Integrated Master in Biomedical Engineering
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Apnea Detection and Classification During Sleep

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1. Abstract

Apnea is a sleep disorder in which an individual stops breathing for repetitive periods of time during sleep. To be determined as apnea, these periods of time have to be of 10 seconds or more. The gravity of the pathology depends on the number of repetitions that the person presents in one hour.

Apnea can be classified into three different types, obstructive, central and mixed. This classification is based on the cause of the disorder. If the cause of the disorder is due to an obstruction of the airways, the apnea is classified as obstructive; and if the syndrome is caused by a neurological disorder, this is considered as central. Apnea could also be caused by a combination of the two classification mentioned before, in this case it is a mixed apnea.

This disorder is the most deadly disease during sleep, not only because it is related to daytime somnolence causing many accidents, but it can also increase the probability of cardiovascular diseases, like hypertension, cardiac arrhythmias, ischemic cardiopathy and cerebrovascular accidents (strokes). Apnea also can cause insulin resistance and chronic hypoxia effects.

The severity presented by this disorder is the reason why the development of better treatments and more sophisticated diagnostic tools for apneas is extremely important. The objective of this project is to implement an effective system to detect and classify apneas with by the analysis and correct processing of whole night sleep recordings of different patients with the use of Matlab coding.

2. Problem and Motivation

Nowadays, the discipline of sleep medicine is growing due to the fact that more and more people present sleep disorders. In particular, breathing disorders has increased its relevance in the past two decades. In 1993, a study on this type of diseases showed that sleep disordered breathing had prevalences of 2% in women and 4% in men. A recent study showed the increase of these percentages of 10% in men and 3% in women (between 30 and 49 years) and 17% in men and 9% in women (between 50 and 70 years). The comparison between the two studies clearly shows the increase over time and the increase of presenting breathing disorders in older people. One important point to take into consideration is that many people with this kind of disease result undiagnosed or untreated, and this presents the need for the development of detection techniques. [3] [4] [5]

Apnea means “absence of breathing” during sleep. This sleep disorder is characterized by repetitive episodes (upto 50 episodes per hour) of hypoxemia during sleeping with a duration of 10 seconds or more each. Apnea episodes cause not only a lot of stress and fatigue in the person suffering from this disease, but also it increases the risk of cardiovascular diseases, such as stroke, hypertension, cardiac arrhythmias and ischemic cardiopathy, chronic hypoxia effects and insulin resistance. [6]

Apnea is highly related to some conditions and characteristics that a person could present, such as obesity, advanced age, male gender, family history, craniofacial abnormalities, smoking and alcohol consumption. The mentioned characteristics increase the probabilities of developing and aggravating this syndrome.

Apnea can be classified into three different types depending on the cause of the disorder, as it is shown in Figure 1:

- Obstructive sleep apnea: although the patient's brain is able to send the signals to the respiratory muscles, and the correct movements and efforts are being done, the ventilation is reduced or obstructed by a partial or total occlusion in the upper airway. This condition inhibits the oxygen to reach the lungs, and the patients starts being in a hypoxia state. There are many possible causes of obstruction, such as excessive relaxation of respiratory muscles during sleep, the neck's weight that narrow the airway, tonsillitis or other temporary reasons and structural reasons (shape of the nose, neck or jaw). [9]

- Central sleep apnea: the cause of this disease is that the brain stops sending signals to the muscles in charge of the breathing, or delays the signals, so the person is not able to obtain the necessary oxygen due to the absence of respiratory effort, leading to hypoxia. There are four types of central apneas: idiopathic, high altitude, narcotic induced, CSR. This type of apnea can be caused by heart failure or an illness or injury involving the brain, such as cerebrovascular accidents, brain tumors, viral brain infections or chronic respiratory diseases. [9]

- Mixed apnea: This disease is a combination of the other two apneas, first with a component of central apnea followed by another one of obstructive apnea. So, the patient experience an absence of respiratory effort in the beginning (central), and then the respiratory effort starts but it is not enough to take air through the air way (obstructive). [1][2]

