# A SOFTWARE SYSTEM FOR SLEEP AND SNORING ANALSIS

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*Abstract-* **Snoring is caused by the vibration of some of the tissues in the human upper airway. It has been reported in the literature as a risk factor of diseases such as obstructive sleep apnea syndrome (OSAS) and other breathing abnormalities during sleep. Several methods are available for the treatment of snoring, depending on the location of pathology such as "uvulopalatopharyngoplasty" (UPPP) for uvuloal snoring and "radiofrequency tissue volume reduction of the tongue" for tongue based snoring. However, determination of the treatment success is a common problem for both snoring and apnea patients. It is possible to assess the medical treatment by analyzing the snoring sounds. A software system has been developed to analyse the whole night respiratory sound recordings, to compute related statistics and to assert the success of medical treatment in terms of objective criteria. The system uses a formerly developed algorithm that detects each snoring episode automatically. The sound recordings were taken synchronously with polysomnography recordings from patients that are suspected of OSAS pathology in the Sleep Studies Laboratory of Gülhane Military Medical Academy. The designed system uses polysomnography information for improving sleep analysis studies such as determining the relationship between snoring and OSAS.**

*Keywords:* Snoring, Apnea, OSAS, monitoring

## I. INTRODUCTION

Snoring is frequently observed among humans during sleep. It is caused by the vibration of some of the tissues in the human upper airway. Relaxed tissues of soft palate and/or tongue blocks the airflow and the pressure developed on either side of the blocking yields the vibrational movements. Snoring has been reported to be a risk factor of diseases such as obstructive sleep apnea syndrome (OSAS) and other breathing abnormalities during sleep [1]. Therefore, snoring signal analysis may be a promising method to detect breathing abnormalities during sleep, related to OSAS or other pathologies such as upper airway resistance syndrome. In addition, detection and analysis of nonapneic snoring could be an important tool to assess its possible impact on individual's health [1].

OSAS is also common in the population. It is defined as the cessation of breathing during sleep for 10 sec. or more [2], [3]. It may result from either upper airway collapse (OSAS) or lack of neural input from the central nervous system to the diaphragm (central sleep apnea) [3]. OSAS is the more common form of sleep apnea. Symptoms of OSAS are fatigue, daytime sleepiness, coroner problems, and systemic hypertension [3],[4]. It is usually associated with loud, heavy snoring [5]. In the last 15 years, snoring problem has entered the realm of clinical medicine. It is a prevalent symptom, and about 50% of adult population snores frequently [5],[6].

It is an established clinical practice to investigate whole night polysomnography recordings of people under the risk of OSAS. Recording sleeping sounds synchronously with polysomnography makes it possible to investigate the relation between snoring sounds and other physiological polysomnography signals. Recently, studies on snoring sound intensity together with polysomnography recordings revealed significant differences between snores, with and without OSAS [7]. Other works showed different spectral properties in the two cases [8], [9].

Several methods are available for the treatment of snoring, depending on the location of pathology such as uvulopalatopharyngoplasty (UPPP) for uvuloal snoring and radiofrequency tissue volume reduction of the tongue for tongue based snoring. However, determination of the treatment success is also a common problem for both simple snoring and OSAS**.** The possibility of assessing the results of medical treatment by analyzing snoring sounds has been a point of motivation of this work. Manual labeling of a whole night respiratory sound recording is a time-consuming and labeler-dependent task. It is possible to process these recordings automatically, and compute related statistics. In order to extract snore related parameters from the signal, we have first developed an algorithm to detect each snoring episode automatically, while discarding undesired sounds such as cough, nasal congestion, speaking and other environmental noises. After detecting snoring episodes, some relevant statistics are computed. These statistics include the ratio of the snoring time to the total sleeping time, the mean and maximum time between two snoring episodes, and the intensity and distribution of the snoring episodes with respect to sleep stages. Pre and post operation statistics can be computed, and an objective assessment of the medical treatment can be obtained from their comparison [10].

The goal of this paper is to present the system developed to help assessing the success of the applied treatment in terms of objective criteria**.** The sound recordings used in this study were taken simultaneously with polysomnography recordings from patients that are suspected of OSAS pathology in Sleep Studies Laboratory of Gülhane Military Medical Academy (GMMA), Ankara. The system has been found useful by medical experts and has been integrated with the polysomnography analysis system for improving sleep analysis.

