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Android-Arduino Platform for Detecting and Monitoring Obstructive Sleep Apnea (OSA)

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منصة أندرويد–أردينو لاكتشاف ومراقبة انقطاع النفس الانسدادي النومي

الملخص

انقطاع النفس الانسدادي النومي (OSA) هو اضطراب في النوم يتوقف فيه التنفس بسبب الانسداد المتكرر للمجرى الهوائي العلوي لمدة عشر ثوانٍ أو أكثر أثناء النوم. تؤدي هذه الحالة الطبية الخطيرة إلى عواقب صحية منهكة وتؤثر على نوعية الحياة المتعلقة بالصحة. يتسبب توقف التنفس أثناء النوم في حدوث انخفاض مفاجئ في مستوى الأكسجين في الدم، مما يؤدي إلى ارتفاع ضغط الدم ونقص الأكسجين في أنسجة الجسم. لذلك، فإن التشخيص الصحيح والمراقبة المستمرة لانقطاع النفس الانسدادي النومي أمر بالغ الأهمية. يعد تخطيط النوم (PSG) أحد أكثر طرق التشخيص شيوعًا لاضطرابات النوم وهو المعيار الذهبي لتشخيص هذه الحالة. بإستخدام طريقة PSG ، يتم تسجيل الإشارات الفسيولوجية (موجات الدماغ، مستوى الأكسجين في الدم، معدل ضربات القلب، والتنفس) أثناء إقامة معملية باهظة الثمن حيث يُطلب من المريض النوم في المستشفى ويتم الربط عبر أسلاك كبيرة ومتعددة بين جسم الإنسان والجهاز. تصف هذه الدراسة تطوير وجدوى منصة منخفضة التكلفة لاكتشاف OSA من خلال تحليل قراءات مقياس مجس التسارع الموجود في مستشعر MPU6050 الذي يراقب حركة الصدر الناتجة عن الضائقة التنفسية ويمكن أيضاً تحديد وضعية الشخص النائم بواسطة مقياس التسارع. تنقل وحدة Bluetooth على الرقاقة البيانات عبر تطبيق الهاتف المحمول من المرضى إلى أخصائيي الرعاية الصحية لإجراء مزيد من التحليل لبياناتهم الصحية ومراقبة حالة الجهاز التنفسي لديهم بشكل مستمر. قد توفر هذه الطريقة اختباراً بديلاً لـ PSG بواسطة جهاز محمول ومريح وغير مكلف ومتوفر بسهولة من شأنه أن يسمح للمستخدمين بإجراء تشخيص OSA في المنزل دون الحاجة إلى الاختبار الليلي في مختبر النوم بالمستشفى.

Android-Arduino Platform for Detecting and Monitoring Obstructive Sleep Apnea (OSA)

Abstract

Obstructive sleep apnea (OSA) is a sleep disorder in which breathing stops due to repeated obstruction of the upper airway for ten seconds or more during sleep. This serious medical condition leads to debilitating health consequences and affect health related quality of life. OSA causes a sudden drop in the level of oxygen in the blood, which leads to high blood pressure and hypoxia to body tissues. Therefore, the correct diagnosis and continuous monitoring of OSA is critical. Polysomnography (PSG) is one of the most common diagnostic methods for sleep disorders, and is the gold standard for diagnosing this condition. In PSG, physiological signals (brain waves, blood oxygen level, heart rate, respiration) are recorded during an expensive lab stay in which the patient is required to sleep in the hospital with large and multiple wires between the human body and the machine. This study describes the development and feasibility of a low-cost platform for detecting the OSA by analyzing the accelerometer readings of the MPU6050 sensor that monitors chest movement resulting from respiratory distress and it is able to determines the position of a sleeping person by the accelerometer as well. The on-chip Bluetooth module transmits data through a mobile application from patients to health care professionals for further analysis of their health data and to monitor their respiratory status continuously. This method may provide an alternative test to PSG with a portable, convenient, inexpensive, and readily available device that would allow users to perform OSA diagnosis at home without the need for nighttime testing in a hospital sleep laboratory.