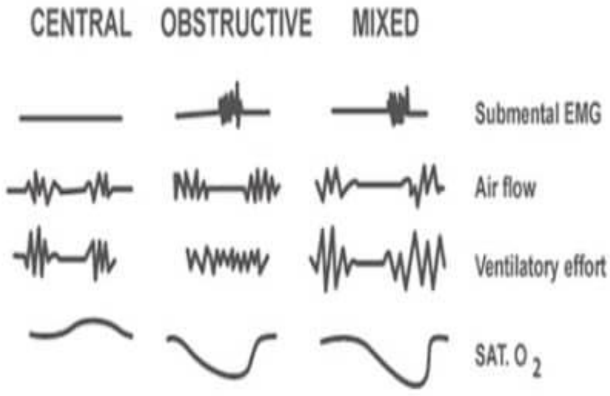

Figure 1. Representative signals of electromyography (EMG), air flow, ventilatory effort and oxygen saturation (SAT. O2) for each type of apnea (central, obstructive and mixed).

To perform a correct detection of apnea, multiple signals measured from the body must be taken into consideration. These include signals obtained from electroencephalogram (EEG), electromyography (EMG), electrocardiogram (ECG), body position, air flow measurements, snoring recordings, abdominal muscle activity and blood oxygen levels.

The EEG and EMG are used to determine the stages of sleep. In particular, the EEG shows possible relationships between neuronal activity and a central apnea and the EMG is performed to diagnose possible sleep-related movement disorders such as PLM (periodic limb movement) disorder, as it records the changes in the position of both legs. The ECG records the heart activity for detecting possible arrhythmias caused by sleep disorders. When a patient presents an apnea event, the heart rate increases in order to raise blood oxygen levels. [3]

One of the principal signals to analyze when detecting an apnea is the documentation of air flow performed with a nasal pressure sensor. The absence of air flow in the patient is the determinant for an apnea, either obstructive, central or mixed. Another important signal is the blood oxygen level, due to the absence of air flow. When a patient stops receiving the necessary air, the blood oxygen levels decrease, causing the patient to wake up. Also the appearance of snoring in patients is highly related with apnea events due to the fact that when an individual experimenting an apnea starts breathing again, he can present snoring.

The main signals that offer relevant information about a possible apnea depend on the different types. For example, while for obstructive apnea measurements of abdominal muscle activity are obtained by the abdominal belt, an increase of the blood oxygen levels can be detected because of the decrease in the air flow. Meanwhile, for the central apnea a decrease in both the air flow and the blood oxygen levels are also measured, but also there is not measurement of abdominal muscle activity.

3. Background and Related Work

As mentioned before, sleep disorders are very common. Thomas Penzel et al. presented a work on new technology to assess sleep apnea. They present wireless recording of sleep to improve the diagnostic tools and to investigate new mechanisms to understand the physiology of this kind of disorders. This idea came up, since continuous measurements of sleep are expensive and need special equipment and space. Wireless applications like telemedicine are a very good cost effective alternative [3].

Furthermore, Chen et al. also investigated the physiological signal acquirement of apnea. The signals obtained are usually partitioned into channels and subsequently modified to have the same length. Such an approach can weaken the apnea detection and the performance of the disease diagnosis, so they proposed an alternative with three new steps to acquire the signal. First, they used an automatic signal segmentation instead of the habitual equal length segmentation. Afterwards, they improved the local median filter to reduce the unexpected RR intervals. The OSA severity index and the gained data were plugged into a support vector machine (SVM). SVM is well known in the machine learning area and it is used for classification purposes. In this specific study, the disease could be classified by this method [7].

Machine learning algorithms were also used in the elaboration of the work presented by Xie et al. In this study, they investigated real time apnea detection based on ECG signals and the saturation of peripheral oxygen signals. This was performed both separately and combined to obtain better results. In their approach, ten different machine learning algorithms were used to get the correct classification. With decision tables, kNN and other learning algorithm a high sensitivity and specificity was achieved. In the end, the detection based on peripheral oxygen saturation outperformed the ECG signals [8].

4. Approach

Materials and Methods

During the development of this study, Matlab was used to process and analyze the different sleep signals of 13 different patients. A set of three files per patient was given to make the correct signal processing. Each set consisting of 1edf file and 1xml. Edf stands for European data format and it is used for exchange and storage of multichannel biological and physical signals. On the one hand, the edf file contains a header with the main information about the recording, such as the patient ID, the record ID, the start date, the start time, number of bytes, number of records, the duration, the number of signals (ns), channel's label, the transducer, the units, the number of samples and the sampling frequencies. On the other hand, the edf contains the recording. Annotations regarding these recordings can be found in the simple xml file.

