the patients at their home. The obtained results are mainly based on the analysis of the oximetry. Furthermore, this project's main innovation consists on the crossing of these data with video images, in order to reduce false negatives rate.

Results suggest that Sleep@Home can be a powerful tool in this scope.

Resumo

A Síndroma da Apneia do Sono é uma disfunção das vias respiratórias que atinge adultos e crianças, sendo que para as crianças as consequências são mais nefastas.

O seu diagnóstico é feito comummente usando a Polissonografia (PSG). Contudo esta técnica é bastante complexa e implica que o doente seja monitorizado durante uma noite completa num hospital. Este estudo é caro e está disponível em poucos hospitais pediátricos do País, sendo dramático principalmente para as crianças que se vêm envoltas em fios e que se vêm obrigadas a passar uma noite num ambiente que lhes é estranho. Assim, a possibilidade de ocorrência do efeito de bata-branca não pode ser posta de parte.

De modo a colmatar estes efeitos indesejáveis, têm sido vários os dispositivos a ser desenvolvidos para o despiste da Síndroma da Apneia do Sono em ambiente domiciliário. Porém, como a maioria destes dispositivos baseiam os seus resultados na análise da oximetria e de parâmetros internos do paciente, o número de falsos negativos é ainda elevado.

Nesta linha de pensamento, o Sleep@Home foi desenvolvido para fazer uma triagem aos pacientes no seu domicílio. Os resultados obtidos baseiam-se principalmente na análise da oximetria, sendo o cruzamento destes dados com imagens de vídeo a principal inovação, de modo a reduzir o número de falsos negativos.

Os resultados sugerem que o Sleep@Home poderá ser uma ferramenta poderosa neste âmbito.

Acronyms

ISA	Intelligent Sensing Anywhere
CEI	Centro de Electrónica e Instrumentação
PSG	Polysomnography
TCP/IP	Transmission Control Protocol/ Internet Protocol
VB.NET	Visual Basic. NET
IBILI	Instituto Biomédico de Investigação da Luz e da Imagem
HPC	Hospital Pediátrico de Coimbra
OSAS	Obstructive Sleep Apnea Syndrome
REM	Rapid Eye Movement
ADHD	Attention Deficit Hyperactivity Disorder
CPAP	Continuous Positive Airway Pressure
EMG	Electromyography
EEG	Electroencephalogram
EOG	Electrooculography
AHI	Apnea/Hypopnea Índex
LED	Light-Emitting Diode
SpO_2	Saturation of Peripheral Oxygen
PAT	Peripheral Arterial Tone
ANS	Autonomic Nervous System
GB	Gigabyte
GSM	Global System for Mobile Communications
GPRS	General Packet Radio Service
UMTS	Universal Mobile Telecommunication System
ADSL	Asymmetric Digital Subscriber Line
Kbps or Kbits/s	Kilobits per second
Mbps or Mbit/s	Megabits per second
VDSL	Very-high-bit-rate Digital Subscriber Line
LAN	Local Area Network
CD	Compact Disc
DVD	Digital Video Disc
RAM	Random Access Memory

JPEG	Joint Photographic Experts Group
MPEG	Moving Picture Experts Group
EDF	European Data Format
ASCII	American Standard Code for Information Interchange
PDA	Personal Digital Assistant

1. Introduction

1.1. Scope

Sleep@Home is a project developed within the scope of Project Discipline ("*Disciplina de Projecto")* of Licenciatura in Biomedical Engineering (*"Licenciatura em Engenharia Biomédica*") of the Physics Department of the University of Coimbra ("*Departamento de Física da Universidade de Coimbra"*). It was developed by Lara Aires (lccaires@gmail.com) and Samuel Pereira (pereira.samuel@gmail.com) under the orientation of Eng.º Jorge Rodrigues (ISA - Remote Management Systems) and of Prof. Dr. Carlos Correia (Physics Departement).

Project Discipline which is part of Biomedical Engineering course aims to put in practice the knowledge acquired throughout the course, the achievement of new predominantly technical knowledge, as well as the acquisition of skills for the integration in a real company.

Therefore, Sleep@Home resulted from a project proposal made by the company ISA to be developed in Project Discipline in a partnership with the Centro de Electrónica e Instrumentação (CEI) of the Department of Physics.

This initiative was based on the contribution of a company who idealized and received the idea - ISA -, as well as on the support given by the Hospital Pediátrico de Coimbra, to validate Sleep@Home.

1.2. Motivation

Quality of life represents a growingly primordial factor on society. One of the illnesses that harms quality of life is Sleep Apnea Syndrome, mainly due to its medium/long period stated consequences.

According to Helpguide.Org, 90% of people who have sleep apnea don't know that they have it [1].

Levy *et al* [2] say that the prevalence of sleep apnea is estimated at between 4 to 8% of the population. And in the journal of American Family Physician it is stated that from

3% to 12% of children snore, while obstructive sleep apnea syndrome affects 1% to 10% of children [3].

Whereas in adults these consequences are reflected mainly in the cardiovascular system, in children damage can be verified at the level of the physical and neurocognitive development, even influencing their behavioural skills [4].

The diagnosis technique currently used is the Gold Standard of sleep studies – Polysomnography – whose access is reduced due to its diminished existence in Central National Hospitals, mostly in Paediatrics Hospitals. Thus, the accessibility to this type of diagnosis is currently scarce, delaying diagnosis.

Levy *et al* [2] states that the high prevalence of the disease, the cost and the inconvenience of polysomnography make simplified techniques desirable for diagnosing OSAS.

The American Thoracic Society has reached a consensus that "Assessment of sleep and breathing in the home using video and cardiorespiratory recordings with extended oximetry appears promising, but recommendations regarding their use require further clinical trials." [5]

Several portable devices have been created with the purpose of replacing the sleep study in laboratory and controlling the pathology at the patient's house.

However, the certainty that improvements can be introduced towards the already existing technologies, so as to create a new device, whose main objective, besides monitoring at home, is to make a triage for the study of complete sleep, as well as the support and interest revealed by physicians and technicians of this area in Hospital Pediátrico de Coimbra, were a strong motivation to bring the Sleep@Home project forward.

1.3. Project Presentation

1.3.1. Objectives

Sleep@Home aims to be a device of triage for the complete sleep study (Polysomnography - PSG), portable, simple and efficient.

In order to fulfil all the considered requirements, the generic idea consisted of a connection between an oximeter and a video camera to a portable device, in which an application analysing the resulting data from the two devices would be installed.

The Sleep@Home would be able to detect apnea events and emit alarms that would be available through access to a server, or they would be sent to a mobile device.

As it will be explained in the chapter concerning the Architecture of the System, as the project was being developed, some alterations were made to the work during the project.

The deadline was set forward and all the work related to the access to the data by wireless transmission was not included in the planning of the project.

1.3.2. Initial Project Plan

Since this project had an academic end, its length consisted of one school year. Therefore, all the tasks were planned for two semesters.

Due to its strong Medicine-related basis, this project required a comprehensive research on Apnea: its causes, consequences, manifestations, ways of diagnosis and treatment. Only this way could we obtain the theoretical background that allowed an accurate analysis of the problem and the choice of a correct approach to solve it.

During the first semester there was a focus on the research needed for this problem's theme and on the elaboration of state of the art documents, requirements analysis, architecture and planning.

Furthermore, we realised that there was a need to acquire knowledge on language programming, such as C and VB.NET for future application in the project. This phase of learning was also planned to be accomplished in the first semester.

The most practical part of the project was planned for the second semester. It was thus intended to put in practice everything that was studied in the first semester: collecting data, developing the application of detection of apneia events and graphical interface.

This planning is fully examined in subchapter **Project Planning**, in which there is an analysis of the tasks to develop, as well as the decision of who would responsible for their execution. Moreover, in this chapter the Gantt Diagram has been included. This diagram is related to the initial planning, which was then subject to some adjustments, options which are also explained in detail in this subchapter.

1.4. Involved Entities

1.4.1. ISA – Remote Management Systems

ISA is an awarded global telemetry company, leader in different segments of the market, offering innovative remote management systems with a broad range of applications: gas, oil, chemical products, water and sewers networks, industry, environment and domotics.

Its main areas of application are Telemetry Solutions for the Utilities, Industrial Telemetry and Logistics, Building Management Systems, Environmental Monitoring and Control and Health Care and Medical Solutions.

It is located at Rua Carlos Seixas, in Coimbra [6].

This project's central idea - Sleep@Home came from ISA. Throughout the project, we have relied on their support namely in technical and logistic terms.

1.4.2. CEI – Centro de Electrónica e Instrumentação

CEI has been recently founded in the Physics Department of the University of Coimbra. Its research areas are Atomic and Nuclear Instrumentation, Biomedical Instrumentation, Plasma Physics Instrumentation, Microelectronics, Optical Signal Processing and Telemetry and Industrial Control.

CEI keeps a close cooperation with several national and international institutions that develop their investigation work in common research areas with unquestionable scientific results. Among these, special reference should be made on the work performed along with "Centro de Fusão Nuclear" (Nuclear Fusion Center) of the "Instituto Superior Técnico" in Lisbon, as well as the work developed with Biomedical Institute for Light and Image Research (IBILI), responsible for the Instrumentation and Biomaterials' Department [7].

The development of this project took place in our usual working place in CEI, where we have had support in every situation.

1.4.3. HPC – Hospital Pediátrico de Coimbra

The Hospital Pediátrico de Coimbra belongs to the Centro Hospitalar de Coimbra, EPE [8].

It is located at Celas area, in Santo António dos Olivais near the “Hospitais da Universidade de Coimbra” and “Instituto Português de Oncologia de Coimbra Francisco Gentil, EPE”.

Hospital Pediátrico’s area of influence encloses the country’s central region, and it presents itself as a hospital of reference for the district hospitals in the central region and for the health centres of the district of Coimbra. Nowadays, it is still a national reference for specific pathologies.

In the HPC we have counted on support from the team at the Laboratory of Studies of Sleep, mainly in relation to the execution of tests for Sleep@Home validation. We have also received support from Drª Helena Estêvão who has given us specific medical counselling and a global appreciation of the project, from the perspective of a potential user of the Sleep@Home.

Drª Helena Estêvão is the director of the Service of Paediatric Medicine whose objectives are to give general support to children who live in the central region, to aid children who have sleep respiratory pathologies all over the country, and within a national scope in the area of liver transplant [9], [10].

1.5. Contributions to This Work

This work, as a discipline of Biomedical Engineering course aims, essentially, to reveal to external entities and to put in practice skills acquired by students throughout the course. Furthermore, it also intends to provide us an entrance to the work market.

For this purpose, integration within a company - ISA – was negotiated, and the project developed from there. This partnership resulted in a product that can be soon commercialized: Sleep@Home is a device which intends to be a market innovation especially for OSAS diagnosis.

Sleep@Home will combine the technology of oximetry with video recording, providing an interface sufficiently simple to use and, yet very complete, as it allows the crossing of several parameters and results.

Therefore, Sleep@Home presents itself as an innovative technology since it is portable, simple to use, complete and efficient in the selection of the OSAS. Moreover, it also aims to contribute to a faster and easier access to sleep tests reducing Polysomnography waiting lists in some Hospitals.

1.6. Report Organization

This report aims to reflect upon my role during the participation in the development of the project Sleep@Home.

Furthermore, it also wishes to explain all the procedures that the project has been through since its beginning, until the present time. The project has now been concluded as an academic/pedagogical project in the scope of Project discipline, part of Biomedical Engineering course.

Thus, this report is structured in five main chapters.

In the first chapter, **Introduction**, there is a brief explanation of this project: its scope, motivation and objectives. The preliminary planning is presented, as well as the entities involved in it. In addition, a brief reflection on the contributions to this work is also made, and finally there is a summary of the organization of the report.

Afterwards we go through the second chapter, **Theoretical Background**, which presents important concepts for the understanding of Sleep@Home, as well as the problematic that is to be solved. Among these concepts are Apnea and Oximetry. An analysis to the state of the art documents is also done.

The third chapter, **Project Development,** introduces an analysis of the problem that Sleep@Home aims to solve and a description of the requirements, architecture, planning and development of the Project. This chapter provides an approach to the project development since its beginning until its conclusion including all the methods developed and procedures involved.

In the fourth chapter, **Tests and Results**, there is a description of the tests done during the development of Sleep@Home and an analysis to the acquired results.

The fifth chapter, **Conclusions**, reflects upon the accomplishment of the objectives set for this project, also focusing on the future work. Finally, it develops a global appreciation of Sleep@Home.

It must be pointed out that the references used during the development of this report are presented at the end of each chapter.

1.7. References

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2. Theoretical Background

2.1. What is OSAS?

Sleep Apnea is a respiratory dysfunction that affects children and adults. There are three different types: obstructive, central or mixed.

Therefore, Obstructive Sleep Apnea Syndrome (OSAS) is one type of Apnea that exists and is commonly referred to as Sleep Apnea.

In SleepNet Corporation's site it is mentioned that for some people, apnea occurs when the throat muscles and tongue relax during sleep and partially block the opening of the airway. When the muscles of the soft palate at the base of the tongue and the uvula (the small fleshy tissue hanging from the centre of the back of the throat) relax and sag, the airway becomes blocked, making breathing laboured and noisy and even stopping it altogether. Sleep apnea also can occur in obese people when an excess amount of tissue in the airway causes it to be narrowed. With a narrowed airway, the person continues his or her efforts to breathe, but air cannot easily flow into or out of the nose or mouth. Unknown to the person, this results in heavy snoring, periods of no breathing, and frequent arousals (causing abrupt changes from deep sleep to light sleep) [1] . More symptoms are excessive daytime sleepiness, loss of energy and fatigue, depression and trouble concentrating [2].

In the long run, this pathology has serious cardiovascular consequences like high blood pressure, due to the effort that the heart is subject during the period of no breathing, memory problems and headaches [3].

2.2. Apnea in children

Obstructive sleep apnea (OSA) is the most common type of sleep apnea in children, but there are also registers of hypopneas [4]. According to Michael Steffan, hypopneas are episodes of shallow breathing during which airflow is decreased by at least 50%. They are usually accompanied by some degree of oxygen desaturation, which can be minor and transient. Like apnea, hypopnea is subdivided as being obstructive, central, or mixed [5].

Such events occur mainly during the Rapid Eye Movement (REM) sleep that is a phase of sleep marked by extensive physiological changes, such as accelerated respiration, increased brain activity, eye movement, and muscle relaxation [6].

According to Ronald B. Kuppersmith, in several studies from the literature, the prevalence of paediatric obstructive sleep apnea is estimated to be between 0.5 and 3% [7].

The majority of sleep apnea sufferers range in age from two to six, and in rare instances, the condition can be found in newborns and adolescents. Obstructive sleep apnea occurs equally in boys and girls and is often caused by large tonsils, adenoids, cleft palate or cleft palate repairs, a receding chin, allergies, anatomical abnormalities or obesity. Additionally, research suggests that children with Downs Syndrome may be at greater risk for obstructive sleep apnea [8].

Symptoms of OSAS in children are frequently recognized by their parents or teachers and can be divided into night time and day time, according to Ronald B. Kuppersmith [7]. Night time symptoms are typically more severe and reported symptoms include snoring, restlessness, enuresis, sleep walking, restlessness, profuse diaphoresis, loud gasping respirations, paradoxical chest movements, and retractions.

During the day children may seam happy and otherwise healthy. Daytime symptoms include noisy breathing, mouth breathing, chronic rhinorrhea, morning headache, behaviour disturbances, poor school performance, and excessive daytime sleepiness.

There are several consequences of the presence of OSAS. According to American Family Physician when children don't get the amount of sleep they need, they become moody, don't pay attention, and can cause problems at home and at school. Their school-work and sports abilities may get worse. They may lose their overall sense of well-being.

Children with sleep apnea may lack energy. They may prefer to sit in front of the TV instead of joining in school and home activities. This can lead to weight gain and obesity, which make the problems of sleep apnea even worse.

Another problem of sleep apnea in children is called failure to thrive. Growth hormone is released when a child sleeps at night, and sleep apnea can interrupt this process. This means that some younger children with sleep apnea will not gain a normal amount of weight and height.

Behaviour problems have been related to sleep apnea, specifically ADHD (Attention Deficit Hyperactivity Disorder). It is also common for children with sleep apnea to wet the bed [9].

2.3. Diagnosis of Sleep Apnea in Children

According to SleepApneaInfo.com, diagnosing sleep apnea in children is critical because many sleep disorders often go undetected. If a parent suspects that his or her child may suffer from a sleep disorder, it is recommended that the child should have a thorough physical examination by his or her paediatrician [8].

As part of the exam, the doctor will check his/her mouth, nose, and throat for extra or large tissues; for example, tonsils, uvula (the tissue that hangs from the middle of the back of the mouth), and soft palate (the roof of mouth in the back of throat) [10].

On the advice of a physician, the child should undergo a polysomnography, commonly referred to as a sleep test, administered by a sleep specialist, who will ask the parents to provide a complete medical history. At that point, a pediatrician, pulmonologist or physician specializing in sleep disorders will be able to diagnose the condition and recommend treatment [8]. This process is shown in the next image (Figure 1)[1].