Keywords: Obstructive Sleep Apnea; Polysomnogram; Mobile application; Sleep Position; Sleep monitoring; Acceleration Sensor; Bluetooth; Wearable Device.

Introduction

Sleeping is a human need and good quality of sleep is a sign for good health. Not getting enough sleep on a daily basis leads to health complications such as mental disorders, fatigue, cardiovascular diseases [1]. OSA is a sleep disorder in which breathing stops due to repeated obstruction of the upper airway during sleep and it is one of the major sleeping problems. It affects more than 10% of the middle-aged population. The prevalence of OSA is between 9% and 38% of the total population, makes OSA a huge public health burden [2]. Some statistics on sleep apnea mortality estimate that at least 38,000 people die annually from complex heart diseases directly from sleep apnea [3]. Furthermore, most patients with OSA remain undiagnosed and therefore untreated properly.

The diagnosis of sleep apnea is usually confirmed using Polysomnography (PSG) which is a test performed at a sleep lab in the hospital or at home using special equipment to assess sleep. The PSG sleep study itself provides specific information including brain waves, blood oxygen level, heart rate and breathing, as well as eye and leg movements during the study. Moreover, the diagnosis of OSA is usually confirmed from the overnight sleep assessment. The advantage of test at home over a hospital sleep laboratory is getting rid of wiring and keeping patient's sleep performance..

The main objective of this work is to design and develop a low-cost platform for the diagnosis of OSA at home by analyzing the readings of the accelerometer attached to a chest strap. This objective was achieved through the development of an algorithm for detecting chest movement resulting from respiratory distress. A secondary objective from this study was to determine the best body position for reading respiratory information using accelerometer and gyroscope. Last objective is providing an interface application that makes it easier for the user to know his vital signs while he sleeps.

1. Related works

Rapid developments in smartphones technology enhanced their capabilities and added tremendous features to them. Nowadays, smartphones play an important role in various fields. Kailas et al. in [4] mentioned that there are already more than 7000 documented healthcare applications.

2.1 Obstructive sleep apnea portable devices

In recent years, different approaches have been explored to detect sleep apnea. One of these approaches is to deploy accelerometers to estimate breathing or flow signals during sleep [5]. A second approach uses audio signals to measure breathing and snoring [6]. A third approach supports the with pulse oximetry to estimate the severity of sleep apnea. Mores details about those approaches are given next.

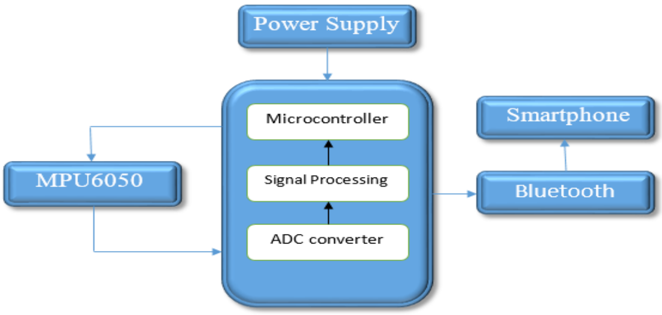
Yao et al. in [7] designed a chest-mounted three-axis accelerometer system that monitors the body's position during sleep by calculating the angles between the gravity vector and its three axes and as well it monitors the OSA. Other studies combined a microphone and an accelerometer to develop an Android mobile monitoring system [8], [9]. Srivida et al. in [8] developed an algorithm to detect sleep apnea by mounting a breathing sensor placed over the patient's nostrils, and whose position is determined by the accelerometer sensor. Wu et al. in [10] developed a portable four-level system with two 3-axis accelerometers that measures chest and abdominal breathing efforts and an oximeter to measure oxygen saturation to identify sleep apnea events. Although several portable health approaches have been proposed to improve the diagnosis and monitoring of sleep apnea at home, more studies are still needed to obtain greater accuracy.