## II. MATERIALS AND METHODS

*Recording Setup*

For recording sounds, a high sensitivity condenser microphone was used. The microphone has a cardioid pattern in order to reduce echoes and noises from the environment. It was placed 15 cm over the patient's head during the sleep. We determine this distance by considering many parameters such as the sensitivity of the recording system, pattern of the microphone, and the patient comfort. Edirol UA-1000 model multi-channel data acquisition system was used to record the data. The acquired signal was digitized at a sampling frequency of 16 KHz with 16 bit A/D converter. The system allows adjusting these values to a number of levels according to the application. The data acquisition card was connected to the personal computer (PC) via universal serial bus (USB) and after digitization, the data were stored in PC to form a snore database with patient information.

*System Outline*

For analyzing the whole night respiratory sound recordings and computing related statistics, we have developed an algorithm that detects start and end points of snoring episodes [10]. Analysis of snoring sounds of a patient follows this segmentation stage. The functions to be performed and statistics to be computed by the system have been determined in cooperation with the experts of ear-nose-throat (ENT) clinic. The user interface of the system is shown in Figure 1. System functions are grouped into 6 modules. These are "patient information", "selection analysis", "time parameters", "episode parameters", "regularity" and "intensity" blocks. A screen with a slider allows monitoring the snoring signal. The interface has buttons for "play" and "print" functions. The blocks and their functions are described in the following sections.

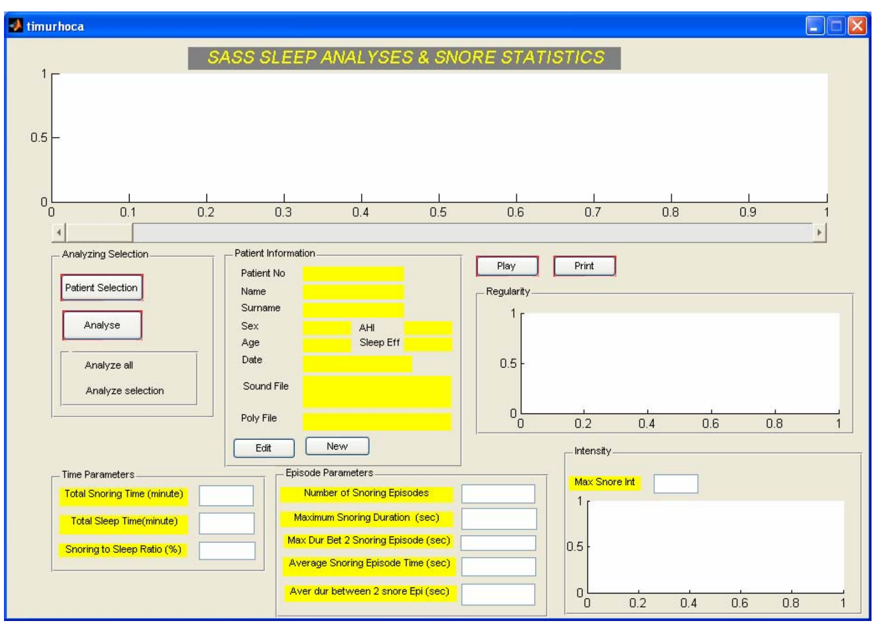


**Figure 1**: The user interface of the system.

*Patient Information Block*

This block was designed for patient registry file operations. Information about a patient can be entered and modified via this block. When the “New” button is clicked, the system allows entering information about a new patient. These information are patient no, name, surname, sex, age, date, AHI (Apnea/Hypopnea Index) and sleep efficiency. The sound file of the patient already stored in the hard disk can be included in the registry. The aim of the poly file will be explained in the “Time Parameters Block”. Upon clicking the save button, the system creates a file with .hst extension that contains patient information. The system allows for edit, save or clear operations on registry files. Figure 2 shows the patient information interface and the hst extend file that covers these information.