Each recording from the edf file represents a signal obtained from diverse body structures, recorded by different instrumentation techniques and mechanisms. These are: 'AIR_FLOWFLUXO', 'CINTA_ABDOMINAL', 'MICROFONERONCO', 'BODY_POSITIONPO', 'CANULATORAX', 'OXIMETRO_SERIAL', 'EEGC3Oz', 'EEGC4Cz', 'EEGO1Oz', 'EEGO2Cz', 'EMG_QUEIXOA5A6', 'EEGFp1Oz', 'EEGFp2Cz', 'ECGA1A2' and 'EMG_PERNAA3A4'. To perform a good diagnosis of a possible apnea, all the channels must be analyzed, like the blood oxygen levels ('OXIMETRO_SERIAL'), the body position ('BODY_POSITIONPO'), the six signals obtained from an electroencephalogram ('EEGC3Oz', 'EEGC4Cz', 'EEGO1Oz', 'EEGO2Cz', 'EEGFp1Oz' and 'EEGFp2Cz'), the air flow ('AIR_FLOWFLUXO'), the recordings from the patient snoring ('MICROFONERONCO'), the muscle activity from the abdomen ('CINTA_ABDOMINAL'), the activity recorded by electromyogram ('EMG_QUEIXOA5A6' and 'EMG_PERNAA3A4') and the electrocardiogram ('ECGA1A2'). All these signals offer the necessary information enabling an apnea detection.

Each channel has a signal related to it with an individual sampling frequency. So for each plot, different filters are needed depending on the signal to extract the noise. The values of the sampling frequencies for each of the 15 channels are: 16, 16, 256, 4, 16, 4, 128, 128, 128, 128, 128, 128, 128, 128 and 128.

Proposed Solution

As a solution to the approach proposed above a Matlab code was written with the purpose of detecting relevant events such as obstructive apnea, in the patients' recordings. The code consists of four main functions. In the first one, called edfread.m (given by the professor and also used during the laboratory classes), the header and the record from the edf files can be obtained. Later, the second function called filterApnea.m performs a search of the events presented in the xml files, and once the event is found, plot the recording associated with that event. These figures are plots that represent the signals' amplitude in function of time. Once an event is detected, both the starting time and the ending time are obtained to represent the figure in that specific period of time.

It has to be taken into consideration that all the plots from the different signals obtained need different specific filters, depending on their characteristics. For lower amplitude signals such as the EEGs and EMG, a Notch filter is used to take the line noise, and for respiratory signals that usually present a lower sampling frequency, a low pass filter is used. The aim of these filters is to process the signal and obtain a better observation of them to improve the diagnosis methods.

5. Results and Contributions

From the code written in Matlab, the results obtained for each patient are exposed in Table 1. The number of relevant events are shown in this table. The events found in the xml files are: OBSTRUCTIVE_HYPOPNOEA, PLM, MICRO_DESPERTAR, and OBSTRUCTIVE_APNEA. However, the ones considered as relevant in this study are obstructive apnea and obstructive hypopnoea.

Patient ID/ Event	O_H	O_A	C_A	M_A
17572A	>100	0	0	0
17578AC	0	0	0	0
17711AP	34	0	0	0
17738A	72	0	0	0
17798A	0	0	0	0
17811AC	0	0	0	0
17828A	26	3	0	0
17835A	0	0	0	0
17913AC	51	0	0	0
18013A	33	0	0	0
18046AT	13	0	0	0
18804A	22	0	0	0
18984A	90	0	0	0

Table 1. Number of obstructive hypopneas (O_H), obstructive apneas (O_A), central apneas (C_A) and mixed apneas (M_A) that each patient presented.

Thanks to the simulation performed in matlab, plots representing all the 15 signals of each sleep recording of different patients could be obtained. In the following figures, an example of an obstructive apnea presented on the recordings of patient 17828A is shown. The starting time and ending time of this specific obstructive apnea event are: 05:55:29.5 and 05:55:51.75. The total duration of this event is of 22.25 seconds.

