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USING TECHNOLOGY TO COMBAT SNORING: THE DEVELOPMENT OF THE EFFICACY OF A MICROCONTROLLER-BASED SMART PILLOW

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Abstract

This article aims to introduce a prototype design for a smart pillow that helps with snoring detection and treatment during sleep. The main purpose of the design is to present an effective solution for snoring without medication or invasive procedures, this device was low cost, and easy to use by individuals, which leads to both: sleep quality improvement and decrease in snoring. The results showed up to 75% decrease in snoring. The proposed design utilizes microcontrollers, sound sensor, air motors, air pads, humidity and temperature sensors. The air motors pumps air into the pillow to change the sleeper's head position in order to reduce snoring when the sound sensor detects the snoring frequency while the microcontroller commands the air motors to fill the air pads accordingly.

Keywords: snore, sleep apnea, smart pillow, microcontroller, medical equipment, humidity

List of Symbols/Acronyms

ADC – Analogue to Digital Converter;
DHT22 – Humidity and Temperature Sensor;
IoT – Internet of Thing;
Kg – kilograms;
KY038 – Acoustic Sensor;
LCD – Liquid Crystal Display;
LED – Light emitted diode;
LM7809 – Voltage Regulator;
MEGA – Arduino MEGA;
OSA – Obstructive Sleep Apnea;
PSG – Polysomnography;
UNO – Arduino UNO;

1. INTRODUCTION

Snoring is a sleep disorder affecting a large percentage of the population around the world [1]. Snoring is caused by the vibration of the upper airway tissues causing a disruptive sound [2]. It affects the snorer's bed partner sleep quality as well as the snorer, leading to reduced quality of life, a daytime fatigue, and maybe relationship problems [2]. Snoring might be a symptom of health problems like obstructive sleep apnea (OSA); if left untreated, it might lead to serious health complications [3]. An illustration of the difference between OSA, snoring, and normal breathing is shown in Figure 1.

Fig. 1. Different position of sleeping with airway passage [1]

Snoring can originate by the upper respiratory tract's anatomical configuration. The snoring's characteristic's noise results from the partial obstruction of the air passage during the slumber state where this obstruction of air causes the surrounding tissues to vibrate. The consumption of tobacco, being overweight, consuming alcohol, can all be main reasons to creating the air way passage obstruction. Additionally, voluminous tongue and irregular structure like a deviated septum can act as snoring cause [4].

A reliable detection system was always needed to detect the OSA development risk. Some of the detection methods of snoring are the polysomnography (PSG) and acoustic analysis, or simply by assessment of bed partners. While the PSG method can prove its effectiveness, it is an uncomfortable intrusive method, time consuming,

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costly, and not convenient for periodic check-up. On the contrary, the acoustic analysis is a non-intrusive methods which is cost effective. While had its shortcomings, in recent years it became more popular and vastly used due to the advancement of the analysis methods of signal processing and machine learning [5].

RELATED WORKS

With the recent technological advancement, the research on smart pillows has increased and showed positive results. Several approaches for detecting and sometimes reduce snoring. One smart pillow research was conducted by Kim and Moon (2018) embedding an accelerometer and a microphone into the pillow in order to detect snoring [6]. The data acquired by the pillow is then communicated to a smartphone application, and their results presented a high level of accuracy.

A more recent research by Lee (2020) allowed the detection and alleviation of snoring by using pressure and acoustic sensors in their smart pillow [7]. Their pillow system had LED indicators and a smartphone application for snore tracking in addition to allowing pillow setting adjustment by the user. Another approach done by McArdle et al. (2022) showed that snoring sound can reduced by up to 40% decibels by using a sound sensor accompanied by a vibrating motor operating when snoring sound is detected to reduce it [8]. Another approach was introduced by incorporated machine learning into the pillow's snoring detection system based on pressure sensors detecting the snoring, the machine learning algorithm classified by 90% accuracy the type of the snoring [9]. Despite the advances in development of smart pillows, there remains some challenges, and the main challenge is the development of snoring detection algorithms and detection sensors. Sensors tend to work well with certain individuals while performing poorly with others, and algorithms customization is required to detect certain snoring patters. Moreover, these studies and development researches require large-scale clinical trials in order to evaluate the performance of the smart pillow.