HealthGear [11] is a Windows mobile application that uses a blood oximeter to detect sleep apnea. The application was examined on scores of participants and OSA detection algorithms were determined and 100% accuracy was obtained for all three known cases of obstructive sleep apnea.

2. System Components

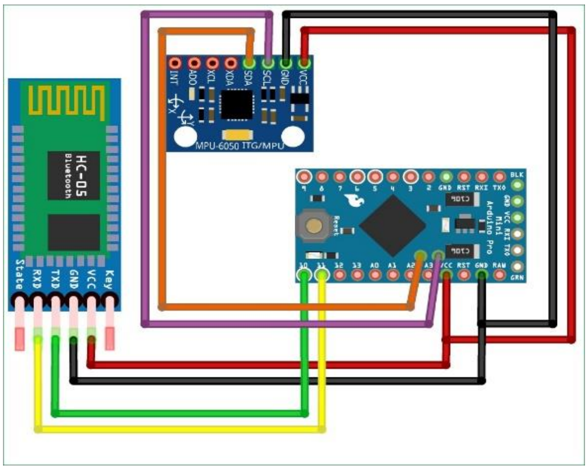
In our system, we used the MPU6050 sensor module to extract the respiratory rate level by the accelerometer and gyroscope placed on the patient's chest. The HC-05 Bluetooth chip connected to the Arduino was used to record the breathing voltage and send it to the application in the mobile phone. The position and movement of the body can be determined by constant detection of the directions of the body along all axes. We used the accelerometer to detect the movement of the body by sensed along three axes (X, Y and Z).

The OSA monitoring platform is combination of a hardware part, which is the sensor circuit connected with the Arduino, and a software part, which is the Arduino code and the Android application. The hardware consists of an Arduino board, an MPU6050 sensor module, a Bluetooth module and a power supply as shown in Figure 1. The Arduino Nano board was selected due to its simplicity and small size.



3. Figure 1: Block diagram of a proposed OSA monitoring platform

The circuit diagram of the OSA detection platform is shown in Figure 2. It is composed of two modules and Arduino board. The MPU6050 sensor module communicates via the I2C communication protocol, so the SDA pin is connected to the A4 pin on the Arduino, which is the SDA pin, and the SCL pin is connected to pin A5 on the Arduino. The HC-06 Bluetooth module operates in a transparent wireless serial communication mode, which we use to transmit the results data to the smartphone so that the Rx pin of the Bluetooth is connected to the D11 port, and the Tx pin of the Bluetooth is connected to the D10 pin of the Arduino. These two pins D10 and D11 connected to the HC-06 Bluetooth module will be configured as serial pins by programming the Arduino. The working voltage of the MPU6050 sensor module and the HC-05 module is +5V, so they are powered by the Vcc pin on the Arduino.



4. Figure 2: Main components of the system

3.1 Microcontroller

The Arduino Nano was selected as the main controller because of its small size. It is based on the ATmega328 (Arduino Nano 3. x). Its operating voltage varies from 5V to 12V.

3.2 The inertial measurement unit (IMU) MPU6050 sensor module

It is a MEMS IMU that includes a triaxial gyro to measure rotational speed and a triaxial accelerometer to measure acceleration. It has a powerful digital motion processor to perform complex calculation, and thus free up the work for Microcontroller. Moreover, it has on-chip temperature sensor. It has I2C bus interface to communicate with the microcontrollers. It has an auxiliary I2C bus to communicate with other sensor devices like 3-axis Magnetometer, Pressure sensor etc.

3.3 The HC-05 Bluetooth Module

It is a class 2 Bluetooth module designed for transparent wireless serial communication Serial Port Protocol (SPP). It is pre-configured as a slave Bluetooth device.