[1] To a more detailed algorithm for diagnosis and management of OSAS in children see "Clinical Practice Guideline: Diagnosis and Management of Childhood Obstructive Sleep Apnea Syndrome." [11]

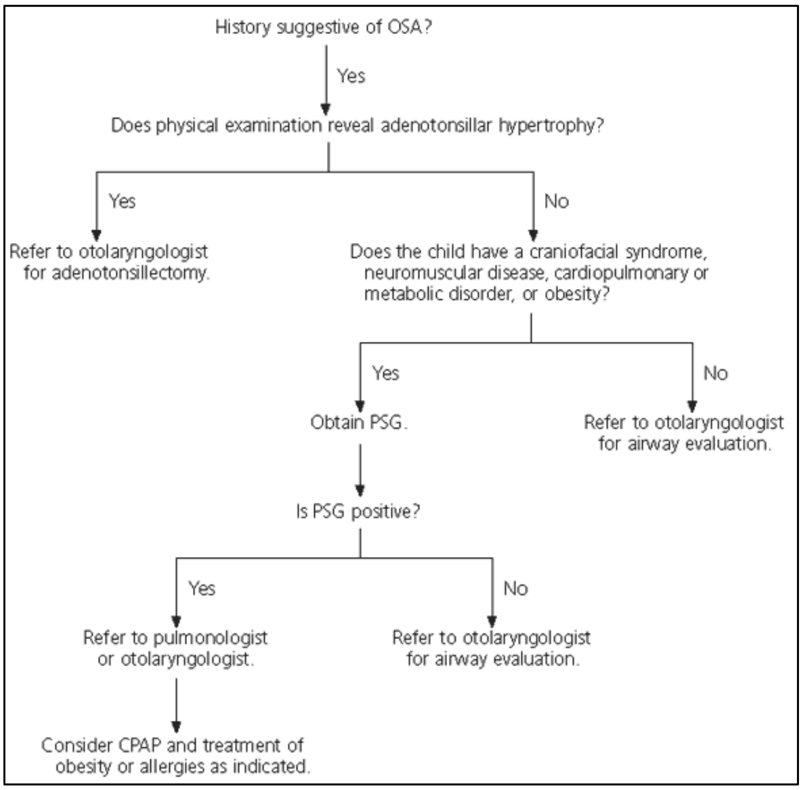

Fig. 1: Algorithm for the management of OSA in children. (OSA = obstructive sleep apnea; PSG = polysomnogram; CPAP = continuous positive airway pressure). From: J. Chan *et al.* (2004, March 1). Obstructive Sleep Apnea in Children. *American Family Physician* [Online]. Available: http://www.aafp.org/afp/20040301/1147.html

In the sub-chapter **Methods of Diagnosis of Sleep Apnea in children,** PSG and some more techniques are completely explored.

2.4. State of the Art

2.4.1. Methods of Diagnosis of Sleep Apnea in children

2.4.1.1. Polysomnography (PSG)

Polysomnography (PSG) in a sleep laboratory is the current standard for the diagnosis of OSA. Patients stay overnight in the sleep laboratory and are constantly monitored by a technician. Level 1 PSG includes electroencephalography, electrooculography, submental electromyography (EMG), electrocardiography, respiratory movement or respiratory effort, nasal or oral airflow, pulse oximetry and limb movement EMG. Level 2 PSG does not include EEG, EOG, and submental EMG. These data are collected to calculate the apnea-hypopnea index (AHI), which is the sum of apneas and hypopneas per hour of sleep [12].

Such a sleep study takes a long time (one to two hours for preparation, 10 to 12 hours to acquire data and 3 to 4 hours to analyze the data) and costs over 1000€ [13].

These tests are used both to diagnose sleep apnea and to determine its severity [1].

The role of polysomnography in the diagnosis of childhood sleep-disordered breathing remains controversial. Although polysomnography is the current gold standard, authorities cite the lack of reliable sleep laboratories for children, excess cost, and lack of consensus on interpretation of polysomnograms as reasons it is not required for diagnosis [14].

Furthermore, according to Jan Frölich and Gerd Lehmkuhl, especially for children, the sleep laboratory is likely to be a particularly sleep-disruptive setting, requiring some adaptation time to eliminate first-night effects. In contrast, this problem does not seem to arise with home polysomnography in adolescent or preadolescent children [15].

The long waiting lists that are a result of the limited number of clinics of study of sleep could be reduced with new diagnosis techniques, some of which will be analyzed in the following subchapters.

2.4.1.2. Monitoring by the Relatives

According to Sivan *et al.* [16], in order to observe children whilst asleep in their natural environment, home video-recording may be used. This may improve physicians understanding of the child's breathing problem and add important information to the physical examination, because that allows the observation of movements, episodes of awaking, chest retractions and oral breath.

The observation of the child’s sleep, through the video, allows the identification of the pathology’s severity. Moreover, sleeping at home provides more accurate and precise data. Additionally, there is a high agreement between the observed events in the video recording and events detected in the PSG.

Nowadays, there are already algorithms that easily allow the detection of movements registered in the video recording, a fact that represents an asset for OSAS analysis.

One of the video's restrictions is not to be able to identify the state of sleep and it can be even worse if there haven't been done registers of the REM sleep phase, when important events can occur. Moreover, it is also difficult to deal with the amount of information, since it is not viable for a physician to analyze several hours of writing, a fact that indicates the necessity of selecting information.

As for the benefits, we must mention its low cost and the fact that it is a method that almost does not interfere with the child's sleep.

In a textbook of paediatric respiratory diseases [17], home video-recording during sleep has been suggested as the first step in the clinical evaluation of children with suspected OSAS, and also as a screening method [16].

These home video-recordings are carried out by those who are close to the child, which means by his/her relatives.

The final results are not always the best, mainly owing to the inherent fatigue that comes from the long recording of several hours of sleep, but also due to image quality. Thus, essential information may be lost.

2.4.1.3. Pulse Oximetry

According to Fearnley, pulse oximetry is a simple non-invasive method of monitoring the percentage of haemoglobin (Hb) which is saturated with oxygen. The pulse oximeter consists of a probe attached to the patient's finger or ear lobe which is linked to a computerised unit. The unit displays the percentage of Hb saturated with oxygen together with an audible signal for each pulse beat, a calculated heart rate and in some models, a graphical display of the blood flow past the probe. An oximeter detects hypoxia before the patient becomes clinically cyanosed [18].

As it is mentioned in Oximetry.org [19], the principle of pulse oximetry is based on the red and infrared light absorption characteristics of oxygenated and deoxygenated hemoglobin. Oxygenated hemoglobin absorbs more infrared light and allows more red light to pass through. Deoxygenated (or reduced) hemoglobin absorbs more red light and allows more infrared light to pass through. Red light is in the 600-750 nm wavelength light band. Infrared light is in the 850-1000 nm wavelength light band.

Pulse oximetry uses a light emitter with red and infrared LEDs that shines through a reasonably translucent site with good blood flow. Traditional adult/paediatric sites are the finger, toe or lobe of the ear. Infant sites are the foot or palm of the hand and the big toe or thumb. Opposite to the emitter is a photodetector that receives the light that goes through the measuring site.

There are two methods of sending light through the measuring site: transmission and reflectance but because the transmission method is the most used type, it will be carefully analysed.

After the transmitted red (R) and infrared (IR) signals go through the measuring site, and are received at the photodetector, the R/IR ratio is calculated. The R/IR is compared to a "look-up" table (made up of empirical formulas) that converts the ratio to an SpO_2 value.

In case of apnea, the results will show high fallings in the values of SpO_2 and an instant increase, which corresponds to the wakening phase when the breath comes back to normal. If the results do not match the normal parameters, the physician may demand a PSG.

The function of a pulse oximeter is affected by many variables, including: ambient light, shivering, abnormal haemoglobins, pulse rate and rhythm, vasoconstriction and cardiac function. In addition, there may be a delay between the occurrence of a potentially hypoxic event such as respiratory obstruction and a pulse oximeter detecting low oxygen saturation [20].

Thus, oximetry only does not identify all the apnea cases disclosing many false negatives, not being able to exclude SAOS cases.

A study of oximetry at the patient’s home, combined with a good clinical history can be in many cases a powerful tool in the diagnosis of OSAS, even though oximetry is less reliable than PSG. However, studies carried out in adults confirm that the data of the oximetry *at home* depend on the sampling frequency (due to data storage) which is inferior in comparison to the pulse oximeters used in laboratory, a place where there are not problems of information storage. This fact proved that in an oximetry study, particularly at home, important episodes of apneas and hypopneas can be lost [21].

The results of an American study in 1996 [22] indicate that an appropriate analysis of SpO_2 variability can be valuable as an initial screening test in helping to decide whether to proceed to further investigation of patients suspected of sleep-disordered breathing.

2.4.1.4. Further than PSG

Doing a research on the Internet, there are several devices that are presented as portable technologies of monitoring, developed to support the SAOS diagnosis.

For instance, NovaSom® QSG At-Home Diagnostic system is a bedside device that gives data connected to respiratory events (apneas and hypopneas), snoring intensity, blood oxygen saturation, pulse rate and respiratory effort. Acquired data are analysed "*a posteriori*". It's presented as an alternative to the diagnosis of OSAS [23], [24].

Another device, SleepStrip®, is a simpler device. Its objective is only helping the physician to evaluate the necessity to appeal to a more complete study of sleep, evaluating the number of apneas through the variations of the respiratory air flow [25], [26].

WatchPAT 100 analyzes oxygen saturation, the cardiac beating and one another parameter named PAT (Peripheral Arterial Tone), which reveals the activity of the ANS through the related vascular events. With PAT and common oximetry data the respiratory events that occur during the sleep hours are identified. This is a device for domestic use and some studies indicate that WatchPAT 100 is a good tool of diagnosis and is indicated for studies of control of the therapy for patients in phase of treatment of OSAS [27], [28].

The Embletta system is a device of small dimensions used for diagnosis and follow up of sleep respiratory disturbs treatment. It can be used in hospitals or at home. Its sensors allow the monitoring of a great amount of signals, among which are: flow/pressure, oral flow, snore, abdominal movement, SpO2 average, pulse rate and body position [29].

Moreover, there are the oximeters, among which we mention the Criticare 504 Oximeter that allows the data acquisition of pulse rate and SpO_2 [30] and has been used in a comparative study that is presented next. For more information on oximeters and oximetry subchapter **Pulse Oximetry** should be consulted.

A study carried out in 2004 [31] makes a comparative analysis between some portable devices and the PSG. In Table 1 the results are registered, thus it must be considered that portable devices are divided in three types (Type 2, 3 and 4, corresponding to a sequence of decreasing complexity) and that the PSG corresponds to Type 1. The adaptation of this table includes the devices already analyzed in this report.

Study	**Type and Name of Device**	**Site of Tests**	**Study Conclusion**
Reichert *et al*., 2003 [23]	Type 3. NovaSom QSG	H e SL	In populations believed to have OSA, the portable device has demonstrated acceptable receptiveness and specificity both in the lab and when self-administered at home, when compared to PSG
Bar *et al*., 2003 [32]	Type 4. Watch PAT 100	H e SL	It is believed that the WP100 is a simple, reliable, and accurate device for diagnosing OSAS in the unattended home set-up. Using a device with sensors placed only on the fingers and forearm makes it simple to self-administer and well tolerated. Using the automated scoring algorithm allows objectivity and saves time.
Shochat *et al*., 2002 [25]	Type 4. SleepStrip	SL	Though not projected as a substitute for PSG, the SleepStrip may provide initial screening information, which may be useful in both clinical and experimental settings
Zamarron *et al*., 2003 [33]	Type 4. Criticare 504 Oximeter	SL	If the test result is negative it is unlikely for the patient to receive an OSA diagnosis
Dingli *et al*., 2003 [34]	Type 3. Embletta	H e SL	The use of Embletta as in the study can save both costs and sleep laboratory usage in the diagnosis of obstructive sleep apnoea/hypopnoea syndrome.

Table 1: Results of *at home* studies from some portable devices for the diagnosis of OSAS (adapted) [31]. "Quality Grade" result is a comparison between portable devices and the PSG. Legend: Home (H); Sleep Laboratory (SL).

Some conclusions of this study are the fact that data were not adequate to recommend the clinical use of Type 2 portable monitors in either attended or unattended settings and that some Type 3 monitors seemed to be potentially acceptable in the attended laboratory setting, but with some limitations [31].

Therefore, this study has also provided us will and strength to do better and to develop a simple, portable and efficient device: Sleep@Home.

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3. Project Development

3.1. Problem Analysis

The most efficient technique for OSAS diagnosis, Polysomnography, is very complex, has a high cost and is scarcely available in Paediatric Hospitals of the Country, delaying the diagnosis.

The alternative ways to control the syndrome at home do not allow a selection regarding the need to do a Polysomnography.

Therefore, it was analysed a possibility to create a system of OSAS selection, that would allow a follow up of the syndrome at the patient's home, which would also be portable and easy to use.

Having in consideration the analysis of the State of the Art documents and after discussion with the supervisors of this project, the general architecture of Sleep@Home was planned in order to answer all the requirements that would make us reach a viable solution of the considered problem.

Another important support for the decision of this architecture was a study developed by Stradling *et al* [1] in which an analysis of the use of oximetry and video recording simultaneously was done. It was concluded that some children with sleep disturbs revealed corporal movements due to situations of apnea or hypopnea, but no register was observed in oximetry, probably because they retook normal breath before any detection. These data confirm the importance of the use of oximetry and video recording simultaneously, as they allow the reduction of the oximeter's rate of false negatives.

Therefore, it was decided that the inherent potentialities of video vigilance and of oximetry would be used, in order to complement each other increasing their utility and efficiency.

Thus, we analysed the requirements that we believe to be necessary for the implementation of this innovative idea, which will be debated in the following point.

3.2. Requirements' Analysis

The study of the essential requirements for the development of this technology gave rise to the document of Requirements' Analysis.

We noticed the existence of two levels of requirements: Functional requirements and Software requirements.

In the category *functional requirements* are included the requirements associated to the module of instrumentation, of processing and transmission of data and image and remote management.

In the category *software requirements* are included the requirements associated to the phase of development of the project and to the phase of its use.

3.2.1. Functional Requirements

The Module of Instrumentation includes a subsystem for reception of signals from an oximeter simultaneously with images of video cameras.

In general, the generic architecture of Sleep@Home in this phase is represented in Figure 2.

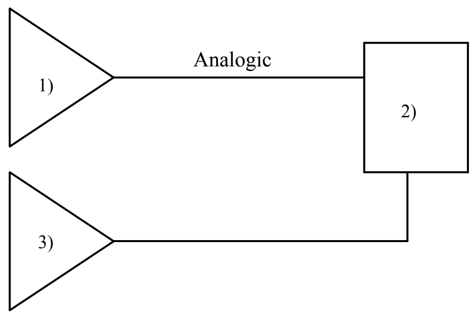

Fig. 2: Generic architecture of the module of instrumentation: 1) Analogic video camera; 2) Concentrative Device; 3) Oximeter

Thus, it is necessary to have a video camera (**1)**), an oximeter (**3)**) and a concentrative device (**2)**).

As the acquisition of images is done at the patient's home and having in consideration that the patients are still children, the luminosity of the environment where the acquisition occurs will be different in each case. This fact means that the video camera must have high sensitivity which allows vision in environment of zero lux, that is, an IV video camera. It must also have an attractive design, in order to get the children's confidence.

The oximeter used was obtained in Smiths Medical PM, Inc., a fact that makes us believe that obstacles to its implementation in the system will not arise. The main problems could be consequences of low fidelity results or bad electric isolation, but having tested its use, there will not be major difficulties. Furthermore, we are going to implement the necessary norms for electric security. The tests done to the oximeter and the evaluation of the results are presented in a following chapter: **Tests and Results**.

The concentrative device used must have enough capacity to save several hours of information recorded, at least eight hours (approximately the number of hours that a child sleeps), as well as having adequate software for the visualization and analysis of that data whenever needed.

This way, it is necessary to create software that can collect, decode and keep the data proceeding from the oximeter in a file, in which will also be included the date and time, in order to have access and synchronization of the information.

Its basic requirements are portability, in order to facilitate its transport, storage capacity of at least 100 GB, network card, video card and an entrance for video signal, sound card (if it is later needed to register the sound) and at least an entrance RS232 to be linked to the oximeter. It must also have technologies that allow the transmission of information in real time to facilitate the system's testing.

Another requirement in the instrumentation module is that it must collect the information proceeding from the oximeter and the video camera, synchronizing each other with the date and hour of the computer. This way, the information can be kept, being simultaneously accessible, so that the physician can relate video information to the registers of the percentage of oxygen saturation in blood and with the heart rate. For this, it is necessary to develop an application that allows the synchronization of all crucial information: video, percentage of oxygen in the blood, heart rate, date and hour.

The module of processing and transmission of data and image is formed by components that allow it to process the acquired signals, compress, codify and transmit them for remote places. This way, it has on its base a concentrative device with adequate software that is linked to a Router (whose function is to place the data in the network) that allows the access to the information by the user and the server through the Internet or LAN network.

The processing of acquired data by the device is essential because it reduces the transmission's costs, makes it possible for the physician to only analyze the essential areas or areas of alarm, saving time, and increasing the income of the oximeter.