Recently, the development of smart pillows resulted in positive outcomes where it enabled the detection and mitigation of snoring.

It is worth to mention that the pillow design should be really comfortable in order to have a good and suitable night sleep for the user. Furthermore, the sensors and feedback mechanism ought to be more understandable to the users so as to track their sleep. To say more, the available authors stated in [10] have designed a pillow which would be equipped with many of parts, namely; a microphone along with machine learning processing. Actually, a novel study that was performed and applied on ten people, it is noted that the study discovered the fact that pillow was so effective to reduce snoring and also improved the quality of their sleeping. Other research stated in [11] have utilized both pressure and sound sensors in their considerable pillow. Moreover, when a detection of snoring occurs, the pillow starts varying its height in an automatic programmed manner so as to make the head position variable and changeable; this would lead to the required reduction in snoring. Once again, it is important to mention that the authors conducted a useful clinical trial with 66 people participated, such authors explained that their pillow could be used to reduce snoring and to improve sleep quality as well.

Concerning this manscript, the aim of the study is virtually to develop an intelligent and substatial pillow which can be used to detect and really to treat snoring. It also could be used to test the major effectiveness of the proposed pillow in oreder that it could reduce snoring events and could improve sleep quality too, by controlling the data obtained by the sensors and controlled by the microcontrollers used.

2. METHODOLOGY

The purpose of this section is briefly to discuss the typical components used in the present assumed work. These components contain:

- The Arduino (MEGA, UNO) [12=15].
- Relay Module [15-16].
- Acoustic Sensor (KY-038) [16-19].
- Voltage Regulator LM7809 [20-25].
- Electric Solenoid Valve (DC 12 - 24V) [26].
- Two Airbags supplied by Air Motor [27].
- Temperature and Humidity Sensors (DHT22) [28-31].
- Two Force Sensing Resistors [32-36].

With regard to these components, the electrical circuit of the proposed device is illustrated in Figure 2. The reason after choosing these mentioned specific components are basically selected because of their valuable features; mainly, their low cost in addition to that it has simplistic software which can be improved easily.

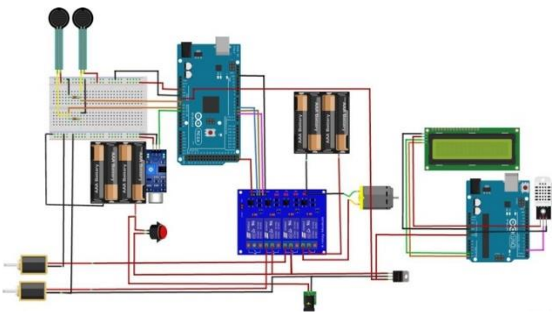


Fig. 2. General proposed connection diagram

The two pressure sensors (which are placed at the right and the left side of the pillow) detect the acoustics resulted from snoring for a duration of 60 seconds and send them to the microcontroller. The first microcontroller (OMEGA) will recognize the frequency of the detected sound and decide if it was snoring or not. Based on this, the pillow's height will change by the air motor to a suitable height where the microcontroller will decide which side of the pillow will be active, this process will continue for a duration of 30 seconds. After that the process will be reset.

During these 30 seconds, the patient will be forced to change the location of his head and snore will be stopped immediately. By the continuous detecting of the smart pillow for the snoring frequency, it will be able to stop snoring for good during sleep.

Furtherly, the proposed device was provided with two other sensors used to detect the humidity and room temp. For further options which can be used in the future to ensure more suitable condition to better sleep for people using this device. The proposed design of the smart pillow and its structure is depicted in Figure 3.