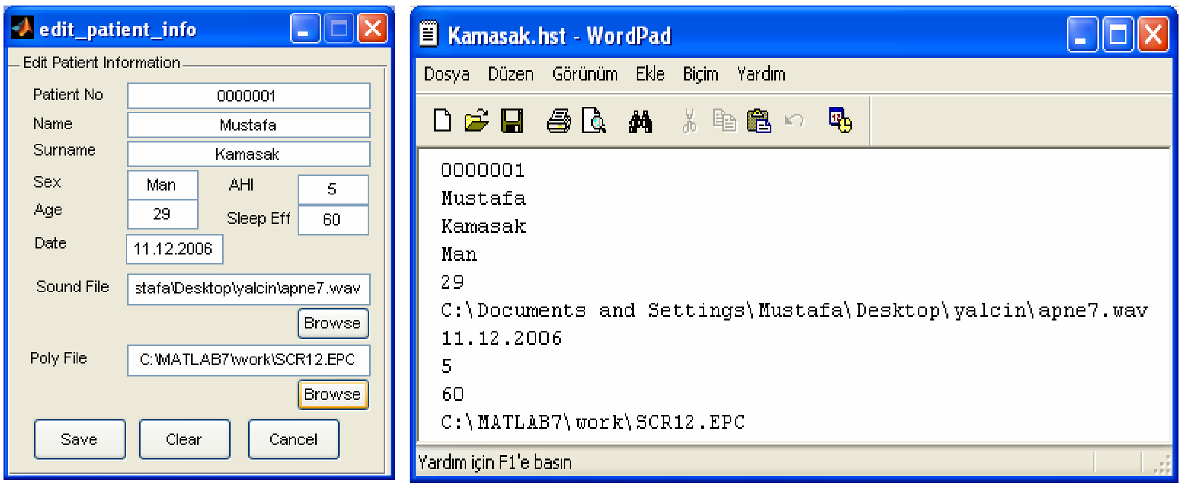


**Figure 2:** Patient information interface and the .hst extend file that covers these information.

*Analyzing Selection Block*

This module was designed in order to initiate the analysis. Clicking “Patient selection” button opens a dialog box in order to select a pre-created file to initiate the analysis. The “Analyzing Selection” module and the patient selection dialog box are shown in Figure 3.

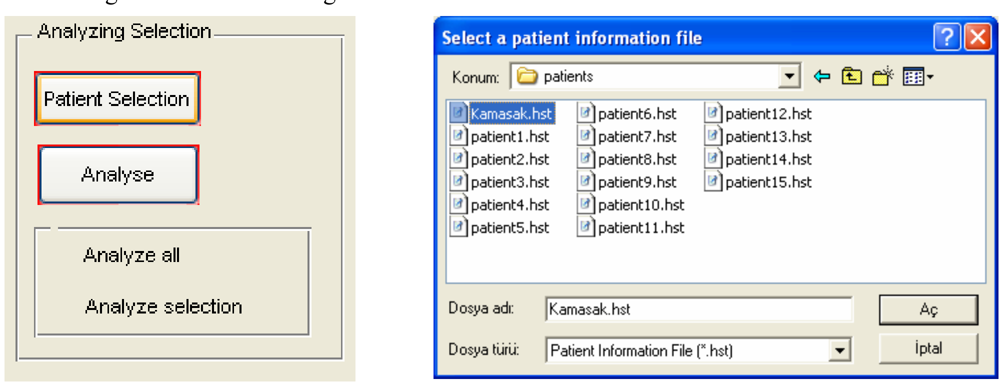


**Figure 3:** The “Analyzing Selection” module and the patient selection dialog box.

When a patient to be analyzed is selected, the information about the patient is shown on the main interface and the snoring signal of the patient is loaded and monitored on the screen. Clicking “Analyse” button after selecting “Analyse all”, the system processes whole-night sound recording and computes the statistics. In case it is required to get the statistics of a part of the signal, such as sleep stage 2 regions, it is possible to analyse signal partially by clicking “Analyse” button after selecting the “Analyse selection” button. Figure 4 shows a 20 second long snoring signal in a window of the interface. It is possible to observe the entire signal in detail by using the slider.