In a first phase it is necessary to create a filter that recognizes a state of possible apnea allowing the identification of essential information opposite to the dispensable data and that emits an alarm for these important regions. This software increases the efficiency of the oximeter.

Moreover, there is the need to compress the data in order to make its transmission to the clinical more efficient and economic by UMTS or by another technology of data transmission.

The information is transmitted by UMTS which was chosen as the most viable option in comparison to GPRS technology, because most of the data are in video format, improving its transference rate.

The physical limit of the transmission is the communication channel. In the table below (Table 1) are presented the speeds of upload and download of the GSM, GPRS, UMTS and ADSL [2].

Technology	Speed of Upload	Speed of Download
GSM	Unknown[2]	Until 9.6 Kbps
GPRS	Until 43 Kbps	Until 86 Kbps
UMTS	Until 50 Mbps	Until 100 Mbps
ADSL	Until 768 Kbit/s	Until 9 or 52 Mbit/s[3]

Table1: Comparison between speed of download and upload of some wireless technologies. Adapted from: http://en.wikipedia.org/wiki/Comparison_of_wireless_data_satndards

[2] Although all done research, was not possible to find the speed of upload of the GSM.

[3] In this case, speed of download of ADSL depends on the distance to the central in which system is installed.

The main objective of the Module of Remote Management is the management of acquired and processed information. This function is sent to the software created for such purpose and to the user who will use it. That is, on the base of this module there is the interface Concentrative Device - User.

The application developed must be easy to use, providing a relation of proximity with the physician/user.

It must allow an access to the patients being studied; visualize its personal data as well as the synchronized information acquired in the study.

Although the main objective of this software is the visualization of the information from the alarm moment, it must also allow the access to the information some time before and after the alarm moment. Moreover, if needed it must be possible to access the information acquired during all the study.

Through this software, it becomes possible to compare different events from the same patient as well as events of distinct patients.

On the other hand, this software must make it possible for users who do not have access to any LAN network or Internet to export the data acquired during the use of the system to a CD, DVD or even to a pen-drive. This Sleep@Home usage possibility aims to facilitate the exchange of data between patient and physician.

3.2.2. Software Requirements

In this subchapter, the software used during this project is analysed. It can be divided into two categories: the software necessary during the development of project and the software that is necessary for the use of the device/application developed.

The software needed for the elaboration of documentation, presentations and elaboration of software of Sleep@Home is summarized in Table 2.

Software	Description of software use
Microsoft Office Word	Document elaboration.
Microsoft Office PowerPoint	Elaboration of the middle and final presentations of the project.
Adobe Acrobat Reader	Conversion of Word documents into pdf format and consultation of documents in pdf format.
Microsoft Office Visio	Construction of diagrams and schemes, nominated the Gantt Diagram.
Matlab	Used to validate and develop some algorithms.
Microsoft Visual Studio 2003	Edition and compilation of code in C and Visual Basic.

Table 2: Software used in the development phase.

To allow the use of Sleep@Home it is only necessary the application developed by our team which functions as an interface between the Concentrative Device (or any system that allows the access of the data acquired through Sleep@Home) and the user.

3.3. Architecture

After the analysis of the State of the Art documents and the rise of the main idea for Sleep@Home's architecture, a detailed analysis of the general proposal of the device's architecture was developed, at physical and logical level.

Firstly the general architecture of the system by modules is presented. After that, each one of these modules is analyzed in relation to its physical architecture and also to its logical architecture.

3.3.1. Architecture of the system in modules

Sleep@Home's architecture is divided in three main modules: module of instrumentation, through which the system acquires the data; module of processing and transmission of data and image, in which the acquired information in the previous module is processed and transmitted; and module of remote management that allows accessing the acquired information by the user. This presentation of the architecture in modules is represented in Figure 3.

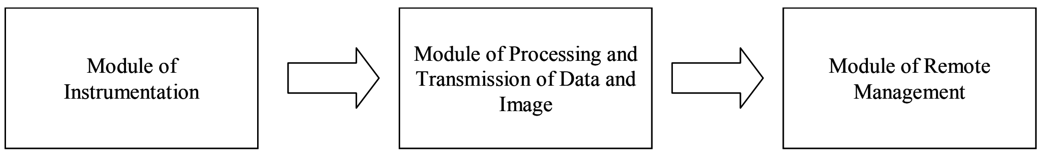

Fig. 3: Architecture of Sleep@Home in modules.

This division simplifies the visualization, analysis and understanding of the structure and functioning of all the system.

As it was already mentioned on the document about the Analysis of Requirements, each module is formed by many components.

Afterwards, there is an analysis of each module of Sleep@Home's architecture in two distinct ways physical and logical.

3.3.2. Physical Architecture

In this sub-chapter it is aimed to describe the devices used in the functioning of Sleep@Home and its interconnection.

Module of Instrumentation aims the acquisition of data by the oximeter and the analogical video camera, keeping them in files in the concentrative device. For such an application in C language was necessary.

The physical architecture of this module is presented in Figure 4.

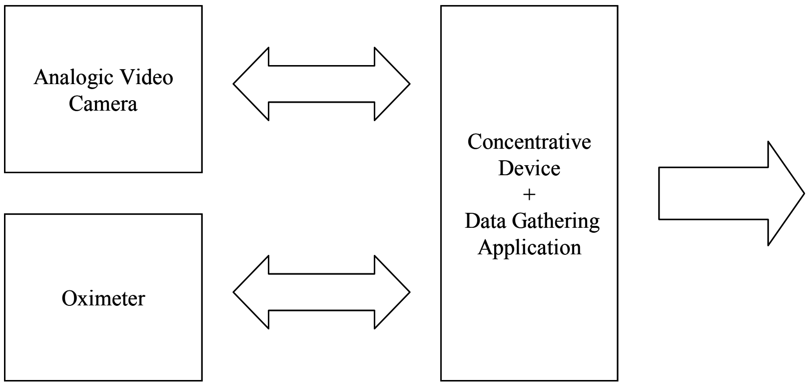

Fig. 4: Instrumentation module physical architecture.

An oximeter and an analogical video camera are connected to the concentrative device, in which an application in C language is installed (whose analysis is done in a subsequent phase).

The linking to the Module of Processing and Transmission of Data and Image is made by Internet or Ethernet, under TCP/IP protocol.

According to Wikipedia [3], TCP/IP is another designation for Internet Protocol Suite. This designation is due to the two most important protocols in it: the Transmission Control Protocol (TCP) and the Internet Protocol (IP), which were also the first two networking protocols defined.

The Internet Protocol Suite is the set of communications protocols that implement the protocol stack on which the Internet and most commercial networks run. It can be viewed as a set of layers. Each layer solves a set of problems involving the transmission of data.

After analysing the available devices in the market, we chose to use the Micro Power Oximeter Board 31392B1, the Weather proof Day & Night Color Video Camera and, as concentrative device, a Mini ITX.

These devices compose Sleep@Home.

The chosen oximeter allows monitoring SpO_2 (%) and pulse rate.

Data is sent at a baud rate of 4800 baud (60 packets per second), 8 bits, one stop bit and no parity. Other specifications that made us choose the Micro Power Oximeter Board 31392B1 are summarized in Table 3.

$\%SpO_2$	Range:	0-99% Functional SpO2 (1% increments)
	Accuracy:	Adult: +/- 2 @ 70-99% SpO2 less then 70% is undefined Neonate: +/- 3 @ 70-99% SpO2 less then 70% is undefined
	Averaging:	8 beats
Pulse Rate	Range:	30 – 254 BPM (1 BPM increments)
	Accuracy:	Greater of +/- 2 BPM or +/- 2%
	Averaging:	8 seconds
Signal Strength		0 – 8 indicates logarithmic strength of patients pulse

Table 3: Some specifications of the Micro Power Oximeter Board 31392B1. Adapted from the document of Technical Description for Micro Power Oximeter Board 31392B1.

The main specifications of the Video Camera that allowed its choice for our system are summarized in Table 4.

Image Sensor	1/3 inch SONY super HAD CCD
Resolution	Horizontal: 480 TV Lines
Minimun Ilumination	0.00 Lux (IR LED on), 16 Leds IV
Lens	Varifocal (3.8 - 9.5 mm)
Colour	Silver

Table 4: Main specifications of the Video Camera used. Adapted from Specifications sheet of the video camera used.

To work as a Concentrative Device we chose Mini ITX. According to its Specification sheet it has, among other characteristics, 512 MB of RAM, 1 GHz of speed of the processor, 200 GB of Hard Disk, video card with four entrances and still an entrance RS232.

The main functions of the module of Processing and Transmission of Data and Image, as the name indicates, consists in making the transmission of the data from the module of Instrumentation for the module of Remote Management, to process them and to make them accessible through this last module.

The physical architecture of this module is represented in Figure 6.

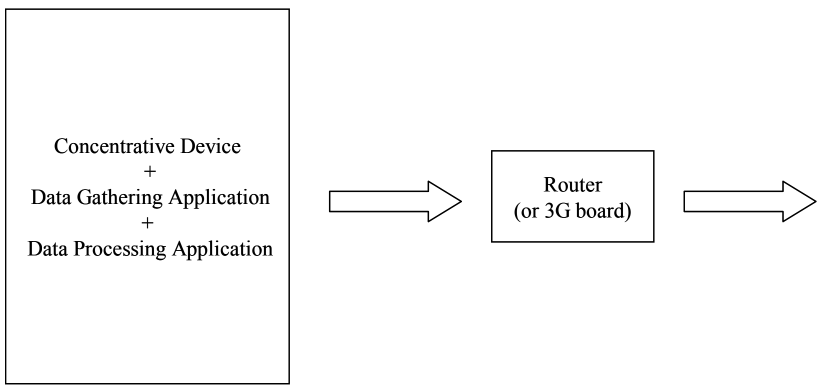

Fig. 6: Processing and Transmission of Data and Image module physical architecture.

As can be noticed in Figure 6, the concentrative device is the same in the Module of Instrumentation and in the Module of Processing and Transmission of Data and Image, a fact that explains its general classification.

After the installation of an application in C language, which allows the efficient gathering of data acquired through the oximeter and the video camera, the concentrative device is also equipped in a first phase, with an application that allowed data processing. As it is pointed out in the following sub-chapter, and fully analyzed in sub-chapter **Development– Application for Detecting Events of Sleep Apnea**, this application is not installed in this device.

The transmission of data from the Module of Processing and Transmission of Data and Image for the module of Remote Management is done by Internet or Ethernet under TCP/IP protocol through a router or another kind of device with the same characteristics (for example, a 3G card) and the user or physician's access to the information is done using communication tools by LAN network or Internet.

The module of Remote Management allows the physician to have access to the acquired data. The access is done through Internet/LAN as it was already mentioned. To be precise, it allows the visualization and analysis of the obtained results before and after its processing.

The physical architecture of this module is represented in Figure 7.

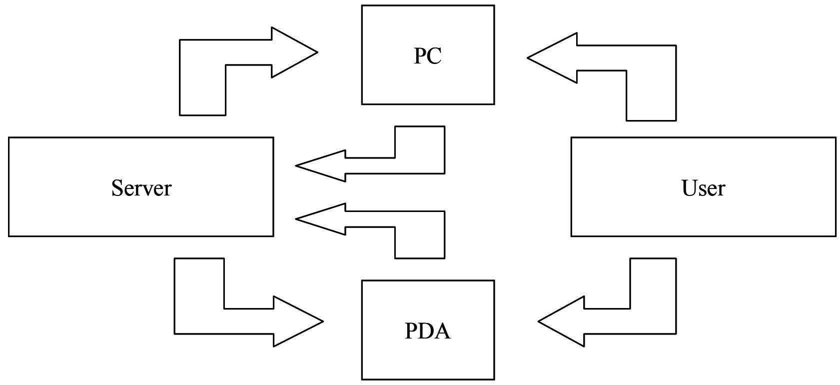

Fig.7: Remote Management module physical architecture.

As it is shown, data are stored in an available database in a server in which they can be accessed by the physician/user, or they can even be sent directly to a computer, or to a mobile device, with appropriate technology, in order to transmit the information that the physician/user has.

3.3.3. Logical Architecture

This sub-chapter aims to analyse how the flow of information inside and between each module is processed.

As Figure 8 illustrates, in the module of Instrumentation the analogical video camera is connected to the concentrative device. During the video acquisition a video-vigilance application, which has previously been done in another ISA project, called Look@It, is also used now [4]. After some alterations in this application, it was installed in the concentrative device. The acquired data are in JPEG format so as to guarantee a higher data security in case of lack of energy, when compared to MPEG format. Despite there is a higher necessity of space in the disc of the concentrative device to store the video signal.

Rough data proceeding from the oximeter go through the linking RS232 to the concentrative device. An application, programmed in C, has been installed on this device. This application makes a selection of the relevant rough data and stores it in a text file that is available for processing.

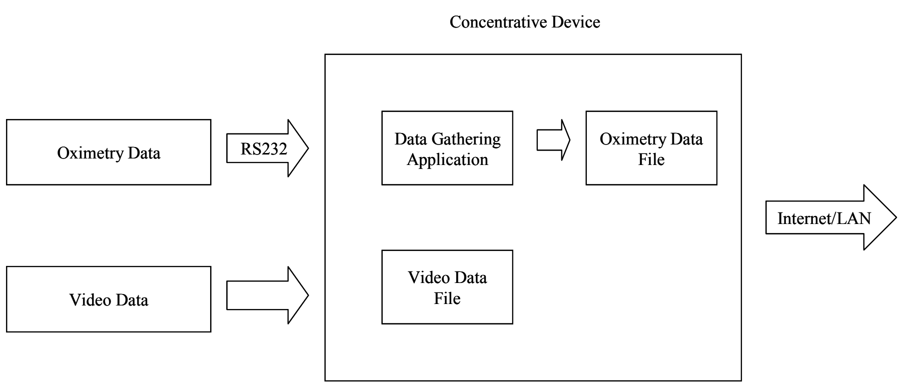

Fig. 8: Instrumentation module logical architecture.

In a first phase of the project, the concentrative device had an application installed in it, developed by our team, whose main objective consisted in processing the acquired data through the oximetry in order to emit alarms whenever an indicative event of possible state of apnea was detected. These alarms, then, would be sent to the physician/user and would be available in the interface of the Module of Remote Management. This idea could provide an analysis of the data in real time.

However, as the project was developed we noticed there would not be enough time to do all the tasks related to the transmission of the information, which meant that this process was outside of the project's academic scope.

This way, the architecture's planning had to be modified.

The application of oximetry data processing was integrated in the interface Concentrative Device - User, which means that the data are processed *a posteriori*. Therefore, each one of the alarms emitted by detection of an indicative event of possible state of apnea is visualized in the graphical interface. We only mention "detection of an indicative event of possible state of apnea" because it is considered that only the analysis/evaluation of these events by the physician provides a correct apnea diagnosis.

Thus, data processing was included in the Module of Remote Management.

In order to analyse the data in a device that isn't the concentrative device it is necessary, at this point, to send the data through a network cable from the concentrative device to another device and install in it the application of processing of information. It is with this structure and way of functioning of Sleep@Home that we have worked.

Is relevant to mention that Sleep@Home is not an inflexible project, that is, it will not stop here its evolution process. Besides, the initial idea of architecture wasn't completely forgotten, being included in the future works of this technology's improvement.

As it was previously said, it is now in the module of Remote Management that occurs the information processing. The application that does this process is analysed in sub-chapter **Development– Application for Detecting Events of Sleep Apnea**.

Furthermore, it is also in this module that the interaction User - Graphical Interface occurs.

This graphical interface was done in Visual Basic.Net language.

Visual Basic. NET (VB.NET) é uma linguagem de programação criada pela Microsoft, orientada a objectos. Permitiu criar uma interface de simples utilização o que permitirá uma aproximação do utilizador ao software.

Visual Basic. NET (VB.NET) is a programming language created by the Microsoft Corporation, directed to objects. It allowed the creation of an interface of simple usage a fact that allows closeness between user and software.

This interaction consists in the user’s free choice to detect the limits of a possible indicative event of apnea in order to occur the emission of alarms.

These limits are registered as parameters in the application of information processing and the user can then have access to the information that let him conclude if it is an apnea case or not, visualizing graphics and crossing the results after-processing with video recording. The object that allows seeing these images of video and that was used in the application that produces the graphical interface was also adapted from the application Look@It.

This process is represented in Figure 9.

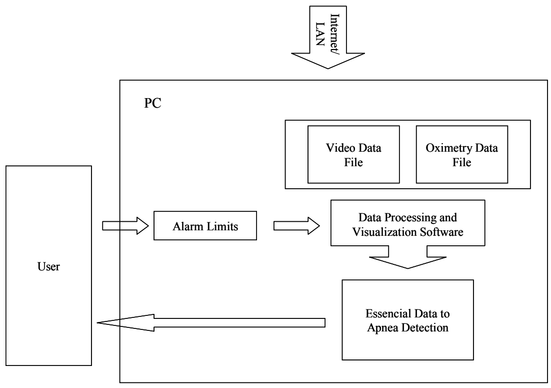

Fig. 9: Remote management module logical architecture.

A final consideration to be underlined relates to another idea that emerged in an initial phase of the project. Although it has not been put in practice due to lack of time, it will be developed in a future work, out of this project’s academic scope.