5. System Operation and Analysis

4.1 Apnea detection

The Arduino Nano receives three axis accelerometer measurements from chest movement via the MPU6050 sensor module installed in the chest strap of the patient and then sends them to the mobile phone via the Bluetooth module and stores data on the phone. Then we pass the data stored on the filter to take the measured maximum (inhale) and minimum (exhale) value of the MPU6050 sensor every 8 seconds, which is approximately two breaths for a normal human, and subtract the two values to get the percentage difference between the two values if this value returns to zero and is repeated. It means that the user has sleep apnea, and the frequency of this condition is shown to the user in the developed application. In addition, the duration of each patient's sleep position is determined by analyzing the three axes that we obtain from the MPU6050 sensor module. The difference is computed as follows:

$$C = Xmax - Xmin \quad (1)$$

Figure 3 shows a flowchart of the mobile app.

4.2 Sleeping Position detection

Then, components of each of the accelerometer axes in the triaxial accelerometer were used to determine the lying, right, left, standing and prone positions. We followed the equations given in [12]. The position is computed for each sample according to the following equations:

Supine position:

$$|Z| > [\ |X|\ ;\ |Y|\ ] \text{ and } Z > 0 \tag{2}$$

Prone Position:

$$|Z| > [\ |X|\ ;\ |Y|\ ] \text{ and } Z < 0 \tag{3}$$

Right Position:

$$|X| > [|Y|\ ;\ |Z|] \text{ and } X < 0 \tag{4}$$

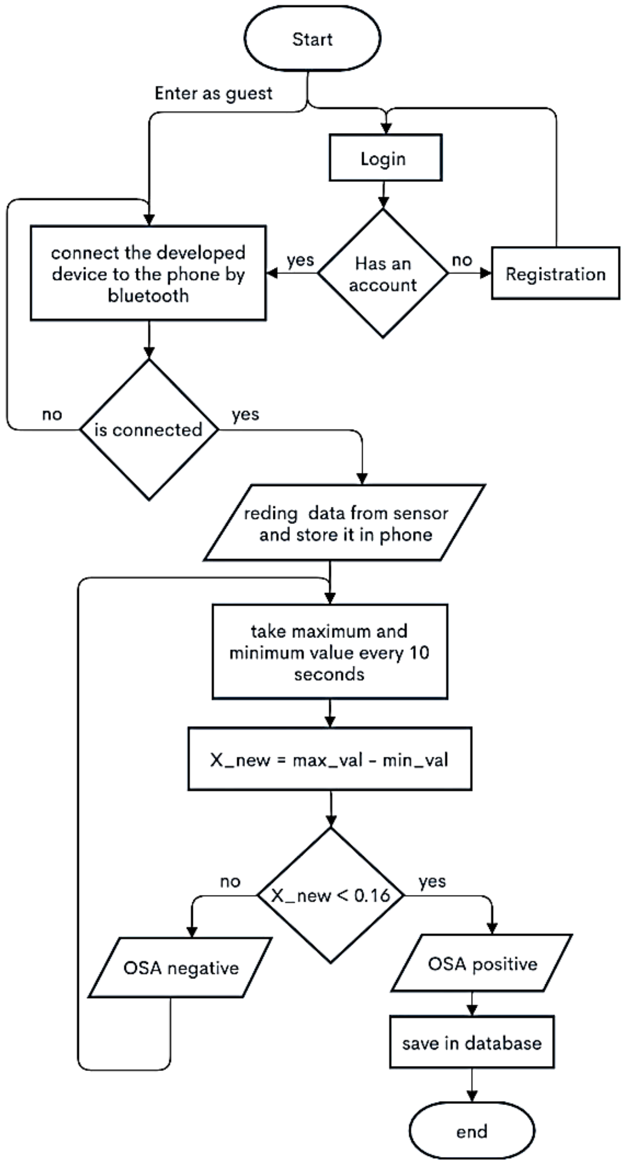
Left Position:

$$|X| > [|Y|\ ;\ |Z|] \text{ and } X > 0 \tag{5}$$

Standing Position:

$$|Y| > [|X|\ ;\ |Z|] \tag{6}$$

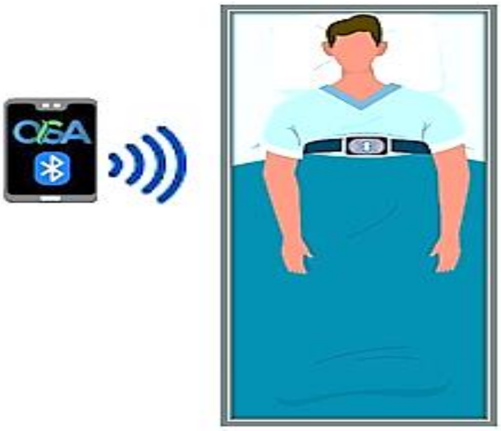
where X, Y, and Z are the triaxial accelerometer values for each sample of the triaxial accelerometer vectors.



6. Figure 3: Flowchart of the OSA detection system

7. System Implementation

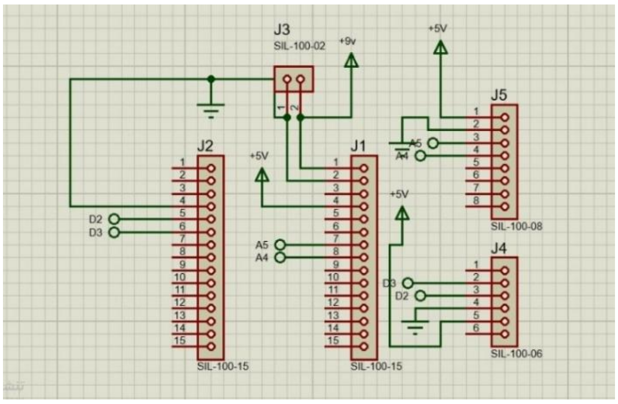
We need communication technologies to connect the project items when the user wants to measure OSA. The user in the hospital or at home needs to open and connect his/her smartphone to the developed OSA system which includes the data we collected above from the MPU6050 sensor module via Bluetooth to connect, so that the measurement readings are stored on the phone Mobile and if the application is not connected to the device, then there are no Bluetooth relays and the information is stored on the mobile phone. Through the Android application and the developed OSA device, the user health status is determined based on the measurement result. The whole elements of the system are shown in Figure 4.



8. Figure 4: Elements of the project

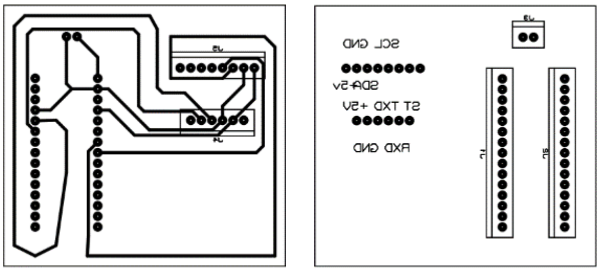
5.1 Schematic circuit

The schematic circuit of the designed OSA monitoring system is shown in Figure 5. It consists of an Arduino Nano, MPU6050 sensor module, Bluetooth module and a DC power supply.



9. Figure 5: Schematic circuit

Figure 6 shows the layout of the MPU6050 circuit connected to the Arduino board.



10. Figure 6: PCB layout of the MPU6050 circuit

5.2 Methods to extract physiological signals

In our developed system, we use the MPU6050 sensor to extract the respiratory rate level by accelerometer placed on the patient's chest. The HC-05 Bluetooth piece connected to the Arduino piece is used to record the respiratory effort and send it to the application in the mobile phone. The position and movement of the body can be detected by constant measurement of the directions of the body along all axes. The accelerometer can be used to detect these movements. However, in the upgraded design, we make use of the accelerometer integrated with the smartphone, and the movement of the body will be detected by calculating the displacement in the three axes (X, Y and Z).

5.3 Methods for analyzing aggregated physiological signals

A sleep apnea event is detected when the airflow is interrupted for more than two breaths or approximately for at least 10 seconds [4]. Based on this definition, we need to detect airflow obstruction, fluctuation of breathing? and chest movement during sleep in the developed system, and we analyze two physiological signals to screen for OSA.

