A nonintrusive system for monitoring the temperature distribution in the bed with applications in the analysis of positional snoring and the prevention of skin ulcerations

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Abstract. The monitoring of patient position in bed is important in the diagnosis of positional snoring and in the prevention of ulcerations of the skin associated with long confinement to a bed. The aim of this work is to describe a system based in the measurement of the temperature distribution in bed able to perform these tasks. The device consists of a PC adapted to modules for measurements of temperature and sound level. The software is developed in LabVIEW environment and manages the reception, analysis and storage of sampled signals. In vivo studies showed adequate performance, confirming the high scientific and clinical potential of this system.

1. Introduction
Approximately 3% to 7% of the adult population presents respiratory disorders during sleep, such as apnea and snoring [1]. The central phenomenon for the emergence of snoring is the increase muscle flaccidness of throat. The tone of the throat muscles is reduced during sleep, which progressively leads to contact between the walls that generates the characteristic noise. This can happen at any age, being more common among men from 45 years. Furthermore, anatomical factors such as obesity, small chin, narrow bite, roof of the mouth (palate) in warhead format, increased tonsils and adenoids may predispose to snoring. In short, all factors contributing to close the air passage and facilitate contact between the throat walls propitiate snoring.

Positional snoring is snoring that disappears with the change of posture. Although it can occur at various positions, the most common is in the decubitus dorsal position. This position can make the tongue project back due to gravitational effects and cause snoring. This disorder is easily treatable provided it is properly diagnosed the position that causes the problem.

This disturbance is usually diagnosed using a video camera with infrared, which records the patient throughout the night. However, for many patients it implies in loss of privacy. Additionally, this method is expensive and extremely laborious in terms of interpretation, which contributes to inhibit the clinical use of such exams. Thus, the diagnostic of this disease is usually performed by interview with the mate of the patient, an unreliable method. It is also worth noting that, although the effect of

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position on sleep apnea is well known, objective evidences concerning the effect of position on snoring have not yet been presented [2]. A recent review pointed out that there is room for technical improvement of the devices to reduce discomfort and consequent disruption of sleep architecture as to improve compliance [3].

Long periods of confinement to bed may lead to local circulatory disorders causing ulcerations of the skin [4]. When pressure is maintained for long periods capillary endothelium is damaged, resulting in thrombosis of small vessels and consequent tissue necrosis and ulceration. The patient's body movement allows distributing the forces potentially causing ischemia, so that the monitoring of the mobility is an important factor in the prevention of ulceration.

This paper describes a system based on temperature sensors, analog and digital signal processing systems, integrated into a personal microcomputer, to identify the position of the patient in bed. The instrument has great potential for use in the applications described previously, reduced cost and allows patient privacy maintenance.

2. Materials and Methods

2.1. System development

Hardware design. Figure 1 describes a simplified block diagram of the instrument. The system evaluates the patient's position using a series of 14 thermistors distributed in equal distances on the bed by means of a band. This apparatus allows evaluating the temperature profile of the bed, providing an indirect assessment of the position of the patient. The thermistors (350 Ω at 25 °C, NTC) were excited by low-current sources (715 μA) in order to avoid self-heating [5]. The resulting signals are amplified and filtered (low-pass, 0.5Hz, first order) to reduce noise and interference. The operation principle is based on the temperature difference between the ambient (usually 25 °C) and the body temperature (usually around 37 °C). Thus, the increase in ambient temperature can introduce unacceptable errors. To avoid this inconvenience, the room temperature is constantly monitored by a thermistor positioned in a different point, separated from the band used to evaluate the patient's position. Experimental studies were performed in order to obtain the resistance versus temperature characteristic curve of the thermistors used in the position sensing subsystem, as well as in the thermistor used in monitoring the room temperature [5]. Based on these studies were prepared subroutines converting the measured voltage to temperature. Thus, the system allows visualizing the behaviour of the temperature of the 14 thermistors placed in the bed as well as the resulting temperature profile, which was obtained from a 4th order polynomial adjustment.
The snoring signal is measured by an electret microphone (CZN-15E), whose signal is amplified and applied to a full wave rectifier (AC/DC converter) [6]. The data acquisition system consists of a virtual instrument (VI) developed in LabVIEW environment (National Instruments, Austin, TX). The system also includes a data acquisition board presenting 12 bit of resolution (PCI6024E, National Instruments, Austin, TX).