We refer to the development of the video recording. That is, it was aimed that video recording would only occur when an event of possible apnea was detected by the processing of oximetry data. Moreover, it was also aimed to define an alarm related to brusque movements and positioning of the patient’s body, obtained through an algorithm of movement detection. This idea is analysed in more detail in sub-chapter **Future Work**.

3.4. Project Planning

In this sub-chapter we intend to provide a more comprehensive image of this project's development, thus it is organized in work modules and it presents the tasks' distribution among the students that worked in Sleep@Home project.

As it has been mentioned, this project was developed during one school year. This way, the project's progress can be divided in the different kinds of tasks that have been done.

During the first semester the theoretical context module was developed – Acquisition of Theoretical Background. Therefore, the knowledge acquired during this phase was put in practice during the second semester.

3.4.1. Modules

As it has been analysed in previous sub-chapters, Sleep@Home project can be divided into three modules depending on its architecture. These modules are not yet inflexible, because they interact, and their functioning even overlaps. We refer to Module of Instrumentation, Module of Processing and Transmission of Data and Image and Module of Remote Management.

However, in this sub-chapter there is also an approach to another work module, regarding the project in its more theoretical phase: acquisition of theoretical background.

3.4.1.1. Acquisition of Theoretical Background

This work module includes the acquisition of necessary knowledge for the project's development. This way, this task was done during the first semester. It consisted in researching on remote monitoring of patients with the Sleep Apnea Syndrome, as well as acquiring knowledge on Apnea, its causes, consequences, symptoms, ways of diagnosis and treatment. This research resulted in the elaboration of some documents, such as *State of the Art*, *Analysis of Requirements* and *Architecture*. The initial project planning was also done. This phase was done by my colleague Samuel and me.

After this analysis, it was noticed that I needed to learn programming in C language and Samuel in VB.NET due to the tasks that had been planned. This learning also took place during the first semester.

For the second semester we planned to develop the more practical tasks that required all the acquired knowledge during the first phase. The following items make an approach to the work planned for the second semester.

3.4.1.2. Module of Instrumentation

3.4.1.2.1. Choice of Devices to use

One of the essential tasks consisted in selecting the oximeter, the video camera and the concentrative device to be used considering all the requirements. Due to its importance for the project's development, this task was done in an initial phase.

3.4.1.2.2. Gathering Data from the Oximeter

Aiming to acquire data from oximeter and to store them in a file in the Concentrative Device, it was necessary to develop software, in C language, that allowed the access to the oximeter.

This submodule is important for the following development of the project because the oximetry data are needed for the module of data processing. Therefore, the development of this issue is done in the initial part of the project.

3.4.1.2.3. *Data Storage*

For an immediate development of the project there was not the need to create a database that would be appropriate to store the data of several patients in the case these were exported to a server, for example.

The format of video file is JPEG in order to guarantee a higher data security in case of lack of energy.

Data obtained from the oximeter are stored in a text file that must match a standard structure to be able to be read by the software developed. Each line of the text file has information from each instant of sampling, among which is the precise moment in time, important for data synchronization (**Data Synchronization**). Using the timer in the Concentrative Device we can guarantee chronological information of the acquired data.

3.4.1.2.4. *Data Synchronization*

Data obtained by the oximeter and by the video camera are stored in independent files in the concentrative device.

The first idea that emerged so that video data were synchronized with oximetry data was that we should guarantee that the sampling beginning was the same for oximetry and for video recording. Therefore, data obtained from the oximetry and from video recording would have the same time period in common, which would correspond to the time in which these signals had been acquired. Thus, software for a computer would be created (of headboard, which must be connected to a monitor or a television) that could give the necessary instructions for the beginning of sampling (data recording) and in which data could be seen in real time.

This idea would be useful if we would start the recordings when the alarms were emitted, to be precise, if the oximetry data were only recorded when an alarm of movement detection was emitted, and video recording occurred only when an oximetry alarm was emitted.

However, we noticed that this premise couldn’t be developed mainly due to lack of time.

Therefore it was decided that the synchronization of the information from oximetry and video would be directly done in graphical interface. As all data video are recorded, when a situation of possible apnea is detected through analysis of oximetry data the physician could visualize a certain period of time recorded before and after the instant of detection, only by clicking the alarm presented in the graphical interface.

This task was planned to be developed after the conception of the application of data processing, what would happen during the development of the project.

3.4.1.3. Data and Image Processing and Transmission Module

3.4.1.3.1. Detection of Movements' Algorithms

The detection of movements in Sleep@Home system is based on technology already used in the Look@it system of ISA. Algorithms of movements' detection are based on alterations in video frames. In a general way, the difference between the current image and the previous or the initial one is determined, through filters of images' difference and of threshold, thus defining the parameters that define a movement.

Aiming to detect movements clinically significant in scope of the OSAS, particularly in children, it is necessary to know which characteristic movements are associated to this syndrome during the sleep. There can be distinguished two kinds of movement with clinical interest: corporal position and abdominal and thoracic movements.

When a child sleeps and is difficult for him/her to breathe normally (he/her may be in a hypopnea or apnea situation), he/she searches for a more comfortable position. This kind of nocturne movements and the position in which the child sleeps can provide clues and are easily detected through the use of technology.

Abdominal and thoracic movements are only detectable when significantly done. This happens in a situation of respiratory difficulty. In the OSAS, movements associated to breathing are very visible. Even if air flow has ceased during an apnea, respiratory effort is present and often exaggerated. The whole body may be moved in a brusque way.

So as to maximize the detection of this sort of movements we need to pay attention to the video camera's position.

As it has been mentioned, these algorithms of movements' detection have been used only for video recording when there was movement (using Look@It's technology). However, they will be useful for future work, when control of data recording by emission of alarms is put in practice.

The execution of this task was planned for an intermediate phase of project's development.

3.4.1.3.2. Detection of Possible Apnea Events

To detect respiratory events with clinical importance, we have to create filters that allow the analysis of three kinds of situations that frequently occur in patients with OSAS, regarding oxygen saturation:

- Decreasing of oxygen saturation below a determined stage, during a determined period of time, with fast replacement of normal values;
- Decreasing of oxygen saturation during a long interval of time (situation of long apnea);
- High variability of oxygen saturation (graphical with aspect of "milling").

These filters are the basis of the data processing application and, in an initial phase, they were developed in MATLAB for results validation, later aiming to be implemented in C language.

However, as the project developed we obtained important improvements in the construction of the graphical interface, a fact that made us conclude that it would be more advantageous to include this application directly in the graphical interface. It would allow an easier visualization of the acquired results after-processing, guaranteeing a constant critical analysis of the results.

This way, data processing application was transcript from MATLAB to VB.NET (language used in the graphical interface) and implemented in this programming language.

So as to define threshold values for emission of alarms used in this project, the best solution was to create the possibility for the user to define them through the graphical interface.

Default values used in graphical interface were, in their majority, suggested by Dr.ª Helena Estêvão.

Since this was one of the most important tasks for the efficient functioning of Sleep@Home, it was planned to start in an intermediate stage of the project's development.

3.4.1.3.3. Data Transmission

UMTS or ADSL technology is going to be used for data transmission from the patient's home to the central hospital. The idea for this prototype is not creating a real time transmission system, but an efficient way to transmit all the information. It must be analyzed if it is advantageous to send all video recording or only the segments corresponding to important events, having in consideration that the physician must have access to information from all sleep duration.

UMTS covering in Portugal was studied [5], [6], [7] and it was concluded that currently, it only encloses the main urban centres of the country, a fact that can difficult the future use of Sleep@Home in some regions of the country, namely rural zones.

It may also be necessary to compress data in order to save time, costs and width of band in transmission.

These tasks were planned to be fulfilled in a final phase of the project.

3.4.1.4. Module of Remote Management

3.4.1.4.1. Data Visualization – Graphical Interface[4]

In this module a graphical interface was created. Its objective consists in allowing that the physician/user has access to relevant data for support of OSAS diagnosis. Therefore, after being processed and transmitted, this application will show the following data, for each selected test:

- Video signal;
- Graphical representation of oxygen saturation;
- Graphical representation of heart rate;
- Alarms definition parameters;
- Alarms;
- Other relevant statistical results.

This task was planned to be developed in an intermediate stage of the project.

3.4.2. Tasks Distribution

It was our intention to make the most equitable distribution of tasks between my team colleague and me. However, this process is not completely rigid, as we always tried to keep each other informed on the work done individually; in addition we have cooperated in each other's tasks.

The phase of knowledge acquisition and conception of essential documents for the project's development was done by both of us, except for learn programming in some languages: I acquired some knowledge in C programming, while my colleague learned VB.NET.

The choice of the devices to use was also done by us, with contributions from our supervisors.

[4] Graphical interface will be fully analyzed in Samuel Pereira's Project Report, who is my team colleague, because this task was mainly done by him, as it can be read in sub-chapter **Tasks Distribution**.

It was my task to work on Oximetry data gathering; however, since we noticed that this would take a long process, it was developed by elements of ISA. This way, we could move on to the most important phases in the scope of this project, such as algorithms for detection of apnea events and graphical interface.

Initially, I was responsible for *data storage*, but this task ended up being done by my colleague Samuel, because at that moment, I was already busy developing the application for the detection of apnea events, whereas Samuel was available to do it. This task included the implementation of some alterations in technologies which had already been developed in other projects.

I was also in charge of developing *data synchronization*. However, this task revealed the need for a different resolution owing to all the reasons already emphasized on the previous sub-chapter. Consequently, it was developed by my colleague Samuel as it had to be integrated in the graphical interface.

Algorithms used for movements' detection were not developed by any of us, because they had been provided by ISA, obtained from Look@It application.

I was responsible for the development of the application for detection of possible apnea events. Therefore, the following sub-chapter **Development – Application for Detection of Sleep Apnea Events** is about this task. In fact, I developed this task more specifically throughout the project.

As the module *data transmission* was planned for a final phase of the project, it ended up being left behind. It was not developed by any of us. And, due to lack of time, it wasn't accomplished. Thus, it was included on the project's academic scope.

Data visualization task (Graphical Interface) was performed by my colleague Samuel.

Initial project plan is summarized in Figures 10 and 11. In order to simplify its visualization, it was divided into two Gantt Diagrams. The first corresponds to the first semester and the second to the second semester.

ID	Task Name	Start	Finish	Duration
1	**Project Presentation**	21-09-2006	09-10-2006	13d
2	**Acquisition of Background**	02-10-2006	22-12-2006	60d
3	Knowing OSAS	02-10-2006	12-10-2006	9d
4	Knowing Oximetry	02-10-2006	16-10-2006	11d
5	Learning programming in C	09-10-2006	22-12-2006	55d
6	Learning programming in VB.NET	27-10-2006	22-12-2006	41d
7	**Pause for Examinations**	25-12-2006	29-01-2007	26d

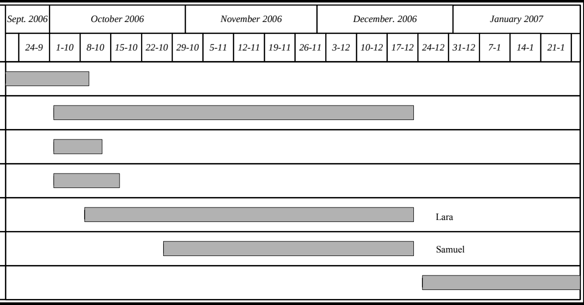

Figure 10: First semester Gantt Diagram. Legend: Sept. means September.

ID	Task Name	Start	Finish	Duration
1	**Analysis and Specification**	01-02-2007	21-02-2007	15d
2	State of the Art	01-02-2007	05-02-2007	3d
3	Analysis of Requirements	01-02-2007	05-02-2007	3d
4	Planning	06-02-2007	16-02-2007	9d
5	Architecture	06-02-2007	16-02-2007	9d
6	Plan of Tests	19-02-2007	21-02-2007	3d
7	**Preparation of Intercalate Presentation**	19-02-2007	22-02-2007	4d
8	**Intercalate Presentation**	23-02-2007	23-02-2007	1d
9	**Development**	26-02-2007	09-05-2007	53d
10	Module of Instrumentation	26-02-2007	02-03-2007	5d
11	Module of Processing	05-03-2007	17-04-2007	32d
12	Module of Transmission	19-04-2007	09-05-2007	15d
13	Module of Remote Management	05-03-2007	17-04-2007	32d
14	**Improving system**	10-05-2007	11-06-2007	23d
15	**Final Report**	12-06-2007	09-08-2007	43d

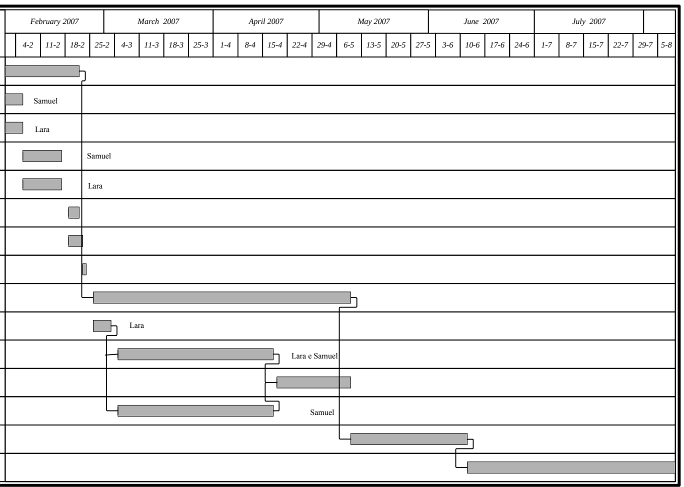

Figure 11: Second semester Gantt Diagram.

3.5. Development – Application for Detection of Sleep Apnea Events

This sub-chapter aims to reflect more carefully upon the module/task that I carried out: data processing application.

The structure of the source code will be explained in a concise way, as well as its evolution throughout the project, and the reason why it was developed that way.

To start this application's development it was necessary to do some research in articles of the specialty, in order to select the parameters to analyze.

According to Álvarez [8], the most common results of oximetry analysed are oxygen desaturation indices of 4% (ODI4), 3% (ODI3), 2% (ODI2) and cumulative time spent below a saturation of 90%. Furthermore, in this study, is also computed the delta index (Δ) that measures the SpO_2 signal variability. This variability, as is said in a study of Levy *et al* [9], derives from the association of repetitive fluctuations in the SpO_2 signal with the succession of respiratory events, whatever the amplitude of the SpO_2 decline.

Taking this study into account, an adaptation of these parameters was done, and it was defined that Sleep@Home would emit three types of alarm:

- Long time desaturation: defined by the amount of time that SpO2 are below of a defined boundary-value. An example of this type of desaturation is represented in Figure 12.

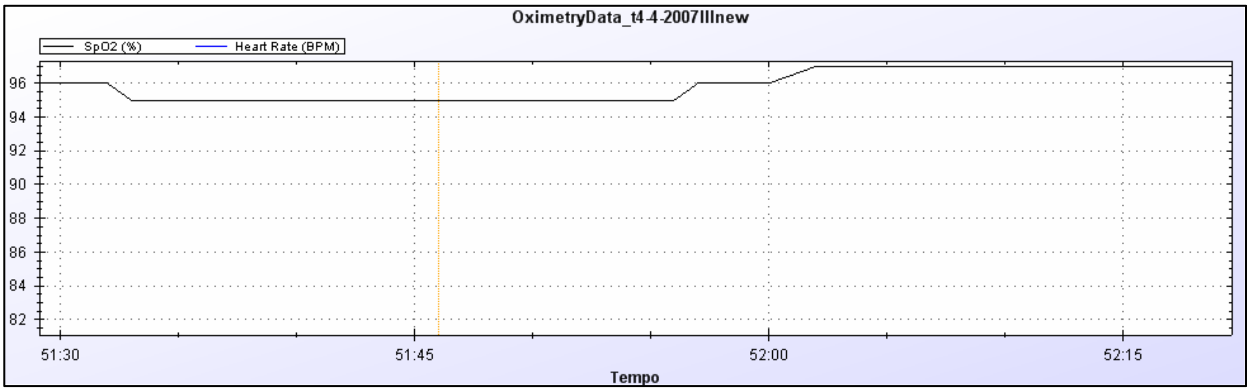

Figure 12: Example of a long desaturation. Representation acquired with Sleep@Home application.

- Fast desaturation: defined by the percentage that SpO2 diminishes below a boundary-value in a determined time interval. An example of this type of desaturation is represented in Figure 13.

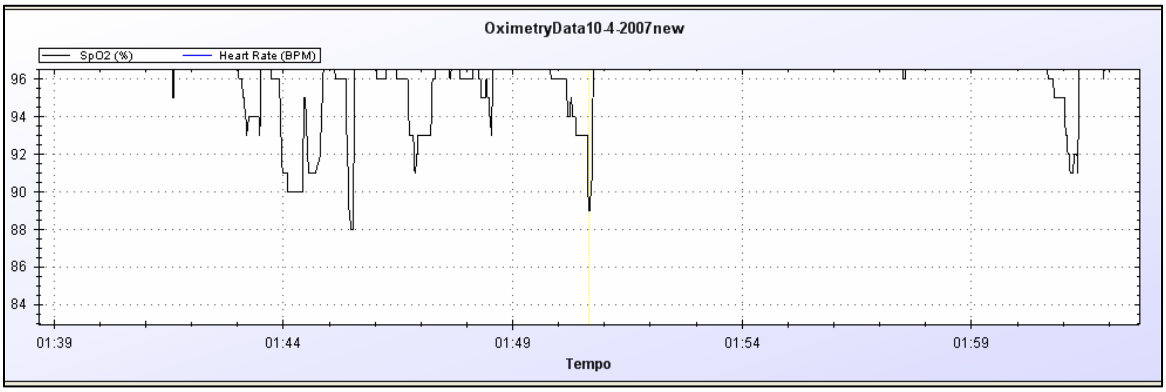

Figure 13: Example of a fast desaturation. Representation acquired with Sleep@Home application.