5.4 Integration of the developed OSA device with the smartphone

The system is designed as an OSA monitoring system where OSA can be monitored for patients in a single smartphone. The integration between the MPU6050 and the smartphone depends on connecting both of them. Wireless communication is achieved via a Bluetooth link where data can be transmitted wirelessly to a compatible paired device. With the application available for Android, the measured data can be sent to your mobile devices to be saved and managed there. Data transfer is enabled via Bluetooth, which most Android devices support. Figure 7 shows the developed OSA device integrated with smartphone.

11. Figure 7: OSA measurement system

Figure 8 shows the system in use that consists of a box containing MPU6050 sensor module, Arduino Nano and Power Supply (Battery 9V) mounted to the chest with a strap.

12. Figure 8: Integrating the developed OSA device with smartphone

5.5 Identification of Obstructive sleep apnea

By wearing the developed system during sleep and successfully running the application, the sleep data can be transferred to the smartphone. Chest movement is measured using the MPU6050 sensor module, and the readings are stored in the application. Figure 9,10, 11and 12 show the user interfaces of the OSA monitoring mobile application.

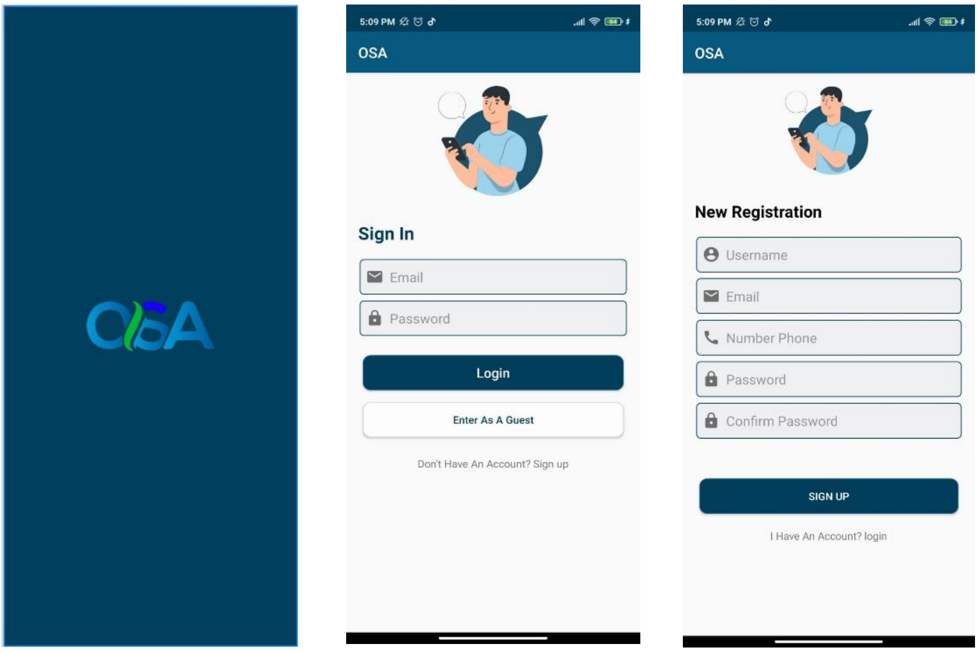


Figure 9: User interface of the OSA monitoring mobile app(Splash Screen , Login Screen , Registration Screen)

Android-Arduino Platform ….

