eSleepApnea - A Tool to Aid the Detection of Sleep Apnea

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Abstract. Nowadays, the appearance of chronic respiratory diseases is something increasingly common. A good example is sleep apnea, a respiratory disease characterized by recurrent episodes of pharyngeal collapse. It's a disease unknown by one part of the population, but when not controlled in time allows the emergence of other diseases. The complexity of symptoms, which are often diseases that arise as a consequence of apnea (e.g. arterial hypertension), makes its diagnosis difficult to be made, leading, in the long term, to a considerable reduction in the quality of life of patients. This paper presents an IoT solution for detecting sleep apnea signals, without the need to place auxiliary devices in the patient's body.

Keywords: Sleep Apnea · Sensors Network · Microwave Sensor · Arduino · IoT

1 Introduction

Identifying some of the key symptoms of the different pathologies (e.g., chest pain in cases of myocardial infarction) is often the key to the patient's full recovery because it enables medical help to be activated in a timely manner [1]. However, whether it's due to ignorance of the existence of various diseases [2] or because the symptoms do not affect the quality of life of patients, usually, medical help is only sought at a later stage of symptoms, delaying its diagnosis and leaving the chances of cure seriously compromised. However, for certain problems, such as sleep apnea, a full recovery is not always possible, but an early diagnosis greatly reduces its consequences.

Sleep apnea [3] is a respiratory sleep disorder described by momentary but frequent obstruction of the airways, causing total or partial interruptions in breathing. The total lack of knowledge of the disease and its long-term complications, associated with a lack of clear perception of interruptions in the respiratory flow by patients, leads to the diagnosis being confirmed long after the

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occurrence of the first episodes of respiratory block, so that the consequences of the disease already affect the quality of life of patients.

Using a mobile application, the Microwave sensor for capturing breathing patterns, an Arduino MKR NB 1500 board for sending data to the cloud and a set of intelligent algorithms for detecting breathing stops in the received data, This article proposes a solution that will help in the identification of signs of sleep apnea without the need to place external devices in the patient's body. The remaining paper is organized as follows: Sect. 2 provides a brief description of sleep apnea; technical details of the proposed solution are described in Sect. 3; in Sect. 4 are presented the conclusions of the work and objectives for future work.

2 Sleep Apnea

Sleep apnea [4] is a pathology that causes momentary blockage of breathing during sleep, resulting mostly in snoring and constant daytime sleepiness. It can also cause symptoms [5] such as difficulty concentrating, headache, irritability, etc. Blockage phenomena occur due to a narrowing of the airways, in the region of the nose and throat, something that happens mainly deregulation in the activity of the muscles in the throat region, which may be excessively relaxed or narrowed during breathing. This deregulation often results from factors such as: the existence of a narrow throat, thick neck and round head, low levels of thyroid hormones (hypothyroidism), and in some cases, the history of stroke.

This pathology can be classified into 3 types [6]: obstructive sleep apnea - occurs most often, due to obstruction of the airways, caused by relaxation of the breathing muscles; central sleep apnea - arises after some pathology that causes a brain injury (ex: brain tumor, post-stroke) and changes the ability of the patient to regulate the respiratory effort during sleep; mixed apnea - is caused by the presence of both obstructive apnea and central apnea. In addition to these 3 types, in people with inflammation of the tonsils, tumor or polyps in the region, the appearance of temporary apnea is frequent.

Despite the characteristic symptoms of the disease, the definitive diagnosis of sleep apnea syndrome [7] is made with polysomnography, which is an examination that analyzes the quality of sleep, measuring brain waves, movements of breathing muscles, the amount of air that enters and leaves during breathing, in addition to the amount of oxygen in the blood. It is through this examination that it is possible to classify the severity of sleep apnea by counting the number of breath stops during sleep. When stops are less than 5 per hour, the test is considered normal, but depending on the number of stops per hour the severity varies between: mild (5 to 15), moderate (15 and 30) and severe (more than 30). In parallel, this examination also makes it possible to understand, if there is a predominance of apnea with position (Positional Sleep Apnea), what happens in many cases and can be improved simply by sleeping sideways. The performance of this examination can be done in the hospital or in an outpatient clinic, however, in any of the cases implies the placement of devices in the patient's body, which in situations where patients reject the presence of the disease can be complicated to perform.