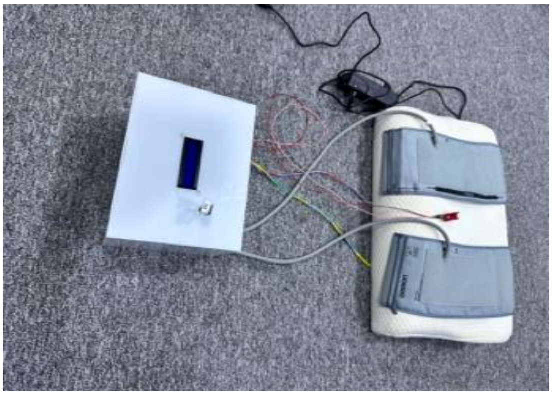


Fig. 3. The optimized design of the pillow

It's worth mentioning the duration of one cycle of the complete process will last for 60 sec. of detection, during this time if snoring was detected the air filling will last for 30 sec.

Also, for the proposed device we used two microcontrollers one is responsible only for detecting the sound frequency and air filling using air motors, the other microcontroller (UNO) was used with the humidity and temp. Sensor with the LED screen which is used for showing the mentioned sensors data and for further modifications without effecting on the main purpose of the device.

3. RESULTS AND DISCUSSIONS

As a prototype design for the proposed device, a pressure cuffs utilized in electronic blood pressure devices have been used as an air pillow along with their air motors and other electronic components. This decision was made to enhance efficiency and to ensure cost-effectiveness, aligning with the project's fundamental goal of creating a cost-efficient and easily manufactural device. Figure 4 shows the basic components which are the two pneumatic motors and the arm cuff, wherever Figure 5 explains the process flow in the pillow device.