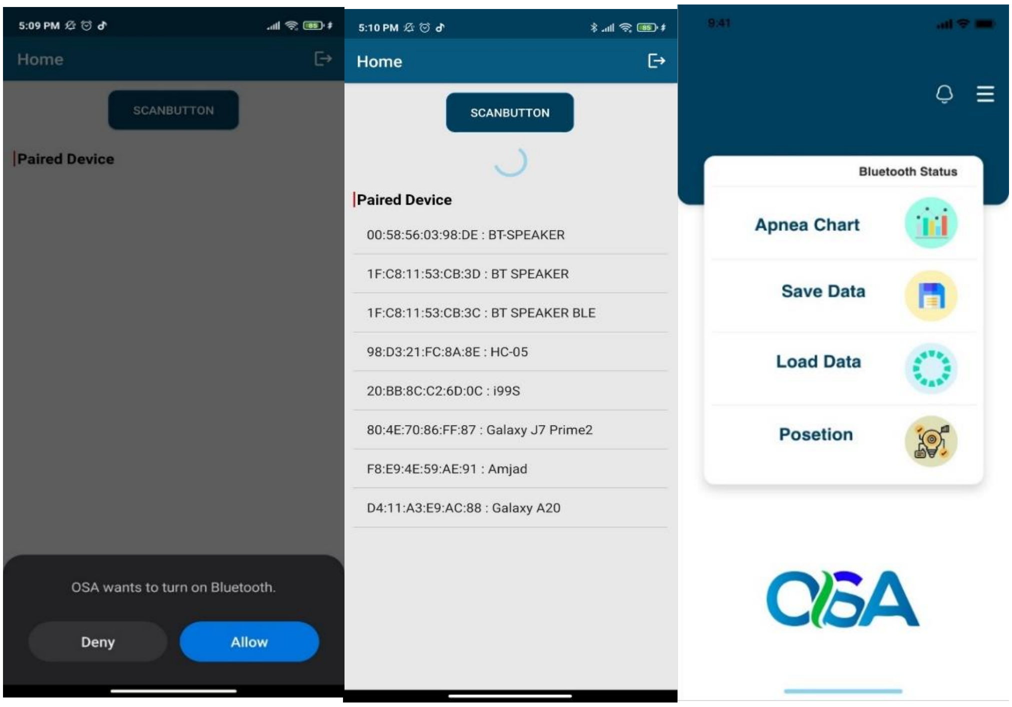


Figure 10: User interface of the OSA monitoring mobile app (Enable Screen , Scanning Screen , Home Screen)

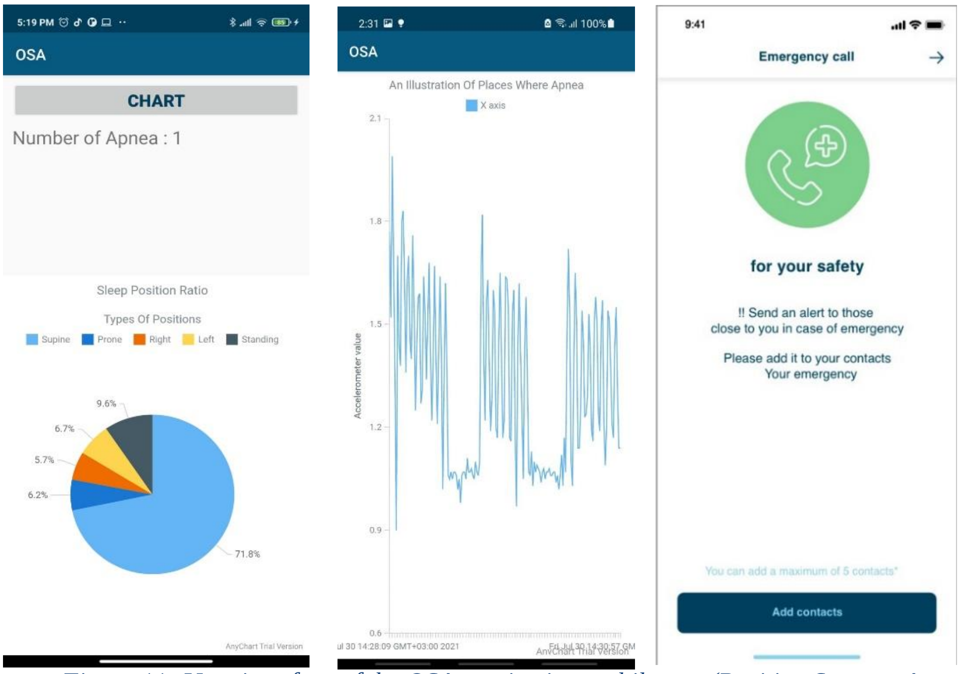


Figure 11: User interface of the OSA monitoring mobile app (Position Screen , Apnea Screen , Call Emergency)