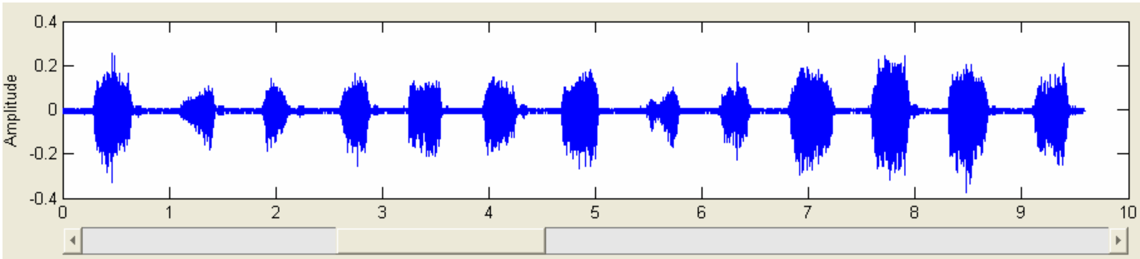


**Figure 4:** A 20 second long snoring signal in  a window of the interface.

*Time Parameters Module*

This module was designed for monitoring time parameters and statistics such as total snoring time, total sleeping time and snore-to-sleep ratio. Total sleep time of the patient is displayed in minutes. Accurate determination of total sleep time is important. The duration of the complete signal, which corresponds to the time in bed, is not necessarily equal to the patient's total sleep time. In order to compute the total sleep time, the system utilizes the information from polysomnography recordings. Polysomnographic data system records in a text file the sleep stage information for every epoch of 30 seconds. Wake time of a patient is estimated from polysomnography data by accessing the information in the "Poly File" created by the polysomnography system. Other statistics, total snoring time and snore-to-sleep ratio, are estimated from the sound recordings. An automatic detection system has been developed to identify the snoring intervals [10]. The objective of this system is to determine sound activity regions and then to assess whether the episode is snoring or not. After detecting each snoring episode, the total snoring time and snore-to-sleep ratio are computed. The information for sleep analysis is provided to the expert via the "Time Parameters" and "Intensity" modules. Pre and post operation comparison of the snore-to-sleep ratio is fundamental for the clinician in determining the treatment success. Figure 5 shows the "Time Parameters" module and a sample "Poly File". The first column of the "Poly File" depicts each 30 second length epoch and the second column is the corresponding sleep stage of that epoch. The letter "W" indicates that the patient is wake in that epoch.

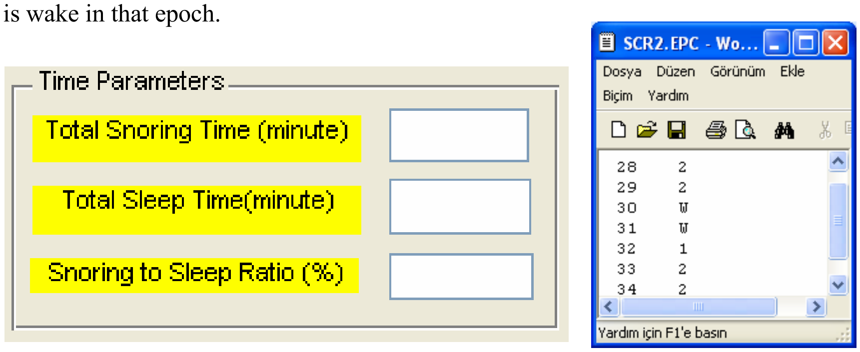


**Fig. 5** "Time Parameters" module and a sample "Poly File".

*Intensity Module*

Observing the pre and post operation average change in the intensity of the snoring signals is essential in determining the treatment success. The intensity of the snoring signal varies among patients or among different episodes of a patient. The system computes the intensity of snoring episodes and displays their histogram.  The maximum snoring intensity of a patient for is also displayed as a reference value. The distribution of the intensity values of a patient gives information about the regularity of his/her snoring. The importance of this concept is further explained in "Regularity Module" section. A sample snoring intensity histogram is shown in Figure 6.

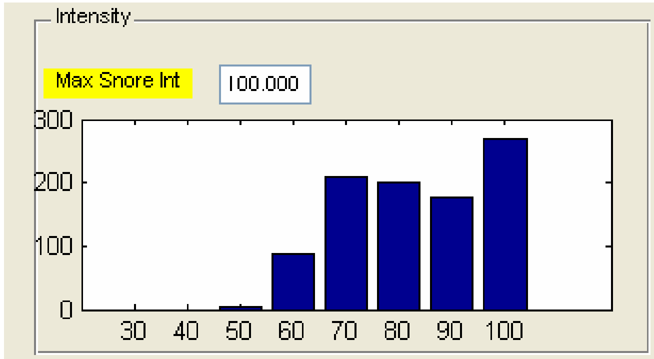


**Figure 6:** A sample snoring intensity histogram.

*Regularity Module*

The regularity of snoring sounds among episodes can be used to identify a patient as a simple snorer or as an OSAS patient. Comparing the snoring signals of simple snorers and OSAS patients, it is seen that snoring episodes of simple snorers exhibit more "regular" patterns than those of OSAS patients. In other words, while simple snorers are regular snorers, OSAS patients are non-regular snorers in general. This is illustrated in Figure 7.a and Figure 7.b. As it is seen in these two figures, while the episodes of simple snorers are highly correlated, the correlation between the episodes of an OSAS patient is much lower.