2.1.1. Software design. The software was developed in LabVIEW environment (National Instruments, Austin, TX). The front panel of the VI is shown in figure 2. The system allows the user to set the time interval between measurements. In each measurement, it is performed a scan where the snoring signals, the bed temperature profile and the environment temperature are evaluated. Thus, the program can be used in both applications envisaged, for sleep studies as well as to monitor the movement of patients in bed preventing ulceration.

Used in the specific case of sleep studies, the snoring monitoring subsystem offers a gain adjustment in the amplifier circuit, an indicator on the front panel of the virtual instrument and a threshold adjustment that allows minimizing the effect of ambient noise. This optimizes the detection of the snoring signal. To this end, before use of the instrument, the level selector is set slightly above the ambient noise. The user simulates the patient snoring and the amplifier gain is adjusted so that, in the presence of snoring, the voltage at the AC/DC converter output is greater than that produced by the background environmental noise, indicating the presence of snoring. It was observed that, in practical exams, transient noises would be erroneously interpreted as snoring. To overcome this inconvenient, the system includes a discrimination routine, where acoustical noise signals with duration < 1s are eliminated. At the end of each exam the instrument allows researchers to save the data in an ASCII file so that they can be analysed later. In this file are stored the environmental temperature data, the temperature in each of 14 thermistors that composes the measurement band and the profile obtained from the adjusted polynomial. The file also includes data on the presence (1) or absence (0) of snoring, as well the scans times and the beginning and end of the exam.

2.2. System evaluation

2.2.1. In vivo simulated tests in healthy individuals. The ability of the system to identify the position of the patient in the bed and the presence of positional snoring was initially evaluated through a comparative analysis of the results obtained in three healthy individuals. The volunteers do not present history of respiratory diseases or snoring. The band was fixed on the bed at the level of the patient's waist height (figure 2A). The system performance in the identification of the patient's position was evaluated in a simulated study conducted asking the volunteer to be positioned in frontal decubitus, dorsal, right side and left side.
The snoring detection system was tested by asking the volunteer to simulate snoring in the mentioned positions. The microphone was adapted to the bedside, as described in figure 3. Three snoring events were simulated in each position for each volunteer, resulting in 36 snoring events. The time (hh:mm:ss) when these events happened was manually recorded. These results were used as a reference in comparison with that obtained in the proposed system.

2.2.2. In vivo test in a snorer individual. This analysis was performed in a typical volunteer with clinical diagnosis of snoring. The volunteer was allowed to sleep freely during the afternoon (nap test). This exam followed a similar procedure to that used in the normal volunteers, using the manually recorded position and presence (or not) of snoring as a reference.

3. Results

3.1. System development

Before initiating the exams, the snoring monitoring subsystem positioned as described in figure 3A, and the gain and threshold adjusted in the front panel of the virtual instrument (figure 2B) to minimize the effect of ambient noise. Then, the exams initiate pressing the button "Start", having the duration controlled controlled by pressing the button "Exit". At the end of the exam, the system offers the possibility to save the results along the measurement time in txt format ("Save” option in figure 2B). The system allows the visualization of the temperature profiles obtained along the examination, as well as the presence of snoring during the examination. An indicative changes the colour (brown for red) during snoring events (figure 2B).

3.2. System evaluation

Figures 3 illustrate the typical temperature profiles obtained in the four positions studied. Clearly discriminative signatures were observed when the volunteer was positioned in dorsal, right side and left side decubitus (figure 3, A, B and C, respectively). Ventral decubitus (figure 3D), however, presented a similar signature to that presented in dorsal decubitus (figure 3A).