- "Milling effect": indicates SpO2 variability. An example of this type of effect is represented in Figure 14.

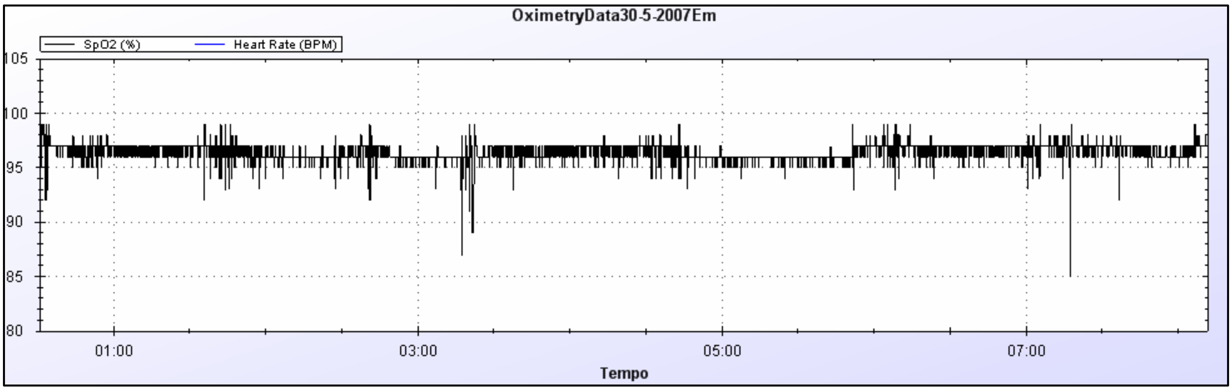

Figure 14: Example of "Milling effect". Representation acquired with Sleep@Home application.

Afterwards, the project development moved on to the practical construction of the application.

3.5.1. Application Inicial Version

The language chosen to develop the first version of the application was MATLAB. This would be later changed to C language, because it is a more universal language.

Wikipedia [10] mentions that MATLAB is a numerical computing environment and programming language specializes in numerical computing. Created by *The MathWorks*, MATLAB allows easy matrix manipulation, plotting of functions and data, implementation of algorithms, creation of user interfaces, and interfacing with programs in other languages.

The main reason that led to its choice was the fact that it is an interactive system whose basic element of information is a matrix that does not require dimensioning. This system allows solving many numerical problems in only one fraction of time that would have to be spent to develop a similar program in VB.NET or C language. Moreover, problems' solutions are expressed almost exactly as they are mathematically written [11].

This version of the main application included four functions (one for each one of the alarm events and another of control) and an application whose function was to activate these functions.

For long desaturations detection *Contador* function was created.

As it was already mentioned in previous sub-chapters oximetry data come to this processing phase kept in a text file.

It was accepted that when successive data during 10 seconds would show values inferior to the reference value of SpO2, which was determined through the values average during the three first minutes of acquisition, a long desaturation event would be detected. This method was based on the study done by Álvarez *et al* [8].

This way, the algorithm for detection of this kind of event is based on the reading of SpO2 data of the text file, being done a comparison between successive data and the reference value.

At this stage of the project, it was still believed, as it is mentioned in the specifications of the oximeter, that data was obtained at each millisecond. Later it was understood that it is not right (this subject is analysed further on).

Thus, we counted the number of milliseconds in which SpO2 values were successively inferior to the reference value. This number was successively kept in a variable that was compared with the defined time (10 seconds). When the variable was inferior to 10 seconds it was not detected any event. When the variable was equal or superior to 10 seconds a message was written in MATLAB prompt, alerting the detection of an event.

As it can be understood, this algorithm was still elementary and rudimentary, although it had obtained good results in the tests that it had been through (see **Tests and Results**). Its bigger disadvantage was not allowing the physician to define the parameters in accordance with each case.

Desaturation peaks (fast desaturations) were detected through *Pico_final* function.

It was assumed that a peak is disclosed when successive data during 2 seconds would reveal inferior values in 2, 3 or 4% in relation to the reference value (average of the values during the three first minutes of acquisition).

Therefore, as in the previous function SpO2 values were read, confirming if these were or not inferior in 2, 3 or 4% in relation to the reference value. If they were inferior, it was added an unit to a variable initialized with zero (*pic*). After that it was confirmed if the value of this variable was between the 2 and the 10 seconds, in order to prevent that the detected peak, for being too short in timing terms, was not a result of oximeter artefacts.

If *pic* value was in this interval, a message in MATLAB prompt would be written alerting to the detection of a peak. In contrast, it would be attributed a zero value to *pic* variable.

If the values were not inferior, *pic* variable would keep its zero value.

Once more, also in this function, the physician was not allowed to define threshold parameters of alarm in relation to each case.

To detect “Milling effect” *Serrilha* function was defined.

The algorithm used in this function was based on the definition of Delta Index present in the study from Álvarez *et al* [8]. In these studies it is said that the delta (Δ) index can be computed as the sum of the absolute variations between two successive points, divided by the number of intervals. These intervals could be of 12 or 10 seconds.

This way, the algorithm determines the number of intervals of 10 seconds from the data file, and the data in the text file are read one by one, determining the absolute difference between successive values. These differences were added and the delta index is given by the division of the total sums by the number of intervals of 10 seconds.

In this in case, similarly to previous functions, an alarm consisted in writing an alert message in MATLAB prompt.

This message was written whenever delta index presented values inferior to 4. This condition was defined in a random way, because at this time the researches to get more information on delta index were unfruitful. We were still waiting for the first visits to the Hospital Pediátrico de Coimbra where some indications on the used parameters were expected.

The last function now presented is *Controlo*.

This function aimed to give information on the oximeter’s functioning condition. In addition to SpO2 and heart rate data, the oximeter also returns information of its state of functioning codified in numbers that go from 0 to 5. Each one of these values has a physical meaning.

These data are also kept in a text file, being read one by one, and writing in MATLAB prompt the oximeter's functioning condition. For example, according to the oximeter's specifications, if the value is 2, in MATLAB's prompt we can read "*Dedo não detectado pelo sensor*".

Thus, any physical problems with the oximeter can be recognised, preventing the occurrence of errors and oximetry invalid values.

All the functions explained above were activated in *Detectapneia* application. In this application the user chose the text file with the data that he wanted to read and these were analyzed in each one of the functions, creating a new text file in which acquired alarms were recorded. It is aimed that this text file can be read by graphical interface in order to allow the access to acquired results.

With graphical interface development there was a possibility of testing in it this application. It could be possible to visualize graphical representation of SpO2, facilitating algorithm validation.

Then, it was noticed that it would be more advantageous and also more efficient the transcript of this application's initial version to the language in which the graphical interface - VB.NET - was being developed, and integrate the application in it. That is, it was decided to integrate the events detection application in the source code of graphical interface.

3.5.2. Application Final Version

Visual Basic .NET (VB.NET) is an object-oriented computer language [12] created by Microsoft Corporation. It allows the creation of an attractive and simple to use interface that establishes closeness between the user and the software, thus being the language chosen to create the graphical interface.

As the project was being developed, it was acquired a lot of additional information.

We understood that only the information from one of the sixty data packs that the oximeter sends per second is valid, that is, only the information from one of the packs is important for oximetry analysis. Moreover, it was also possible to gather real data coming from the oximeter. This subject is not exhaustively analysed here, since it is integrated on Samuel Pereira's part of the project.

To this point, the data used had been simulated. That is, the analyzed text files contained only one series of data acquired with an MATLAB application, which changed from about 65 to 100, in order to be the most similar to oximetry real data.

Real data from oximeter are kept by columns in text files. As there were data that were not important for this application, Samuel adapted in the code of data acquisition from the oximeter, so that text files would only have the essential data. Thus, the amount of information to be transmitted was reduced, a fact that represents an advantage.

This way, the format of a line of a text file with oximetry data is the following:

YYYY-MM-DD HH:MM:SS:MMM Beep, Pleth, Bargraph, AvgSpO2, RealSpO2, HeartRate, Flags, RedGain, IRGain

Data used in events' detection application are only RealSpO2 and heart rate.

Another important acquired data were the existence of SpO2 invalid values that occur when oximeter is searching for signal, for example. This fact meant that we had to do an algorithm that would transform invalid data into valid, so as to be used in *Contador*, *Pico* and *Serrilha* functions.

Apnea detection algorithms have been successively improved in order to increase their robustness and precision. This process was possible mainly due to the fact that data could be analyzed in the graphical interface, what provided the visualization of graphical data and of other important parameters for the results' analysis.

Furthermore, as tests were being performed with real data, we noticed that it would be necessary to make some alterations in algorithms.

Furthermore, a new type of alarm related with events of abnormal heart rate was also added. According to Dr.ª Helena Estêvão, there is a common relation between the occurrence of a desaturation event and an abnormal situation of heart rate: they are usually time coincident. It was also said that the detection of these occurrences would be important for the physician's diagnosis. Algorithm of detection of this type of alarm was inserted in *Contador* and *Pico* functions.

Having done several observations to oximetry data, its analysis revealed the incidence of invalid values.

In order to compensate this fault we decide to create an algorithm that simulates the linking between the last valid value and the first following valid value through a straight line. It attributes each one of the values of this straight line to each invalid value in the defined interval. This process was applied to the SpO2 and heart rate values despite the fact that the algorithms presented reduced significant differences.

Therefore, in both situations, values are read one by one and the numbers of values considered invalid, since the first invalid until the first following valid value, are counted.

After that, the difference between the first following valid value and the last valid before, is determined. This difference is divided by the number of invalid values in order to determine the constant to add to the last valid value so that the values are gradually generated until reaching a value never superior to the first following valid value.

The algorithm applied to Heart Rate is very similar to the previous one; therefore it is not explained in much detail.

Data are now ready to be analyzed by apnea events' detection algorithms.

In this final version of the *Contador* function it was accepted that when successive data, during a determined amount of time defined by the physician, disclosed values inferior to SpO2 (Saturation of Peripheral Oxygen) reference value – RefValue –, that is for default 92% but it can be chosen by the physician, an apnea event was detected. As data had been previously treated, it was admitted that value data are acquired each second.

This application starts with the reading of SpO2 data. When a value inferior to RefValue is detected, the number of successive values inferior to RefValue is counted. If this number is superior to the physician's definition is detected an apnea event in the form of a long desaturation (because it could be assumed that to each data corresponds one second). At this moment Heart Rate alarms detection algorithm is activated.

In this algorithm data are kept in *HR* variable. The ones that are included on the time interval, approximately corresponding to the number of seconds selected by the physician through the *TimeVariationBetweenAlarms* variable in relation to the second in which long desaturation event is detected, are analyzed.

Whenever there is one value superior to the sum of the average value of Heart Rate (*HRAverage* previously calculated) in this time interval, in a constant defined by the physician (*HRVariation*), one unit is added to a new variable defined in order to count the number of cases in which this type of events occurs.

The same happens when there is a value inferior to the difference between *HRAverage* and *HRVariation*, and a one unit is added to another new variable.

If any of these two new variables are different from zero, then we face a multiple alarm: alarm of long desaturation coincident or approximately coincident with Heart Rate alarm. It is also written in the text file, in which all alarms are marked, a line that contains information related to the date and time of the alarm, to the type of alarm and to the amount of time that SpO2 was below the reference value.

If one of these two new variables is equal to zero, no alarm event related with Heart Rate occurs in the analyzed interval and therefore we are facing a simple alarm of long desaturation type. An indicative line of this type of alarm is also written in the alarms' text file.

It could be noticed that a synchronism between an alarm of long desaturation and heart rate is only analyzed when an oximetry alarm is detected.

Another important parameter determined in this function is *Cumulative Time Under (x%)* which indicates the amount of time in minutes that SpO2 was below *x%*. That is, the number of minutes in which SpO2 was below x% is counted. We mention *x* because, as it happens with *RefValue*, *TimeVariationBetweenAlarms* and *HRVariation* variables, it is the physician who defines its value (despite the fact that it was attributed to them a default value advised by Drª Helena Estevão).

Furthermore SpO2 maximum and minimum values are also determined in this function.

In the first case, the first SpO2 registered value is defined as the maximum value and it is successively confirmed if the following value is superior to this. If it is, this last value is considered the maximum value of reference. This maximum value then is considered the *SpO2 Maximum*, allowing its visualization as a parameter in the graphical interface.

As for the minimum value, the only changes are the fact that the first registered value is defined as the first minimum of reference and is successively evaluated if the following value is inferior. If it is, this last value is considered the minimum value of reference. The minimum value then is *SpO2 Minimum*.

In this final version the function initially characterized *Pico_final* is now named *Pico* for clarification reasons.

It is now assumed that a peak of desaturation happens whenever there is a decline bigger or equal to x%: during the number of seconds chosen by the physician through the *Desaturation Time Interval* parameter (5 seconds for default) which followed the detection of an inferior value to the value of reference (*RefValue*), that is 92% by default,

This decline value can be modified by the physician in *SpO2 falling* field, that is expressed in percentage and that assumes the default value of 3%. The reference value can also be chosen by the physician.

For this function data have also been previously treated, thus it is possible to admit that there is acquisition of valid data at each second.

The application is initiated reading SpO2 data. When a value inferior to *RefValue*, the interval of time that follows it, already defined by the physician, is detected, it is analyzed. Maximum and minimum values reached by SpO2 in this interval are determined. Then a new variable is calculated through the difference between the maximum and minimum values determined. This way it is aimed to determine the effective decline that occurred in the defined time interval.

This value of decline is then compared with the value defined by the physician, and if they are equal, or the calculated decline is superior to the value defined, the Heart Rate alarms detection algorithm is activated.

This algorithm is equal to the one used in the *Contador* function. Only the information written in the alarms' text file changes. It is now related to the date and time of the alarm, to the type of alarm and to the decline of SpO2 that occurred in the defined time interval.

At this moment, the alarms text file, which already contains all data related to detected alarms, is read by the graphical interface that provides the visualization of the data contained in it, which are important for the physician's diagnosis. It indicates, for example, the number of events detected per hour, which is close to the apnea-hypopnea index (AHI), and which is one of the variables measured by Polysomnography that has been widely used to diagnose OSAS, as it is emphasized in a study from the Medical Advisory Secretariat of Ontario Ministry of Health and Long-Term Care [13].

In graphical interface, alarms are visualized with a colour index according to its degree of gravity. This subject is not fully explored because it reflects a task developed by my colleague Samuel and is therefore expanded in its Project Report.

The last version of *Serrilha* function does not present significant alterations in relation to the initial version. The algorithm continues to the same, it has only been transcribed from MATLAB to VB.NET language.

In this in case, due to its integration in graphical interface, delta index value is presented in a field of the graphical interface.

It was noticed that the alarm emission limits in the initial version of this function were not correct. According to a study from Levy *et al* [9], if the delta index value is inferior to 0.6 there isn't a "milling effect" that shows an apnea case. If it is superior to 0,6 there could be an apnea case or not. This fact is not very important in this final version because it is not emitted any type of alarm. What is important is that the physician knows this characteristic so as to make a correct evaluation of the patient.

With the progress of the generic application, it was noticed that the implementation of *Controlo* function would not be necessary, because a data treatment algorithm that transforms them into valid data was developed. Furthermore, in SpO2 graphical representation, to intervals of invalid values we gave a colour that contrasts with another given to valid values. Thus visualization and distinction between the two types of data becomes easier. Therefore, it was considered that it was more important to know if the value is invalid, than to know why it happened.

The integration of apnea events detection application in the code source of the graphical interface implied that *Detectapneia* application of initial version had to be replaced, in the final version, by a code block in which only the event detection functions presented are activated.

Another functionality of this final version is the possibility to print a report with relevant information for the physician's diagnosis. It presents the available graphical representations in the graphical interface and some parameters considered more relevant such as: test duration, SpO2 average, cumulative time under a defined value, amount of alarms, Heart Rate average, Delta index, alarms list and graphical representation of SpO2 and Heart Rate.

A very important alteration between initial version and final version, which must be registered, is the physician's possibility to choose most of the definition parameters for the events' detection.

This fact provides the physician's greater closeness towards the application, and its main advantage is the fact that the physician can more appropriately define the parameters for each situation. This fact results in another advantage: the possibility to compare obtained results through the processing with different parameters. Thus, it is easier to detect an oximetry event, which could even be unobserved through certain definitions of detection parameters. In this comparison process, to print the report with results plays an important role, because the physician can more easily cross obtained results, which can influence his/her diagnosis.

For more detailed information in this application final version consult "Relatório do software de detecção de eventos de apneia para o projecto Sleep@Home – V. 0.4" in Appendix.