13. Experimental Results and Analysis

There are no sleep laboratories at Gaza Strip hospitals. Therefore, we could not compare our results from the newly developed system with those of PSG. Therefore, we asked the subjects to stop breathing voluntarily for 10 seconds or more as a simulation for the occurrence of OSA. Multiple occurrences of the simulated OSA were performed and were counted and the detected occurrences by the system count were in harmony with actual ones. Subjects included six people of different ages and genders shown in Table 1. This experiment allowed us to measure the application's ability to detect how often OSA occurs during sleep, as well as to determine the proportion of sleep duration of each position during sleep. Thus, we have achieved the success of the specific goals and objectives required for our project as expected of it. As it can be seen from Table 1, success rate reaches 100%.

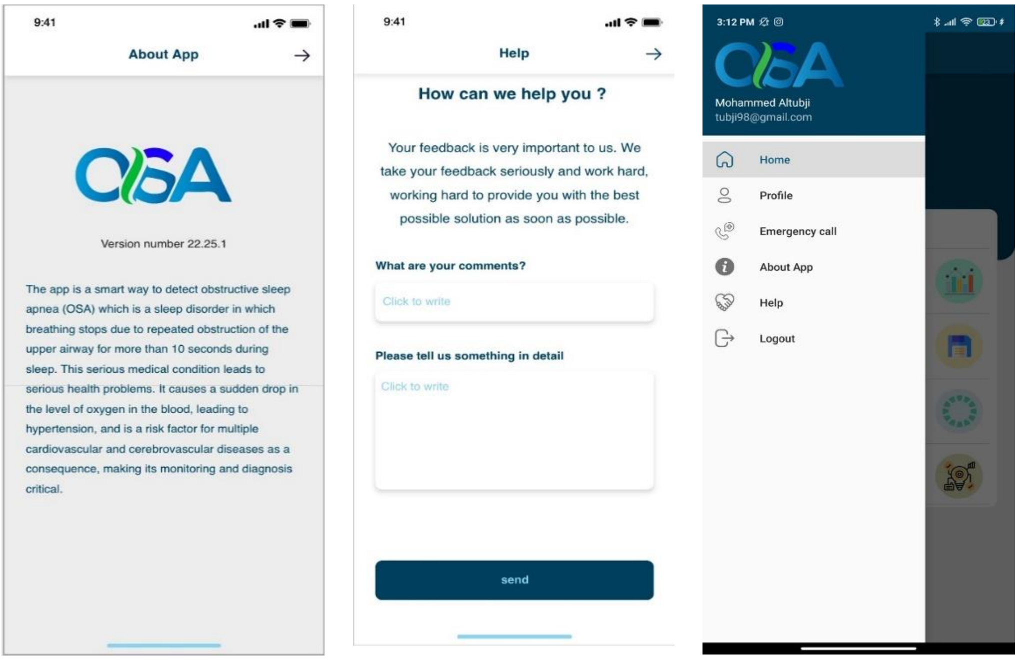


Figure 12: User interface of the OSA monitoring mobile app (About App Screen , Help Screen , Menu Screen)
14.

15. Table 1: The Results

Sub.	*Gender*	*Age*	*Expected number of OSA*	*#.of occurrences OSA*
1	Male	55	4	4
2	Female	45	3	3
3	Male	23	7	7
4	Male	31	5	5
5	Female	18	8	8
6	Male	15	6	6

16. Conclusion

In this study, we designed and developed a low-cost platform with high accuracy for the diagnosis of OSA at home by analyzing the readings of an accelerometer attached to a chest strap. We proposed an approach that builds on previous published work. To confirm the results of the diagnosis, we were in an ongoing consultation with a sleep disorders specialist. The smartphone application was developed to record and analyze the data on the smartphone. It is a standalone, reliable, portable and simple solution.

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