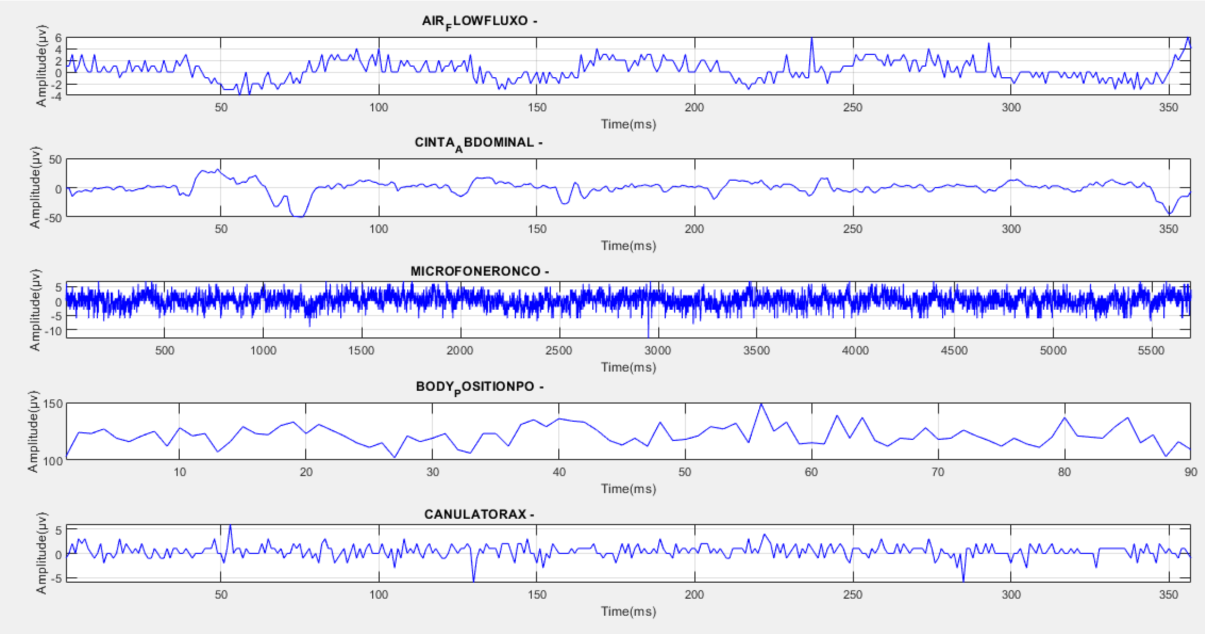

Figure 2. This figure made by Matlab shows the amplitudes of the signal corresponding to the air flow, the abdominal tape, the snoring microphone, the body position and the cannula torax in time.