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4. Tests and Results

In this chapter, the tests carried out during the project are presented, and there is a reflection upon the obtained results. These tests aim to validate the applications developed, providing simultaneously information that allows a continuous improvement of Sleep@Home's performance, also intending to test the functionality of the choices made in relation to the integrated devices as the oximeter and the video camera.

4.1. Developed Tests

4.1.1. Sleep Apnea Event Detection - Application Tests

The elaboration of this initial version of apnea events detection algorithm, in MATLAB language, was greatly based on tests.

When this application was being developed, it was not yet possible to obtain oximetry data in a format that could be analyzed (text file format). Thus, it was necessary to simulate data. For this purpose, it was also developed an application in MATLAB language that generated one series of random numbers, whose values changed in the closest possible way to the values intended for each function, never exceeding the interval between 100 and 60%.

In these series of random values, some changes had to be performed, so as to simulate possible cases of apnea related events.

This way, *Contador* function was developed to detect events such as the one represented in Figure 10.

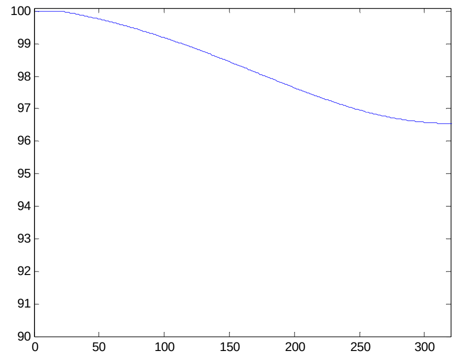

Fig. 10: Long smooth SpO2 desaturation graphical representation.

In Figure 10 only one part of the simulated data for this test are represented in order to make clear the visualization of this type of event.

The result obtained while analyzing these data with *Contador* function is presented in Figure 11.

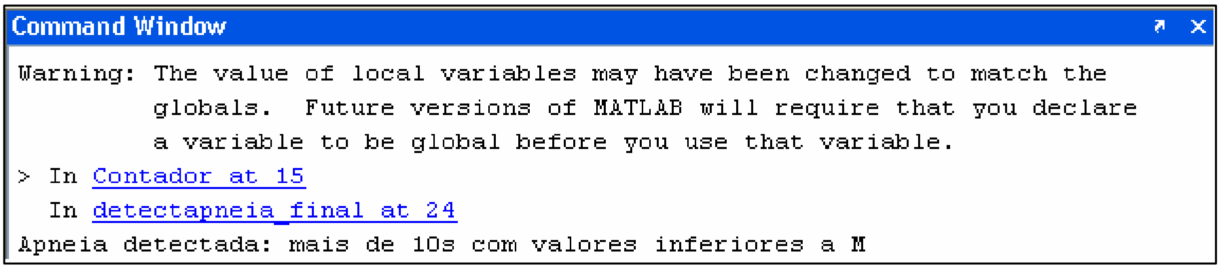

Fig. 11: Long desaturation detection through *Contador* function.

As it can be noticed the algorithm detected one long desaturation giving indication of the reference value for its detection (M means average of the measurements during the three first minutes of acquisition), as it was intended. It must be considered that, so as to make the results' analysis easier, adaptations were done to the *Contador* function, so that to each data corresponded one second of acquisition, without, however, making alterations to algorithm's bases.

Other cases were tested but, since they were too specific, they were not considered so important and therefore, are not presented in this report.

To analyze *Pico* function functionality, we generated data whose graphical representation is represented in Figure 12.

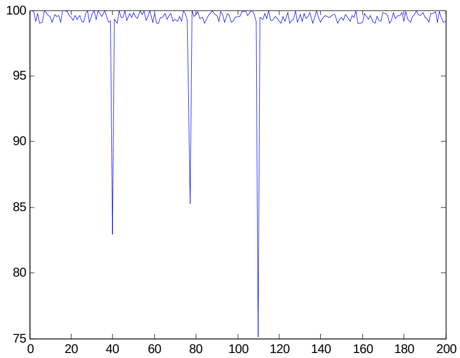

Fig. 12: SpO2 desaturation peaks representation.

In Figure 12 only one part of the generated data through simulation is represented, in order to allow a clearer visualization of the interval where fast desaturations (peak desaturations) were simulated.

The obtained result while analyzing these data with *Pico* function is presented in Figure 13.

```
Apneia detectada aos 40 segundos: 82.9479
Apneia detectada aos 77 segundos: 85.2746
Apneia detectada aos 110 segundos: 75.0911
```

Fig. 13: Detection of three fast desaturations through *Pico* function.

It can be observed that the three peaks evidenced in Figure 12 were detected. It must be emphasize that so as to facilitate results' analysis we made some adaptations to *Pico* function. This means that, to make the analysis it is considered that to each data corresponds one second of acquisition, therefore explaining its timing position presented in the result. Moreover, it is revealed the value until each detected fast desaturation decreases (in percentage).

In the case of *Serrilha* function, it only could be tested if a message of alert was printed in MATLAB prompt, when the Delta Index value was inferior to 4, as it had been defined in this phase of the project.

After having generated a series of random numbers that varied in an interval of only 10%, the result obtained through *Serrilha* function is represented in Figure 14.

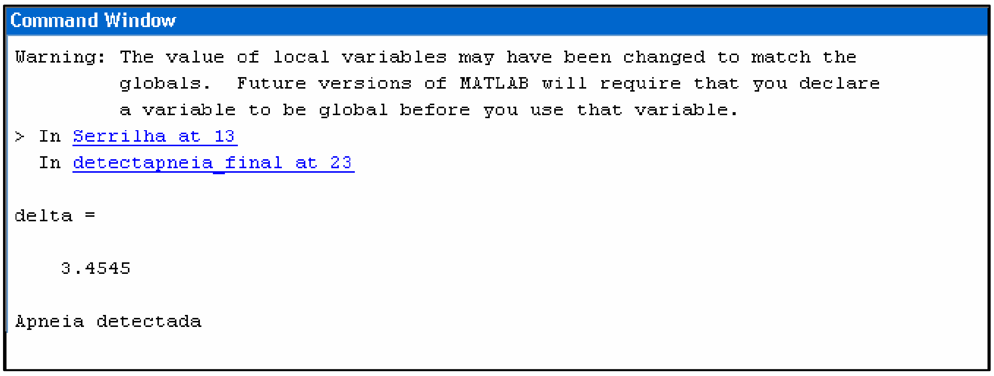

Fig. 14: Result of the analysis of a data series that vary in a range of 10% through *Serrilha* function.

Alert emission when the Delta Index has a value inferior to 4 can thus be confirmed.

The result of the test applied to *Controlo* function will not be presented, because it was concluded that this function would not be implemented in the final version for the reasons already mentioned.

Through the developed tests it was observed that this version of the application had good results in relation to what was aimed.

4.1.2. Oximeter Acquired Data Test

When it became possible to obtain oximetry data kept in a text file, they went through the algorithm of events' detection which, at this moment, had already been transcribed to VB.NET language.

Then it was realised that it was necessary to make changes to this application's version, mainly so as to read data of the text file, which have a different format from the one that was simulated to test the version in MATLAB.

As at this moment we already had a functional prototype of Sleep@Home concerning data acquisition and graphical interface, we asked some colleagues to spend one night with Sleep@Home, so that it was possible to acquire data the closest to reality, in order to test these prototype's functionalities and also the algorithms of apnea events' detection. They were also asked to hold their breaths for a few seconds in order to simulate an apnea event.

The data obtained through analysis of acquired results with events' detection application, allowed the conclusion that the used algorithms needed an adjustment, in order to detect more efficiently possible events of apnea.

For this analysis, it was really important the level of development obtained so far by the graphical interface; because the visualization of SpO2 graphical representation with timing information allowed understanding more easily if, in fact, there were events not detected or detected events that should not be considered as such.

From these results it was necessary to implement some improvements in the application that would result in a more robust version regarding events detection.

It was also noticed that video recording worked correctly, acquiring data during the entire night, at the moments when movement was detected.

Graphical interface also revealed its efficiency, mainly when allowing the synchronization of the oximetry data with video data, that is, in the visualization of the video whenever it was asked for, especially in instants when possible apnea events were detected.

4.1.3. Presentation of the functional prototype in Hospital Pediátrico de Coimbra

As soon as a functional prototype of Sleep@Home was completely developed (data acquisition, events detection and graphical interface) it was needed a presentation to Drª Helena Estêvão, in the Hospital Pediátrico de Coimbra.

This presentation was highly productive, because we received accurate appreciation from a professional specialized in the area of sleep disturbs in children diagnosis.

According to Drª Helena Estêvão's opinion, the parameters analyzed in our application have an essential role in the OSAS diagnosis.

It was also asked, due to its importance, to visualize a graphical representation of heart rate and also to define a new alarm that was based on the synchronization between

SpO2 desaturation and heart rate out of normal defined limits. According to what was said this synchronization is very common.

We were also advised about default values that must be used in our application.

It was also understood the importance to give the physician the possibility to choose some parameters of definition of events related to long and fast desaturations detection, as well as parameters of visualization of graphical representations and video.

So as to follow the advices, we developed other improvements concerning events' detection algorithms as well as the graphical interface; these changes originated the final version of the application.

4.1.4. Oximeter Test

Since this project's beginning our team was concerned about the accuracy of the data acquired through the oximeter selected.

Thus, during one of the visits to the Hospital Pediátrico de Coimbra, so as to achieve new developments in the project, a test to the oximeter was performed.

Drª Helena Estêvão placed in a finger the oximeter used in the Sleep Laboratory and in a finger on the other hand the oximeter used in Sleep@Home that was connected to a portable computer in which the developed application was available.

According to Drª Helena Estêvão, given the fact that the oximeters are connected to the same person even if on different hands, there are not significant variations on the acquired data.

Both oximeters were turned on and the acquired data by each of them were compared.

It was observed that among the data collected from both oximeters the maximum difference occurred was of 2%.

According to Drª Helena Estêvão, this is a very good result, a fact that certified, in a certain way, the accuracy of the data acquired with Micro Power Oximeter Board 31392B1.

4.1.5. Test with real data from the Hospital Pediátrico de Coimbra

To test final version of oximetry events' detection algorithms, we asked the Sleep Laboratory techniques in the Hospital Pediátrico de Coimbra the results of some tests performed with the technology used there (PSG), mostly acquired data related to SpO2.

Respecting patients' identity protection, four tests were selected because although they presented different situations, in some way, all examples were significant in the area of sleep pathologies.

We also had access to the analysis software of the data that are acquired through the PSG used in the Sleep Laboratory, in order to know all the results obtained after data processing, so that these results could be compared to the ones obtained with Sleep@Home processing.

After a first analysis to the data provided, still unexplored, it was understood that these were in EDF (European Data Format) format. According to Wikipedia [1], EDF is a standard file format designed for exchange and storage of medical time series. It is widely used for EEG and polysomnography recordings in commercial equipment and multicenter research projects.

This format wasn't compatible with the application developed for Sleep@Home and therefore, we needed to use an EDF to ASCII converter so that the data were available in text format compatible with the developed application.

The first idea was to compare the results obtained through the processing of the available data in both softwares.

However, we realised that this was an unfruitful idea, because the software from the Hospital Pediátrico de Coimbra did not allow a comparison event by event as it only presents the total number of detected events. Moreover, its temporal localization must be done by someone specialised in this area, since it is necessary a graphical analysis of other parameters simultaneously. This analysis is very complex and slow.

Therefore, it was only possible to analyze Oximetry events' detection comparing the graphical representation obtained by the graphical interface of Sleep@Home and the analysis of the rough data.

The results obtained were considered acceptable, because according to the analysis of the rough data all events detected through this way were presented as alarms in the graphical interface. Furthermore, some parameters that define oximetry events detection were modified and yet the events continued to be detected in relation to these variations.

4.1.6. Final Test in Hospital Pediátrico de Coimbra

The final test in Hospital Pediátrico de Coimbra is composed of tests on two different children, done in Sleep Laboratory facilities of this hospital.

In each case, Sleep@Home was placed on the patient and data, from the duration of the night, was recorded. Simultaneously, the patient was undergoing a PSG exam. The main idea was to compare the results acquired with Sleep@Home and PSG.

The first test was done on a three year old child.

From this test we could easily observe why undergoing a PSG can be so harmful to children. In Figure 15 we can see the amount of cables placed on the patient to make a PSG. An oximeter, concentrative device and video camera, constituting elements of the Sleep@Home, can also be seen, along with a personal computer with Sleep@Home's graphical interface installed.

Figure 15: Photography took before the first test in Hospital Pediátrico de Coimbra, showing all the devices used in a PSG, which are already placed on a child. It is also possible to see the devices that constitute Sleep@Home.

Despite the test case being an atypical OSAS case, because the child didn't desaturate significantly, it was possible to arrive to some conclusions.

It was verified that Sleep@Home detected more events than PSG, becoming necessary to understand why this happened.

With help from Drª Helena Estevão and a technician from the Sleep Laboratory we understood that most of long desaturations detected by Sleep@Home corresponded to arousals. And these kinds of alarms are not classified. It was concluded that it will be useful to make a selection of detected alarms in order to eliminate the ones detected when the child is awake. For that, it is necessary to identify REM and non-REM sleep.

To search for more reasons to explain this occurrence, we analysed SpO_2 and Heart Rate graphic representation.

Figure 16 and 17 show the graphical representation of Heart Rate acquired with PSG and with Sleep@Home, respectively.

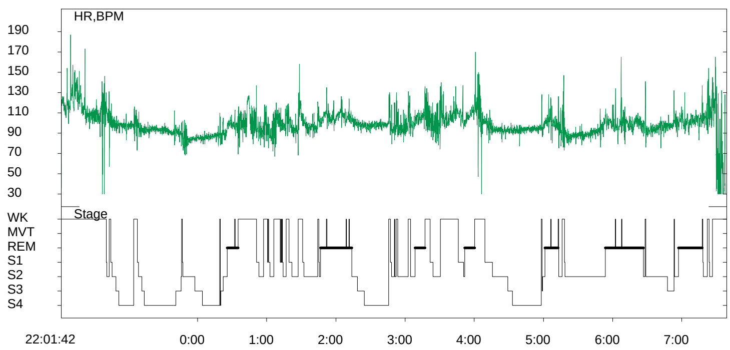

Figure 16: Graphic representation of Heart Rate (green) and sleep stages obtained with PSG in the first test done in Hospital Pediátrico de Coimbra.

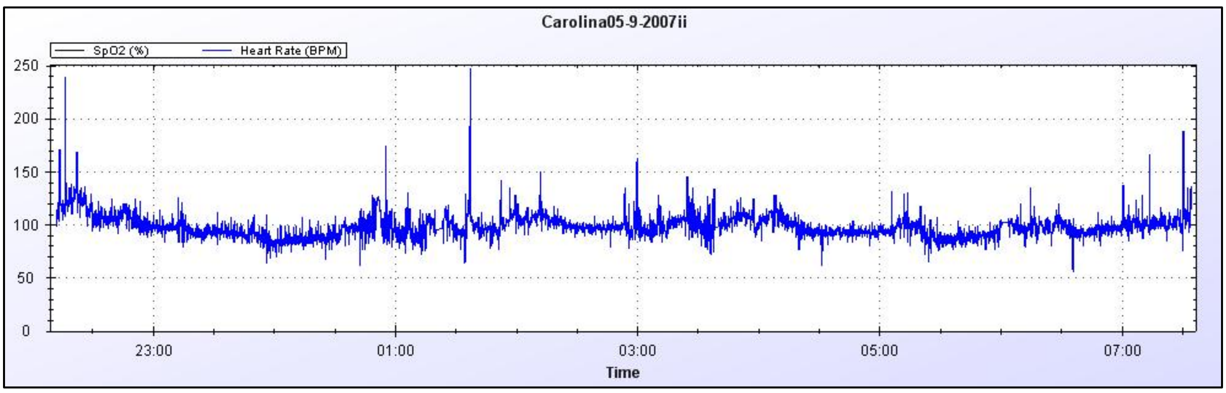

Figure 17: Graphic representation of Heart Rate obtained with Sleep@Home in the first test done in Hospital Pediátrico de Coimbra.

Comparing the two graphics above, we conclude that Heart Rate measurements with Sleep@ and PSG are similar.

The following graphics show SpO2 readings, acquired from each device.

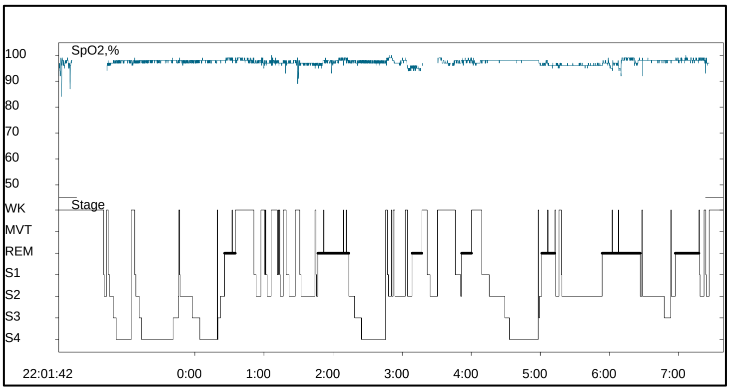

Figure 18: Graphic representation of SpO_2 (blue) and sleep stages obtained with PSG.