**Figure 7.a:** Snoring episodes of a simple snorer.

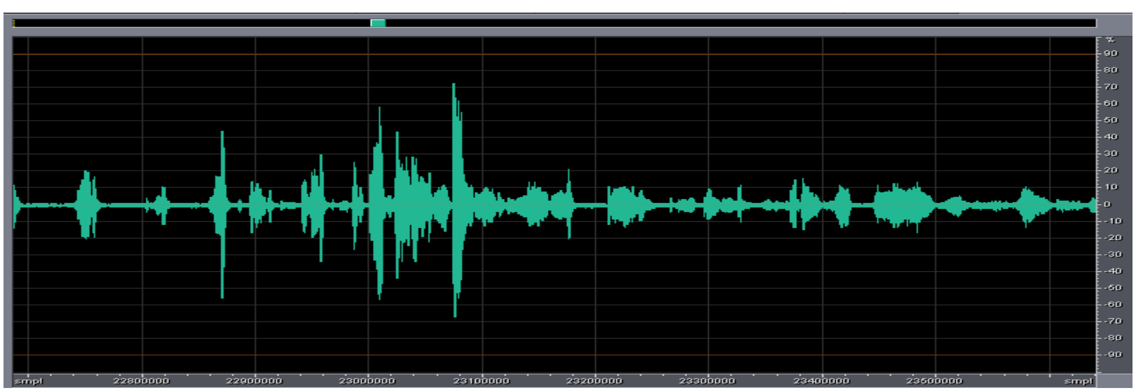

**Figure 7.b:** Snoring episodes of an OSAS patient.

The information about the regularity of snoring sounds can be accessed via the "Regularity" module. The correlation among the episodes of a patient can be used to quantify the regularity of snoring episodes. However, this method is computationally demanding. Instead, in this study, the regularity is asserted by computing the energies of episodes. Plots of episode energy values versus time, the flatness of energy curve gives information about the similarity of the episodes. This is shown in Figure 8. The flatness of the red curve is a indicator of regular snoring. In Figure 8.a is the regularity plot of a snoring signal of a simple snorer and in Figure 8.b is the regularity plot of a snoring signal of an OSAS patient. It is seen that the regularity curve of simple snorer is flatter. The information provided by the regularity curve is important in the diagnosis of pathology. Another regularity parameter is the intensity histogram. The wider spread of the intensity values implies a non-regular snoring.