![Figure 3: Typical temperature profiles obtained in dorsal (A), right side (B), left side (C) and ventral decubitus (D). Positioning of the microphone used in the snoring monitoring subsystem (A).](image-url)

Typical results observed in simulation of snoring are described in figure 4. The system was able to correctly identify the presence of snoring in all of the 36 simulated events. The exam performed in the
snorer lasted approximately one hour, and showed adequate identification of all of the events produced during of exam. Additionally, it was also noted that transient noises, such as the fall of glasses and cough, did not introduced erroneous measures.

4. Discussion
The monitoring of the patient's position in bed has great practical interest. The diagnosis and treatment of positional apnea depend on the accurate identification of the position in which the individual snore during sleep. Another important application relates to patient monitoring in long periods of confinement to bed in order to avoid ulcerations on the skin. To this end, various methods of assessing the position in bed can be used, including methods based on pressure transducers [7], motion picture recording [8], as well as integrated temperature sensor circuits [8]. Methods based on pressure transducers have a high cost, while the image-based methods are intrusive, require large memory and complex and/or time-consuming analysis [8]. Solutions based on tilt sensors [9], three-axis accelerometers [10], nasal pressure monitoring [11] and wireless tracheal acoustic sensors [12] demands intrusive adaptations of the instrument to the patient's body, which may reduce patient compliance to the exam. This study employs an completely nonintrusive alternative based on low-cost temperature transducers [8, 13], which allows monitoring the temperature profile of the bed. As can be seen in typical results described in figure 3, the individual's body positioning causes the temperature to rise on specific thermistors, approaching body temperature. Thus, the temperature profile obtained by the analysis of the 14 thermistors evaluates the position of the individual, whereas a temperature pattern is produced depending on the type of decubitus.

Similar to other instruments, the limitations of our system need to be recognized. The patterns produced by the right and left lateral decubitus are easily identified when compared with each other and the patterns achieved in the dorsal and frontal decubitus. However, the patterns produced by the dorsal and front decubitus are identical. Although this is not a problem in monitoring aimed at preventing ulcerations, this characteristic introduces limitations in the study of positional snoring. A possible solution to this problem would be to use a small emitter of infrared signal, which could be tailored to the patient's pajama and positioning a detector in the ceiling of the room where the test is performed. In dorsal decubitus position the signal would be picked up by the detector, while in ventral decubitus this signal would be blockaded, allowing the appropriate identification between the quoted decubitus. This solution, however, would introduce a small intrusive characteristic in the system. Another possible solution would use of a thermographic camera, which would be less intrusive.

Another possible limitation is the production of erroneous results due to the increase of the exam room temperature. We performed tests simulating the case of an unexpected room temperature increase due to the fault of the air conditioning system. The room temperature monitoring circuit adequately avoided the production of erroneous results. The presence of this fault, as well as the timetable in which the fault took place, are clearly described in the archives produced at the end of the exam and easily recognized by the user.
Tests simulating the effect of external transient noises such as coughing and falling objects in the identification of snoring showed an adequate discrimination, so that these transient signals were not interpreted as being associated with snoring. This was achieved adjusting a discrimination routine to eliminate acoustical noise signals with duration < 1s.

5. Conclusion & future work
A new instrument for the analysis of the position of patients in the bed was developed. The system allows a completely nonintrusive analysis, without the necessity of coupling any device to patient. Preliminary results in normal subjects and a snorer showed adequate results, providing evidence that the system may contribute to improve the diagnosis and treatment of positional snore, as well as to avoid ulceration in the skin. The use in the diagnosis of positional snore, however, depends on the introduction of a subsystem that allows the discrimination between the dorsal and ventral decubitus.

Future plans include to simplify the interpretation of the exams. Considering a sampling period of 10 s, a whole night exam would produce approximately 2880 measurements. Thus, an automatic interpretation of the temperature pattern produced by the instrument in terms of decubitus and the presence (or not) of snoring would simplify the clinical use of this system. We plan to develop this clinical diagnostic support system using machine learning algorithms [14].

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