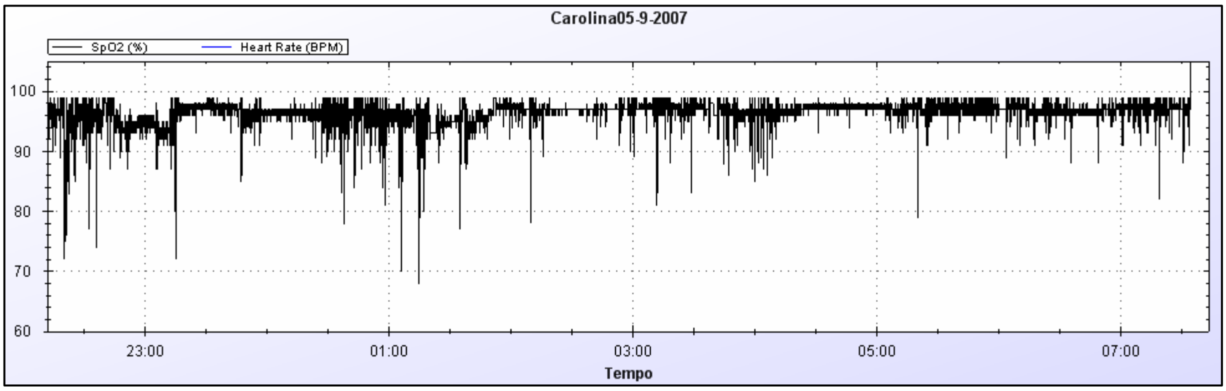

Figure 19: Graphic representation of SpO_2 obtained with Sleep@Home.

Comparing the two graphics above, we conclude that SpO_2 levels measured with Sleep@Home have much more variability than SpO_2 measured with PSG.

Dr[a] Helena Estevão said that the SpO_2 signal obtained with the oximeter used in the Sleep Laboratory is result of an average of SpO_2' values taken during a short time interval. On the other hand, SpO_2 values analysed with Sleep@Home results from instantaneous samplings of SpO_2. This could be a reason for the variability of SpO_2 signal obtained from the test.

In order to explore this hypothesis the source code of Sleep@Home was changed, analysing SpO_2 signal result of an average of SpO_2' values in a short time interval. Graphical result is represented in Figure 20.

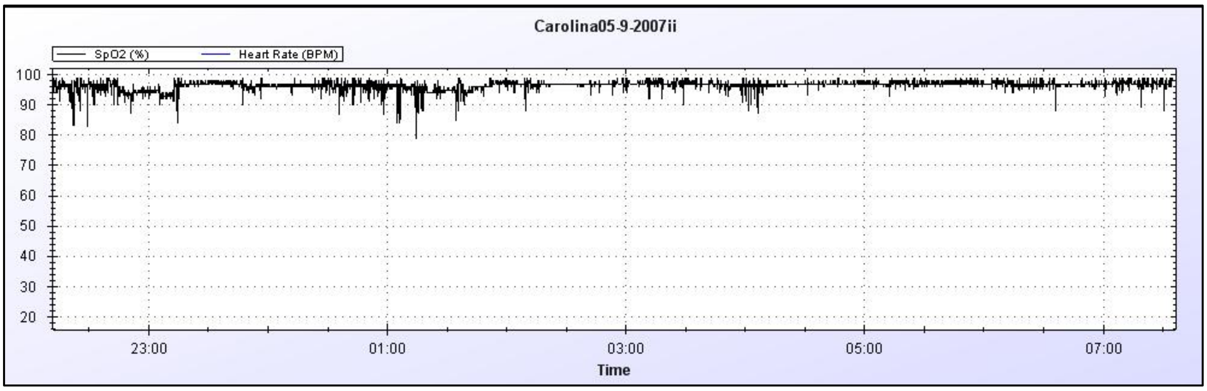

Figure 20: Graphic representation of SpO_2 obtained with Sleep@Home, with the application's source code changed from the first test.

As can be seen in Figure 20, SpO_2 variability greatly decreased, but is still higher than in the SpO_2 signal acquired with PSG.

So, in future work it is important to analyse a SpO_2 average instead of instantaneous SpO_2.

Dr[a] Helena Estevão also said that recent devices on the market use small time intervals to calculate a SpO_2 average in order to calculate the returned SpO_2 values, which could mean that Sleep@Home having more sensitivity than PSG may not prove to be an advantage.

Another hypothesis for SpO_2 variability is the presence of artefacts due to oximeter movements.

From these hypotheses was realised that, in order to cross the largest number of parameters to detect the most significant events, there was the additional need to acquire and analyse sound data during the test.

The second test developed in Hospital Pediátrico de Coimbra was done in a five year old child. The proceeding was similar to the one used in the first test.

At printing time, we don't have access to these test results, so an analysis of the results can not be presented in this report.

4.2. Analysis of the Results

The results from the tests developed were very important for the development of Sleep@Home. They provided diverse information that helped in the development of a robust and efficient application of detection of events of oximetry, mainly detecting long and fast desaturations of SpO2 in time.

We also realised the good Sleep@Home's functioning in its development stage, which corresponds to the final phase of the planning done for this project part of an academic discipline, because it keeps the recordings done during a night and they can be seen with good quality, allowing the crossing of this information with the oximetry alarms through the graphical interface.

It was also realised that at the moment it is not possible to detect with safety hipoapneia events. This because, in a hipoapneia, the reduction of SpO2 can be so minimal that is not reflected in the oximetry data. Video recording can solve this question but, in this phase, only if the physician chooses to analyze all the recordings, because an application for detection of apnea events was not developed to execute in video recording. Thus, physician can not know when a situation of alarm could have happened if this is not disclosed in the oximetry data. In a future development this can be an innovation to place in Sleep@Home.

With tests elaborated we could also conclude that it is very necessary record and analyse/process sound.

4.3. References

1. (2007). European data format. *Wikipedia* [Online]
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5. Conclusions

5.1. Fulfilled Objectives

During one school year, time during which this project has been done, the work developed by my colleague Samuel and me has changed.

We started studying Apnea/OSAS, its causes and consequences, methods of diagnosis and treatment.

After researching on the state of the art documents and constructing a reflection upon the necessary requirements for Sleep@Home and for its architecture, we developed documents in which these studies are presented. Among these documents, there is also the initial planning of project.

Furthermore, we also acquired some skills of programming in C and VB.NET languages, needed for the accomplishment of some tasks for the project's development.

After the acquisition of theoretical background, we started the more practical stage.

The devices to implement in Sleep@Home were chosen (Oximeter, Video Camera and Concentrative Device).

The following step consisted in the development of an application to keep the data from the oximetry and from video recording in a compatible format with the application of events' detection, which was developed simultaneously.

Moreover, we also studied and put in practice the transmission of the data proceeding from oximetry and video recording.

The graphical interface was also developed throughout this stage of practical work.

On the other hand, while the project was being developed, some tests to the system were done.

Thus, we reached the end of project in the academic field, with a system relatively portable, able to detect events of apnea, analysing simultaneously oximetry and video recording data – a functional prototype of Sleep@Home.

We mention "relatively portable", because one of the basic requirements for portability is the possibility of data transmission without the need to use, for example, wires, which is a module not developed due to lack of time, not being included in the project's development in its academic feature.

Nevertheless, the main objectives for the development of Sleep@Home in its academic feature were fulfilled.

5.2. Future Work

This sub-chapter aims to reflect upon the work that was not done, mainly concerning the limitations that emerged and prevented us from the development of any task, or that the expected results were not obtained. It is also aimed to present assumptions of solution for some problems encountered and suggestions of different forms of broadening the solutions used in this project.

5.2.1. Transmission of Information

As it was already mentioned, due to lack of time, transmission of information in Sleep@Home was not deepen. Some research in this scope was done, but we only worked on the essential to allow the acquisition of data for analysis through a network cable.

Thus, it would be an asset for Sleep@Home if the transmission of data could occur by wireless, for example, for a server or even though directly to the physician's PDA.

This kind of information transmission would be advantageous for a patient whose home is far from the Central Hospitals, because it allows sending data without the patient's immediate need to deliver them to the physician.

On the other hand, with this modality it also became possible data analysis in real time, as well as the consequent emission of alarms in real time for the physician. This would be advantageous because it allows an almost uninterrupted accompaniment of the patient by the physician, what shows a new possible function for Sleep@Home besides its already developed function of selection: a continuous accompaniment of patients.

So as to implement this new approach in Sleep@Home it would also be useful to develop an application that allowed unchaining the emission of alarms related to video recording, a fact that in a way, could also contribute to a reduction of the amount of information to be sent for the physician, making communication cheaper and more efficient. This idea is fully developed in the following sub-chapter.

5.2.2. Detection of Events of Sleep Apnea through video recording

An idea that would improve Sleep@Home's strength would be the detection of events through video recording. This detection would be done through a more specific application detection of movements than the one that was used in this phase of project. This application would detect specific positions of the mouth and neck of the patient, as well as abrupt movements that mean apnea events. It will be necessary to make an extended research on this subject, in order to know what is being developed at this level.

The detection of events through video recording could also emit alarms. In such way, the recording of video data could be controlled, because the emission of oximetry alarms could unchain video recording and the emission of video alarms could unchain the recording of oximetry data.

This idea would be advantageous due to the reduction of the amount of data transmitted to the physician, facilitating its analysis because only data related to detected events would be sent, as well as for making communication cheaper and more efficient.

Another advantage is the possibility to detect hypopneas through the video events, which could escape the processing of the oximetry data, because they are not included in these data. Although in these cases there is not frequently a significant decrease of SpO2, the patient reveals problems to breathe, making him/her move looking for a position that allows his/her normal breath recovery. These movements are frequently abrupt. Moreover, there is also an abnormal thorax movement because the patient makes an exceeding effort to breathe. All these movements could be detected by this application, increasing the robustness and the effectiveness of Sleep@Home in the detection of apneas and hypopneas.

Nevertheless, it must be studied the importance of having available all the data of oximetry or video in rough (without processing), for the physician to consulting. A possible solution would be recording data in an interval of time before and after the events' detection determined by the physician.

5.2.3. Sound Recording

Another interesting parameter that could be analyzed is the sound.

In a study from the American Academy of Pediatrics is recommended that all children should be screened for snoring, in order to diagnose childhood OSAS [1].

According to Vincent Iannelli [2], although snoring is a common symptom in children with obstructive sleep apnea, it is important to know that between 10-20 percent of normal children snore. However, the recording of sound can be important to register sounds related to asphyxia and chokes, contributing to an easier understanding about when the patient is in effort to breathe.

This could be another contribution for the detection of apnea and hypopnea events.

5.2.4. Analysis of SpO_2 sign

From the results of the final test in Hospital Pediátrico de Coimbra was observed that SpO2 data acquired with Sleep@Home has more variability than SpO2 acquired with a PSG.

We analyse more exhaustively this fact and conclude that Sleep@Home must analyse a SpO2 data average instead of instantaneous SpO2 sampling, in order to avoid many oximetry artefacts (see **Final Test in Hospital Pediátrico de Coimbra**).

As it was already mentioned, SpO2 signal presents certain variability, determined by Delta Index in Sleep@Home. A new method to determine the variability of SpO2 signal could be spectral analysis. This technique, according to a study of Zamarrón *et al* [3], we have shown that spectral analysis could be useful as a first approach to the analysis of nocturnal Oximetry, mainly in peak detection of SpO2.

Some advantages of this technique are as follows: the spectral characteristics of the SpO_2 signal from OSA patients are significantly different from those of non-OSA subjects; better diagnostic indices are obtained than with other traditional oximetric methods; and the good agreement reached between different observers may be due to the ease with which the peak in the spectrum can be seen.

This theory must be exhaustively analyzed before being applied.

5.2.5. Analysis of a new parameter: Peripheral Arterial Tone (PAT)

In the analysis of the state of the art documents, it was noticed that there is a device - WatchPAT 100 - that makes use of another parameter besides the commonly used ones to detect apneas and hypopneas. This parameter is called PAT - Peripheral Arterial Tone.

As it is said by Penzel *et al* [4] the autonomous nervous functions change with sleep stages and show characteristic changes associated with sleep disorders. Therefore, continuous monitoring of autonomous nervous functions during sleep can be used for diagnostic purposes.

According to a study of Bar *et al* [5], the PAT signal measures the arterial pulsatile volume changes of the finger that are regulated by a specific innervation of the smooth muscles of the vasculature of the finger, and thus reflects sympathetic nervous system activity. The WP100 indirectly detects apnea/hypopnea events by identifying surges of sympathetic activation associated with the termination of these events. This information is further combined with heart rate and pulse Oximetry data.

In this device the PAT is measured with a system based in plethysmography [6]. As it was said in sub-chapter **Final Version**, the oximeter used in Sleep@Home provides information related to plethysmography – Pleth. If this assumption was fully studied, maybe it could be possible to implement this new parameter in Sleep@Home, increasing the robustness of the system.

5.3. Final Appreciation

My participation in this project's team was very important for the acquisition of essential skills for my future work as engineer.

This project, which is part of Biomedical Engineering course, revealed its multidisciplinary features.

The Integration in ISA, a company with an innovative spirit, which has already been given awards worldwide, has provided a real vision of the world of work and of scientific investigation. Furthermore, we also acquired academic skills with the learning of new programming languages and the acquisition of knowledge on OSAS in the medical field.

It was very gratifying to participate in the development of a device that may have a significant impact on the diagnosis of a syndrome that already affects between 4 and 8% of the population, and that is already in an advanced stage of development, being ready for the commercialization in the short run.

In conclusion, this was a highly rewarding experience in all its features.

5.4. References

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Appendix

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Relatório do software de detecção de eventos de apneia para o projecto Sleep@Home

Versão 0.4

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Índice

1. Introdução

Este relatório destina-se a explicar o desenvolvimento e funcionamento do software elaborado, comentando as partes mais importantes e dando conta de eventuais pontos subentendidos.

Será explicada cada uma das funções definidas de raiz e só depois a aplicação geral de detecção de apneias.

Será também desenvolvido um item particular onde serão analisados os testes elaborados que permitiram determinar o funcionamento da aplicação sem erros e prevendo possíveis situações-problema.

Nesta nova versão do relatório são várias as alterações efectuadas relativamente ao software anterior.

De modo a conseguir colocar a aplicação de detecção de apneias a correr directamente na interface gráfica (elaborada em VB.NET), o software foi transcrito de Matlab para VB.NET.

Para além disso, os algoritmos de detecção de apneias têm sido sucessivamente melhorados de forma a aumentar a sua robustez e precisão. Para este processo contribuiu em grande escala o facto de os dados poderem ser analisados já na interface gráfica, o que proporciona a visualização dos dados num gráfico e de vários parâmetros importantes para a análise dos resultados.

Foi ainda adicionado um novo tipo de alarme relaccionado com eventos de Frequência Cardíaca anormal. O algoritmo de detecção deste tipo de alarme corre dentro das funções *Contador* e *Pico*. Este assunto será abordado mais aprofundadamente nos capítulos correspondentes a estas funções.

2. Preparação dos dados

Após terem sido feitas várias observações aos dados recolhidos pelo oximetro e estes terem sido guardados num ficheiro de texto, a sua análise mostrou a incidência de valores inválidos.

De modo a colmatar esta falha decidimos elaborar um algoritmo que simula a ligação entre o último valor válido e o primeiro valor válido seguinte através de uma recta, atribuindo cada um dos valores dessa recta a cada valor inválido no intervalo determinado. Este processo foi aplicado quer aos valores de SpO_2 quer aos relativos à Frequência Cardíaca ainda que os algoritmos apresentem algumas diferenças.

Para isso, em ambos os casos, os valores são guardados numa variável do tipo *Array*. Posteriormente são lidos um a um e é contado o número de valores considerados inválidos desde o primeiro inválido até ao primeiro valor válido seguinte.

O bloco de código correspondente para SpO_2 é:

```
If Real(i) > 100 Then
   Invalido = Invalido + 1
Else
```

De seguida é determinada a diferença entre o primeiro valor válido seguinte e o último válido anterior a este. Esta diferença é dividida pelo número de valores inválidos de modo a determinar a constante a somar ao último valor válido para que os valores vão sendo criados progressivamente até atingir um valor nunca superior ao do primeiro valor válido seguinte.

Para isso, temos o seguinte bloco de código:

```
   Dim range As Double = Real(i) - Real(i - Invalido - 1)

   If Invalido <> 0 Then
      Dim incr As Integer = CInt(range / (Invalido))

      If range = 0 Then
         For k As Integer = (i - Invalido) To (i - 1)
             Real(k) = Real(i)
         Next
         Invalido = 0
      End If

      If range > 0 Then
         For k As Integer = (i - Invalido) To (i - 1)
```

```
            If (Real(k - 1) + incr) < Real(i) Then
                Real(k) = Real(k - 1) + incr
            End If
            If (Real(k - 1) + incr) >= Real(i) Then
                Real(k) = Real(i)
            End If
        Next
        Invalido = 0
    End If

    If range < 0 Then
        For k As Integer = (i - Invalido) To (i - 1)
            If (Real(k - 1) + incr) > Real(i) Then
                Real(k) = Real(k - 1) + incr
            End If
            If (Real(k - 1) + incr) <= Real(i) Then
                Real(k) = Real(i)
            End If
            Next
            Invalido = 0
    End If
End If
```

O algoritmo aplicado à Frequência cardíaca é bastante semelhante ao anterior, por isso não é explicado com muito detalhe.