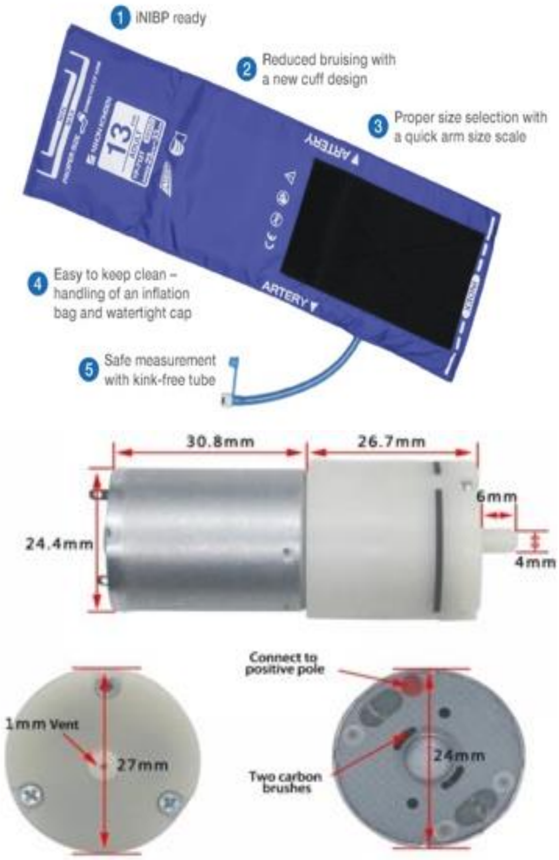


Fig. 4. Basic Components of pneumatic system

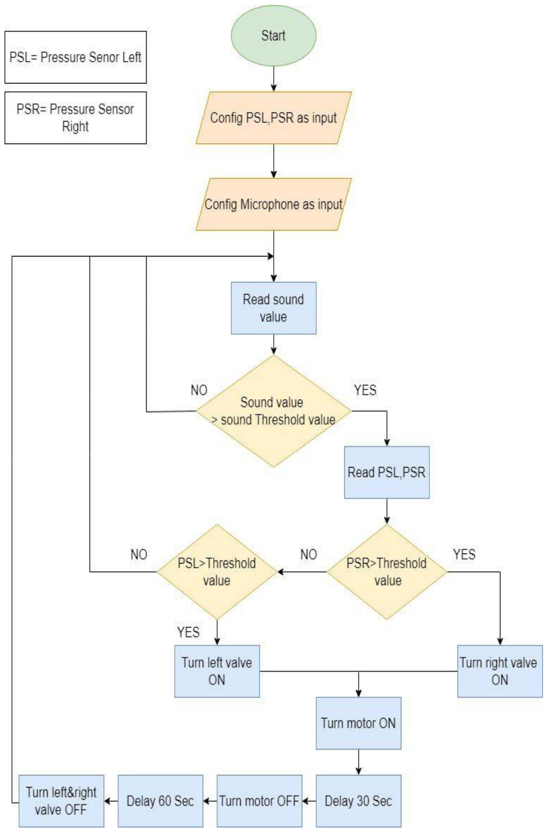


Fig. 5. The proposed process flow

At the beginning, the inaugural microcontroller (Mega) is set to detect the snore frequency of the snore by utilizing the expected sound sensor, subsequent to which the microcontroller will exactly assess the patient's head place relayed on data from the resistance of sensors. This particular sensor is designed to trigger the pneumatic motor, directing airflow towards the designated air-pad for inflation. This sequence persists for a duration of 30 seconds until the air pad reaches its full capacity, following which the motor deactivates, allowing for the gradual release of air from the air pad. Consequently, this approach facilitates the movement of the patient's head, ultimately resulting in cessation of snoring. The aforementioned procedure is reiterated every 60 seconds to effectively manage snoring throughout the duration of sleep.

The 30 sec of filling process was examined practically using the air motor, on the other hand, the release of air from the air pads after treatment of snore which will last for approximately 20 sec. which was also examined practically.

The sound sensor utilized in this study possesses the capability of both analogue and digital sound detection. In other words, the sensor can detect sound through both its analogue and digital pins. This paper aims to empirically investigate the feasibility of snoring detection utilizing both the analogue and digital pins. Concerning analogue detection, the sensor's output voltage, ranging from 0 to 5 volts, will be mapped to integer values between 0 and 1023, as the Arduino ADC resolution is 10 bits. Conversely, in digital sound detection, the sensor's output will be binary, with 1 denoting the absence of sound detection and 0 indicating the detection of sound. Figure 6 shows analogue snoring detection samples, it is obvious that the obtained values are random and it is difficult to implement in the detection process. On the contrary, in the digital snoring detection, the results shows robustness in the detection process. As mentioned earlier, the digital zero indicates sound detection, while digital one implies there is no sound detected. To distinguish between snoring and noise, five consecutive zeros are considered snoring; otherwise, it is noise as shown in Figure 7.

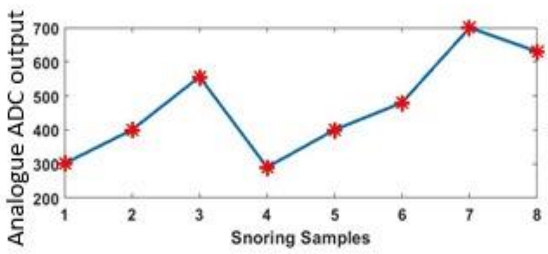


Fig. 6. Analogue snoring detection process. The Y-axis is the 10-bits ADC reading of the Arduino

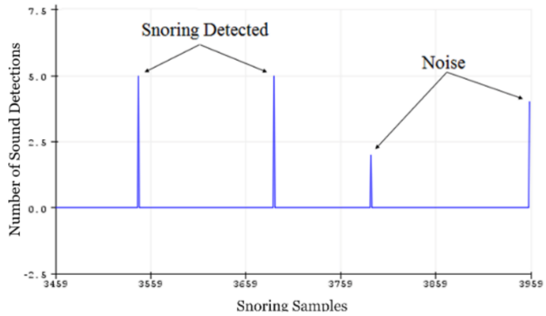


Fig. 7. Digital snoring detection process. Five sound consecutive sound detections were considered snoring, while less than five is considered noise. The sampling frequency is 2Hz