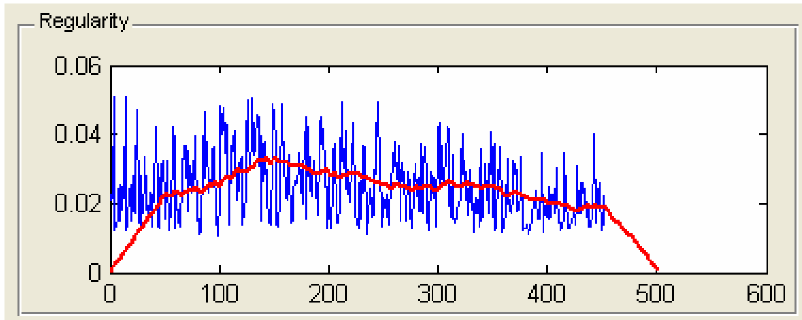


**Figure 8.a:** Regularity plot of a snoring signal taken from a simple snorer.

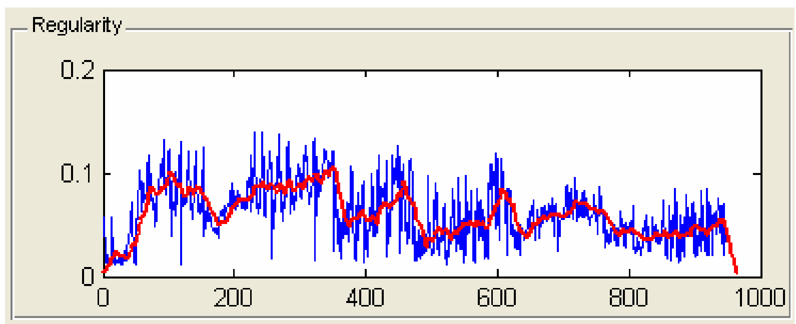


**Figure 8.b:** Regularity plot of a snoring signal taken from an OSAS patient.

*Episode Parameters Module*

This module was designed to extract the parameters such as number of snoring episodes, maximum snoring duration, maximum duration between two snoring episodes, average snoring episode time and average duration between two snoring episodes. These parameters are also useful in determining the treatment success by making their pre and post-operation comparison. Figure 9 shows the "Episode Parameters" module. These values also differ among simple snorers and OSAS patients.

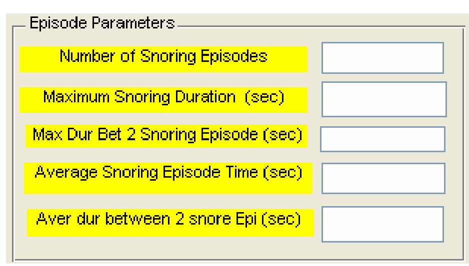


**Figure 9:** "Episode Parameters" module.

## III. RESULTS

By analysing the whole night respiratory sound recordings and computing related statistics, it is possible to assess the success of medical treatment. In Figure 10, the analysis results of an OSAS patient are seen. The snoring episodes are identified with the upper red lines. It is possible to play a selected portion of the signal.

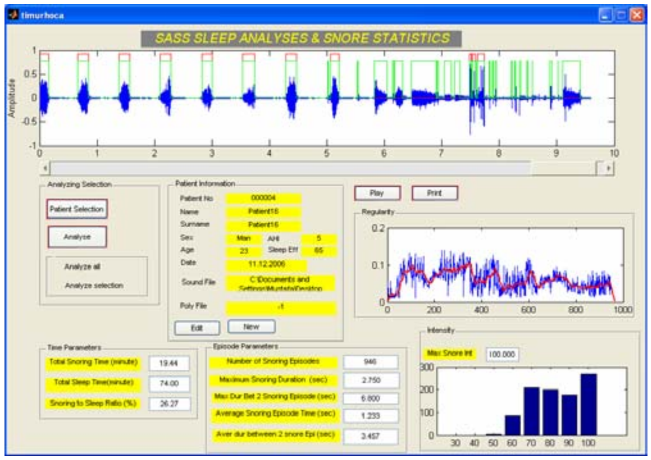


**Figure 10:** The analysis result of an OSAS patient

After analysing the sound recording of a patient, the system allows save the results or prints them for pre and post-operation comparison. In Figure 11 the print out page of the computed statistics is shown.