Os dados estão agora prontos a ser analisados pelos algoritmos de detecção de eventos de apneia.

Estes eventos podem ser de três tipos:

- Dessaturação prolongada no tempo (Long desaturation) detectado pela função *Contador*;
- Pico de dessaturação (Fast desaturation) detectado pela função *Pico*;
- Índice delta determinado pela função *Serrilha*.

Foram ainda incluidos nas duas primeiras funções enunciadas algoritmos de detecção de alarmes relativos à Frequência cardíaca, resultando desta actualização um novo tipo de alarme: Alarme Múltiplo. Este alarme ocorre quando são detectados alarmes de eventos de apneia e de frequência cardíaca dentro dum intervalo de tempo passível de ser determinado pelo clínico.

Estas funções serão todas abordadas detalhadamente nos próximos capítulos.

3. Função *Contador*

Esta função tem por objectivo detectar apneias que se manifestam na forma de uma dessaturação prolongada no tempo. Assim sendo, foi admitido que quando os dados sucessivos durante uma quantidade de tempo definida pelo clínico no campo *Long Desaturation time interval (sec.)* revelarem valores inferiores ao valor de referência da SpO_2 (percentagem de saturação de oxigénio no sangue) RefValue, que é por defeito 92% mas que pode ser escolhido pelo clínico, é detectado um evento de apneia.

Como os dados foram previamente tratados admite-se que há aquisição de dados válidos a cada segundo e que os dados de SpO_2 provenientes da oximetria se encontram guardados na variável a que chamámos SpO2Real.

A aplicação é iniciada com a leitura dos dados de SpO_2. Quando é detectado um valor inferior a RefValue é contabilizado o número de valores seguidos inferiores a RefValue na variável des.

```
For c As Integer = 0 To ln - 1
    Dim g(ln) As Integer
    If RefValue <> "" Then
        If SpO2Real(c + 1) < CInt(RefValue) Then
               des = des + 1
```

Quando des é superior ao valor definido na variável NumericUpDown6 que corresponde ao valor seleccionado no campo *Long Desaturation time interval* é detectado um evento de apneia na forma de dessaturação prolongada.

```
If des > NumericUpDown6.Value Then
    Dim meio As Double = (des / 2)
    Dim meioint As Integer
       meioint = CInt(meio)
```

Neste ponto é activado o algoritmo para detecção de alarmes de Frequência Cardíaca.

3.1. *Detecção de eventos relativos à Frequência Cardíaca*

Neste algoritmo os dados estão guardados na variável HR. São analisados os que se encontram dentro do intervalo de tempo correspondente a mais ou menos o número de segundos seleccionados pelo clínico através da variável TimeVariationBetweenAlarms relativamente ao segundo em que é detectado o evento de dessaturação prolongada.

Sempre que nesse intervalo de tempo existe um valor superior à soma do valor médio da Frequência Cardíaca (HRAverage calculado anteriormente) com uma constante definida pelo clínico (HRVariation) é somada uma unidade a uma variável (Something) definida de modo a contar o número de casos em que eventos desse tipo ocorrem.

O mesmo acontece quando existe um valor inferior à diferença entre HRAverage e HRVariation, sendo somada uma unidade a uma outra variável (SomethingNew).

Em código:

```
   For j As Integer = (c - c - TimeVariationBetweenAlarms) To (c - c +
TimeVariationBetweenAlarms)
        If HR(c) > (HRAverage + HRVariation) Then
           Something = Something + 1
        End If
        If HR(c) < (HRAverage - HRVariation) Then
           SomethingNew = SomethingNew + 1
        End If
   Next
```

No fim de percorrer todos os valores no intervalo podem verificar-se as seguintes situações:

- Se a variável Something for diferente de zero estamos perante um alarme múltiplo: alarme de dessaturação prolongada coincidente ou aproximadamente coincidente com alarme de Frequência Cardíaca e é escrita no ficheiro de texto onde são marcados os alarmes a seguinte linha (por cada alarme detectado):

```
alarms.WriteLine(TestDate(c + 1) + " " + Hour(c + 1) + " " + "000" +
",2")
```

em que TestDate(c + 1)é a data em que ocorreu o alarme (no instante c), Hour(c + 1) é a hora em que ocorreu o alarme (no instante c), e o parâmetro 2 é indicativo de tipo de alarme (neste caso *Multiple Alarm*).

- Se a variável SomethingNew for diferente de zero estamos novamente perante um alarme múltiplo e é escrita no ficheiro de texto uma linha igual à anterior (por cada alarme detectado).

- Se qualquer uma das variáveis anteriores forem iguais a zero, então não ocorreu nenhum evento de alarme relacionado com a Frequência Cardíaca no intervalo analisado e por isso estamos perante um alarme simples do tipo dessaturação prolongada. A linha escrita no ficheiro de texto de alarmes é então:

```
alarms.WriteLine(TestDate(c - meioint) + " " + Hour(c - meioint) + " "
+ des.ToString + ",0")
```

em que TestDate(c - meioint)é a data correspondente ao meio do intervalo em que se verificou a dessaturação prolongada (de modo a centrar o alarme), Hour(c - meioint) é a hora correspondente ao meio do intervalo em que se verificou a dessaturação prolongada (de modo a centrar o alarme), o parâmetro des indica a quantidade de tempo que estev em dessaturação (em segundos) e o parâmetro 0 é indicativo de tipo de alarme (neste caso alarme simples do tipo *Long Desaturation*).

A estas três situações distintas corresponde o seguinte bloco de código:

```
If Something <> 0 Then
   alarms.WriteLine(TestDate(c + 1) + " " + Hour(c + 1) + " " + "000"
+ ",2")
ElseIf SomethingNew <> 0 Then
    alarms.WriteLine(TestDate(c + 1) + " " + Hour(c + 1) + " " + "000"
+ ",2")
Else
    alarms.WriteLine(TestDate(c - meioint) + " " + Hour(c - meioint) +
" " + des.ToString + ",0")
End If
```

Outro parâmetro importante determinado nesta função é *Cumulative Time Under (x%)* que indica a quantidade de tempo em minutos que a SpO_2 esteve abaixo de *x*%.

Para além disso são determinados também nesta função os valores máximos e mínimos registados de SpO_2.

No primeiro caso é definido como valor máximo o primeiro valor de SpO_2 registado e é verificado sucessivamente se o valor seguinte é superior a este. Se for, passa este último a ser o valor máximo de referência. Este valor máximo é então passado a *SpO_2 Maximum*.

Em código tem-se:

```
Dim q As Integer
Dim max1 As Integer = SpO2Real(0)
For q = 1 To ln - 1
    If SpO2Real(q) > max1 Then
        max1 = SpO2Real(q)
    End If
Next

Dim Maximum As Integer = max1
TextBox12.Text = max1.ToString
```

No caso do valor mínimo apenas varia o facto de o primeiro valor registado ser definido como o primeiro mínimo de referência e é avaliado sucessivamente se o valor seguinte é inferior. Se for, este último valor passa a ser o valor mínimo de referência. O valor mínimo é então passado a *SpO_2 Minimum*. Ou seja:

```
Dim f As Integer
Dim min1 As Integer = SpO2Real(0)
For f = 1 To ln - 1
    If SpO2Real(f) < min1 Then
        min1 = SpO2Real(f)
    End If
Next

Dim Minimum As Integer = min1
TextBox11.Text = min1.ToString
```

Este algoritmo foi testado em dados obtidos com o protótipo funcional do Sleep@Home, registados em várias noites e em diferentes indivíduos. Para melhor validação primária foram simulados alguns eventos de apneia.

Os resultados foram analisados com mais facilidade devido à comparação com o gráfico obtido no interface gráfico.

4. Função *Pico*

Esta função inicialmente designava-se *Pico_final,* tendo agora recebido o nome de função *Pico*.

Pretende-se com esta função a detecção de apneias na forma de um pico de dessaturação.

É agora assumido que acontece um pico de dessaturação sempre que durante o número de segundos escolhido pelo clínico através do parâmetro *Desaturation Time Interval* (5 segundos por default) que se seguem à detecção de um valor inferior ao valor de referência (*RefValue*), que é por defeito 92%, há um decaimento maior ou igual a x%.

Este valor de decaimento é passível de ser alterado pelo clínico no campo *SpO_2 falling* que é expresso em percentagem e que assume o valor de 3% por defeito. Também o valor de referência pode ser escolhido pelo clínico.

Também para esta função os dados foram previamente tratados podendo assim admitir-se que há aquisição de dados válidos a cada segundo e que os dados de SpO_2 provenientes da oximetria se encontram guardados na variável a que chamámos SpO2Real.

A aplicação é iniciada com a leitura dos dados de SpO_2. Quando é detectado um valor inferior a *RefValue* o intervalo de tempo que se lhe segue, já definido pelo clínico, é analisado. São determinados o máximo e o mínimo valor atingidos por SpO_2 nesse intervalo. Depois é calculado uma nova variável através da diferença entre o valor máximo e mínimo determinado. Deste modo pretende-se determinar o decaimento efectivo que ocorreu no intervalo de tempo definido.

```
If SpO2Real(c) < RefValue1 Then
    Dim LimiteFinal As Integer = ((ln - 1) - c)
    If LimiteFinal >= DesaturationTimeInterval Then
        Dim MaxPic As Integer = SpO2Real(c)
        Dim MinPic As Integer = SpO2Real(c)
        For i As Integer = (-1) To (DesaturationTimeInterval - 1)
            If SpO2Real(c + i) > MaxPic Then
                If SpO2Real(c + i) > SpO2Real(c + i + 1) Then
                    MaxPic = SpO2Real(c + i)
                Else
                    Exit For
                End If
```

```
            End If
        Next
        For i As Integer = (-1) To (DesaturationTimeInterval - 1)
            If SpO2Real(c + i) < MinPic Then
                If SpO2Real(c + i) > SpO2Real(c + i + 1) Then
                    MinPic = SpO2Real(c + i)
                Else
                    Exit For
                End If
            End If
        Next
        var = MaxPic - MinPic
    End If

    If LimiteFinal < DesaturationTimeInterval Then
        Dim MaxPic As Integer = SpO2Real(c)
        Dim MinPic As Integer = SpO2Real(c)
        For j As Integer = 0 To (LimiteFinal)
            For i As Integer = (-1) To (LimiteFinal)
                If SpO2Real(c + i) > MaxPic Then
                    If SpO2Real(c + i) > SpO2Real(c + i + 1) Then
                        MaxPic = SpO2Real(c + i)
                    Else
                        Exit For
                    End If
                End If
            Next
            For i As Integer = (-1) To (LimiteFinal)
                If SpO2Real(c + i) < MinPic Then
                    If SpO2Real(c + i) > SpO2Real(c + i + 1) Then
                        MinPic = SpO2Real(c + i)
                    Else
                        Exit For
                    End If
                End If
            Next
            var = MaxPic - MinPic
        Next
       End If
```

Se esta variável é superior ao valor da variável Decamento1 escolhida pelo clínico no campo *SpO_2 falling* é detectado um evento de apneia na forma de pico de dessaturação.

```
If var >= Decamento1 Then
```

Neste ponto é activado o algoritmo para detecção de alarmes de Frequência Cardíaca.

Este algoritmo é igual ao utilizado na função *Contador*. Apenas a designação dos alarmes varia.

Assim:

- Se for detectado um alarme de Frequência Cardíaca estamos perante um alarme múltiplo: alarme de pico de dessaturação coincidente ou aproximadamente coincidente com alarme de Frequência Cardíaca e é escrita no ficheiro de texto onde são marcados os alarmes a seguinte linha (por cada alarme detectado):

```
alarms.WriteLine(dat(c + 1) + " " + hora(c + 1) + " " + "000" + ",2")
```

em que dat(c + 1)é a data em que ocorreu o alarme (no instante c), hora(c + 1) é a hora em que ocorreu o alarme (no instante c), e o parâmetro 2 é indicativo de tipo de alarme (neste caso *Multiple Alarm*).

- Se não for detectado qualquer alarme de Frequência Cardíaca estamos perante um alarme simples do tipo pico de dessaturação. A linha escrita no ficheiro de texto de alarmes é então:

```
alarms.WriteLine(dat(c + 1) + " " + hora(c + 1) + " " + var.ToString +
",1")
```

em que dat(c + 1)é a data em que ocorreu o alarme (no instante c), hora(c + 1) é a hora em que ocorreu o alarme (no instante c), o parâmetro var indica a percentagem de dessaturação de cada pico e o parâmetro 1 é indicativo de tipo de alarme (neste caso alarme simples do tipo *Fast Desaturation*).

O algoritmo usado nesta função para a detecção de alarmes de Frequência Cardíaca é bastante semelhante ao usado na função *Contador*. Por esse motivo não foi feita uma análise detalhada neste ponto.

Este algoritmo foi testado em dados obtidos com o protótipo funcional do Sleep@Home, registados em várias noites e em diferentes indivíduos. Para melhor validação primária foram simulados alguns eventos de apneia.

Os resultados foram analisados com mais facilidade devido à comparação com o gráfico obtido no interface gráfico.

5. Função *Serrilha*

Esta função foi realizada com o objectivo de detectar eventos de apneia definidos por um comportamento do tipo serrilha por parte da SpO_2. Este facto revela-se no índice delta que, de acordo com Alvarez *et al.* [1] e Levy *et al.* [2], é determinado pela soma das variações absolutas entre dois valores sucessivos, dividida pelo número de intervalos (*intv*) de 10 segundos presentes na amostra adquirida.

Esta aplicação inicia-se com a leitura de todos os dados de SpO_2. O passo seguinte é determinar a diferença entre valores sucessivos e o respectivo valor absoluto. Estas diferenças vão sendo sucessivamente somadas à variável soma que foi inicializada com o valor zero.

```
Dim soma As Integer = 0
Dim dif As Integer
For t As Integer = 0 To ln - 1
    dif = Abs(y(t + 1) - y(t))
    soma = soma + dif
Next
```

Quando este processo termina é determinado o número de intervalos de 10 segundos presentes na amostra (intv), dividindo o número total dos dados adquiridos por 10.

```
Dim intv As Double = (ln / 10)
```

O último passo é dividir a variável soma pela variável intv de modo a determinar o valor do indíce delta que poderá ser visualizado no campo *Delta index*.

```
Dim DeltaIndex As Single = (soma / intv)
Return DeltaIndex
```

De acordo com Levy *et al.* [2], se o valor de *Delta index* for inferior a 0.6 não é detectado alarme, ou seja, não se está perante um efeito serrilha que revele indícios de apneia. Se for superior a 0.6 poder-se-á estar ou não perante um caso de apneia[2].

Desta forma, este parâmetro não pode ser analisado em exclusivo. A informação que revela terá sempre de ser cruzada com as informações obtidas através das outras aplicações.

A fiabilidade deste parâmetro não pode ser confirmada pela orientadora deste projecto no Hospital Pediátrico, Drª Helena Estevão, uma vez que, sendo este parâmetro fruto de pesquisas recentes, neste hospital ainda não é utilizado.

6. Função *Controlo*

Esta função pretendia controlar o funcionamento do oxímetro em função dos valores codificados obtidos nas medições.

Os dados utilizados neste algoritmo de controlo variavam entre 0 e 5, tendo cada um destes valores um significado físico.

Esta aplicação baseava a sua importância na identificação dos valores válidos e inválidos.

Com o evoluir da aplicação genérica, verificou-se que não seria necessária a implementação da função *Controlo* uma vez que foi realizado um algoritmo de tratamento de dados que os torna todos válidos. Para além disso, na representação gráfica de SpO_2 aos intervalos dos valores inválidos foi atribuida uma cor contrastante com a dos valores válidos. Assim torna-se mais fácil a visualização e distinção entre os dois tipos de dados. Considerou-se portanto mais importante saber se o valor é inválido do que o motivo que o levou a ser inválido.

7. Aplicação *Detectapneia*

Esta aplicação pretendia detectar as várias formas de apneia usando todas as funções definidas anteriormente.

Com os sucessivos avanços da aplicação genérica, a passagem dos algoritmos de detecção de alarmes para VB.NET e com a sua inclusão na interface gráfica, esta aplicação apenas faz a chamada de cada uma das funções passando-lhes as variáveis de entrada. Este bloco de código foi, de modo a melhorar a organização do código fonte, incluído numa função a que se designou *PlotDataAndProcessing*.

Corresponde agora ao seguinte bloco de código:

```
   'Funçao Dessatauração prolongada
    Dim des As Integer = 0
    Contador(des, ln, Real, Dat, Time, HRate, Hour, Minute, Secd,
NewDateFormatWithSecd)

   'Função Picos (variações rápidas)
    Dim pic As Integer
    Pico(pic, ln, Real, Dat, Time, HRate, Hour, Minute, Secd,
NewDateFormatWithSecd)

   'Função Efeito Serrilha
    Dim DeltaIndex As Single
    DeltaIndex = Serrilha(ln, Real, Dat, Time)
    TextBox7.Text = DeltaIndex.ToString
```

8. Referências

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