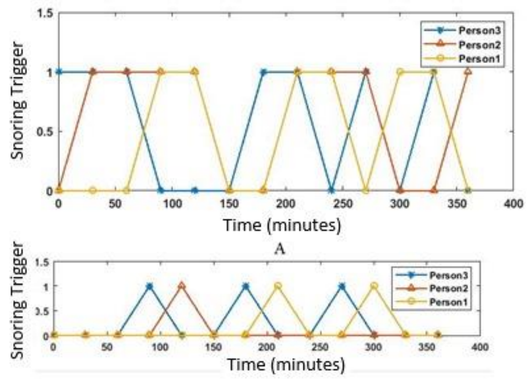
An alternative approach was implemented to the device, involving the utilization of a humidity and temperature sensor (DHT22) which interfaced with the system so as to monitor the major levels of both humidity and temperature consistently. The data obtained would be continuously presented on the Liquid Crystal Display (LCD) linked to the device, where the UNO device is controlling the LCD and the sensor (DHT22). The connection and general arrangement of this setup is illustrated in Figure 8.

Fig. 8. Designing steps of the proposed device

On the other hand, in accordance to previous studies, it has been pointed that the weight of an adult human head is about approximately 5 Kg [37]. Conversely, the weight of the head can be variable on the basis of a number of scientific factors like size of the human body, gender, and how old the human. For elaborating this context, research made by Thiemann et al. (2017) discover that in Italian adults they typically have a mass of their heads vary from 4.3 Kg up to 5.7 Kg, where 4.9 Kg represents the average weight [38]. Another scientific research has been tackled Kim et al (2017) and Kang et al. (2021) who found that in Korean adults, their head mass ranges from 4.16 Kg up to 5.92 Kg, where 4.76 Kg represents their mass average [39-40]. For that reason, the proposed device was tested to deal with different sizes of heads with different weights as shown in Figure 8.

To make sure that the proposed available system can be applied to various conditions of sleeping, three sleeping conditions were used in three different rooms.

To ensure that the proposed system is applicable to different sleeping environments, a system test is conducted in three different sleeping rooms. Initially, the sleeping behaviour of three individuals is tested before and after incorporating the proposed smart pillow during a six-hour sleeping period. Snoring detection is triggered every 30 minutes, with '1' indicating a snoring detection and '0' indicating no snoring. As shown in Figure 9-A, person 1 has been recorded snoring six times throughout the monitoring period, person 2 has been recorded snoring four times, and person 3 has been recorded snoring seven times. Figure 9-B shows the sleeping behaviour after incorporating the smart pillow. It is noticeable that the snoring has decreased in the three individuals. Person1 has been recorded snoring twice, person2 only once, and person3 three times. Thus, the snoring decreased by 66.6%, 75%, and 57% for person 1, person 2, and person 3, respectively.



B

Fig. 9. Comparison of sleeping behavior:
A- without smart pillow, B- with smart pillow.
The system makes snoring measurements every 30 minutes and indicates a logic one for snoring detection, and logic zero for no snoring

4. CONCLUSION

Concerning this present research, a prototype design of smart pillow which was designed is exactly supposed to aid individuals having a major issue with snoring.

The design uses basic apparatuses like microcontrollers, a pneumatic motors and air pads, along with sensors of temperature and humidity.

The major aim is to construct and present a relaxing and useful pillow for enhanced sleep quality. When compared with other kinds of existing commercial pillows, it is noticeable that the achieved design has many features such as being comfortable, low cost and easy to use as well. Added to that, the pillow supports humidity and temperature values during the time of sleeping so as to better aid to achieve environment full of good sleeping. The results of this study uncovered 75% decrease in snoring. Last but not least to say about this work, the proposed pillow has the capacity of improving sleeping with aid of IoT applications, this will help providing so better sleeping conditions for people with snore conditions during sleep.

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