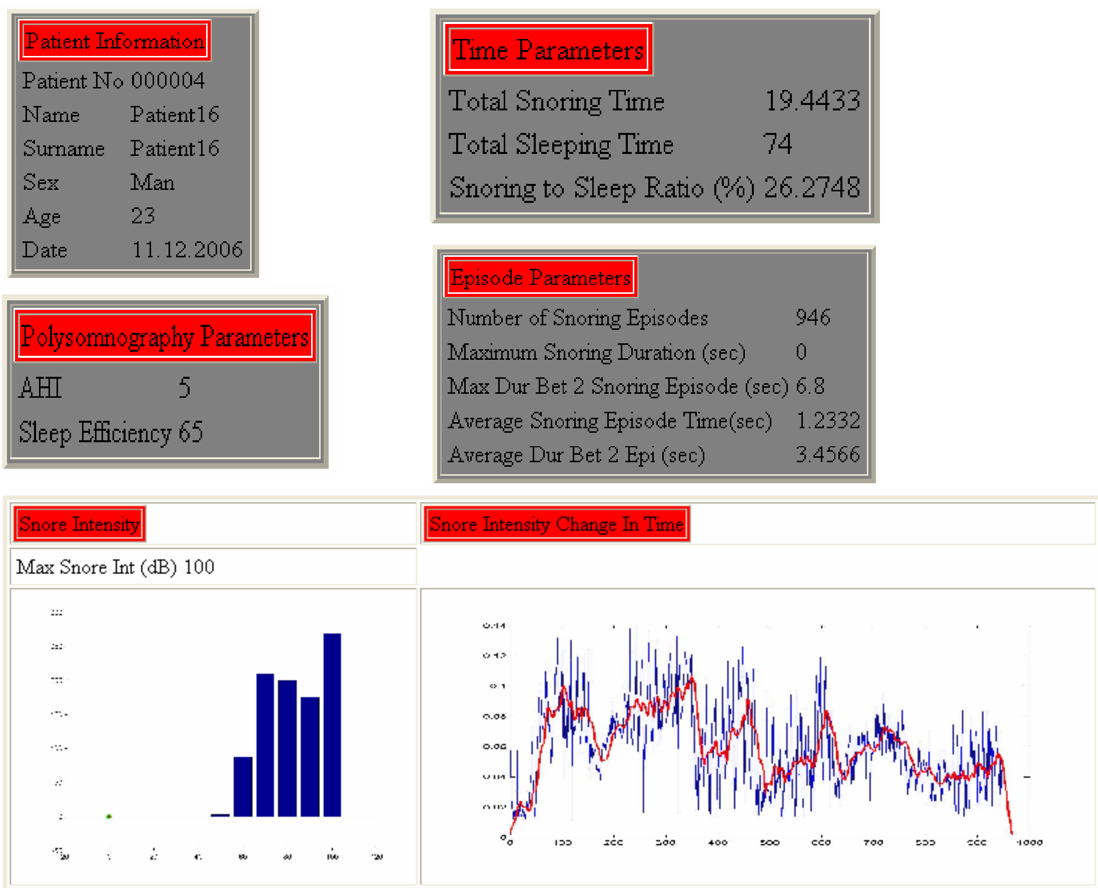


**Figure 11:** The print out page of the computed statistics.

## IV. DISCUSSION

In this paper, we present a software system developed for monitoring the efficiency of snoring treatment in terms of objective criteria**.** The system analyses the whole night respiratory sound recordings and computes some related statistics. The most informative part of the system is the "Time Parameters" module. The comparison of pre and post-operation snoring-to-sleep ratios is fundamental in determining the treatment success. Observing the intensity changes in the snoring signal is also valuable. It has been observed that that while the snoring intensity of the simple snorers is in the range of 40-60 dB, this range for OSAS patients is around 50-100 dB. Another difference between simple snorers and OSAS patients appears in the similarity of the snoring episodes of their own. Contrary to the highly correlated form of snoring episodes in simple snorers, it is hard to observe such high correlation values with OSAS patients. Hence, examining the regularity of the snoring episodes is a useful task in estimating whether the patient is a simple snorer or an OSAS patient before the polysomnography recording. The system also extracts a number of useful statistics about the episode parameters. The numbers of snoring episodes are different between simple snorers and OSAS patients. While it is approximately 600 per night in simple snorers it is mostly over 1000 per night in OSAS patients. The episode parameters are important for the comparison of pre-operative and post-operative situation. Integrating the system with polysomnography allows us to determine the sleep time accurately and to make detailed sleep analysis. As a future study, we are planning to investigate the distribution of the snoring episodes with respect to sleep stages to determine the effect of snoring on sleep organization and sleep efficiency. The system analyses six hour data (the whole night sleep sounds sampled at 16 KHz 16 bits/sample) in six minutes. It can be concluded that the speed of processing is appropriate to be used routinely in the clinic.

## V. CONCLUSION

Several methods are available for the treatment of snoring, depending on the location of pathology such as uvulopalatopharyngoplasty (UPPP) for uvuloal snoring and radiofrequency tissue volume reduction of the tongue for tongue based snoring. Despite the existence of different treatment methods; determination of the treatment success is a common problem for both snoring and apnea patients**.** The goal of this study was to help assess the success of the applied treatment based on an objective analysis of sleep sounds. A computer program has been developed for this purpose**.** The sound recordings were taken from patients that are suspected of OSAS pathology while they were connected to the polysomnography in Gülhane Military Medical Academy (GMMA) Sleep Studies Laboratory. The designed system was integrated with polysomnography for improving the sleep studies.

## ACKNOWLEDGEMENTS

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