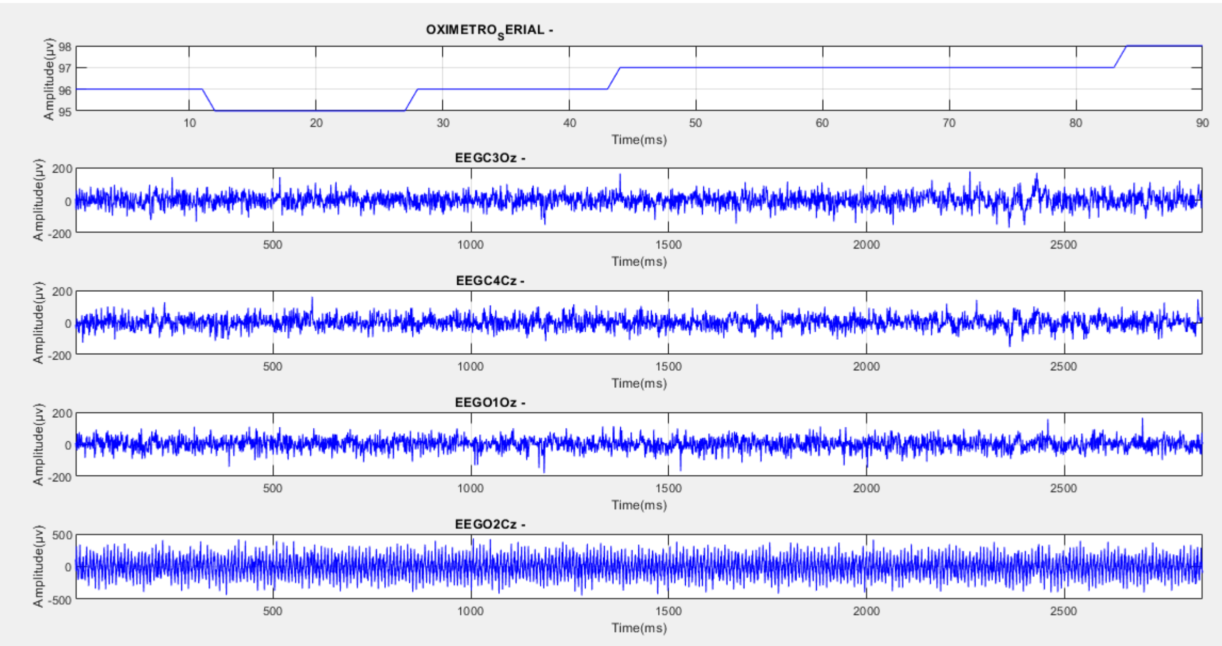

Figure 3. This figure made by Matlab shows the amplitudes of the signals corresponding to oximetry, and four EEGs in time.

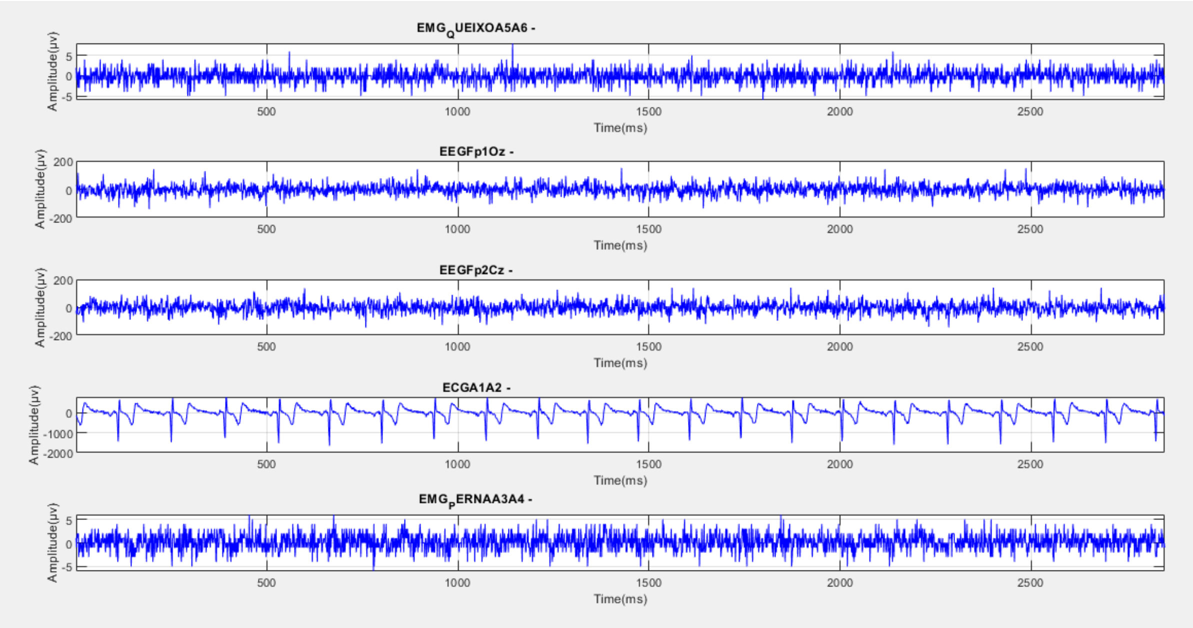

Figure 4. This figure made by Matlab shows the amplitudes of the signals corresponding to EMGs, ECG and EEGs in time.

6. Discussions and Conclusions

Research and investigation on the development of more sophisticated techniques and mechanisms for apnea detection is of great importance for the early diagnosis, and in this way the disease could be treated in earlier stages.

In the moment that the code was implemented to visualize the plot of the different types of measurements for the different apneas, it was noticed that the patients do not present neither mix nor central apnea. Also, only one of them present obstructive apnea. Moreover, the patients present Hypopnea and PLM, which are events with not such importance for the objective of the work of detection and classification of apneas. As a conclusion, a better analysis and signal processing could have been performed with the presence of a larger amount of sleeping disorder events were provided.

7. References

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