Thus, the search for alternative means, such as that presented in this paper, that allow to identify signs of the disease without the need for the placement of auxiliary devices or a trip to the hospital, It can work as a first line of screening and as a counseling, for patients who reject the presence of the disease, to perform polysomnography for final confirmation of the diagnosis.

3 Proposal Solution

In Fig. 1 it's possible to observe the architecture of the proposed solution. Briefly, the solution is composed of two parts. The first part of the solution corresponds to the microwave sensor [8,9] and Arduino board, and is placed in the patient's home, while the second part corresponds to the services, stored in the cloud, that process the data coming from the sensors.

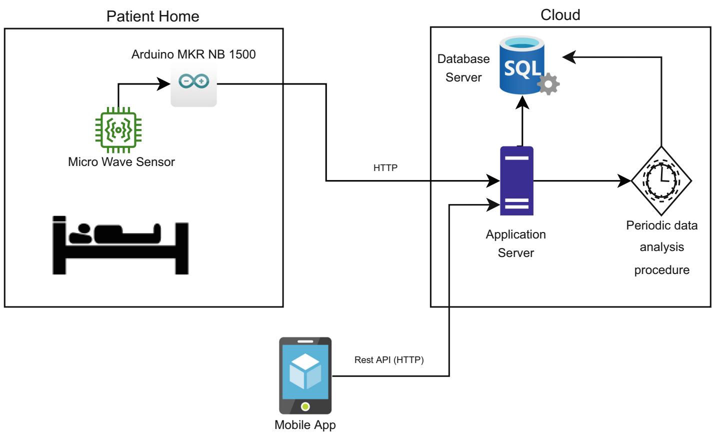

Fig. 1. Overview of proposal solution architecture.

In general, the functioning of the solution involves capturing the patient's breathing pattern. Captured data is sent to the cloud for processing and storage. The processing tasks of this data perform once a day, usually at the beginning of the day, where they try to obtain the number of anomalies in the breathing pattern of each patient. The results produced by the background tasks can be consulted by the doctor or caregiver of the patient, where it is possible to see the number of anomalies detected each night. In the following sections, each component of the solution will be detailed.

3.1 Microwave Sensor and Arduino

The Microwave Sensor is a sensor that uses high-frequency radio waves operating at 360°. The sensitivity in the change of reflected waves, makes the operation of these sensors very similar to that of radars. Continuous monitoring enables changes in return waves to be quickly identified.

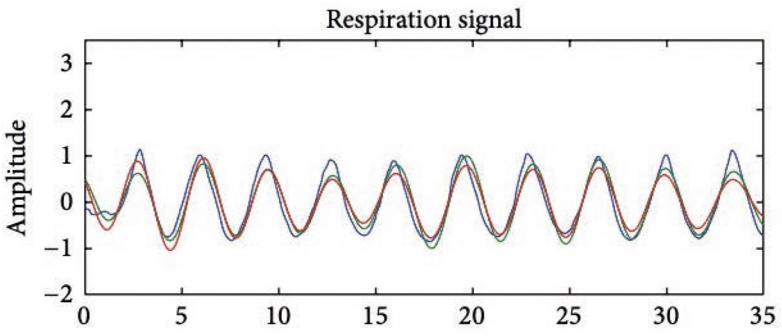

Fig. 2. Comparison of respiration belt signal versus Doppler Radar signal [10]

In Fig. 2, analyzing the red line, this represented a normal pattern of breathing captured by the microwave sensor. Analyzing the waves represented is possible to clearly identify the process of inhalation/expiration of air. The time of a respiratory arrest in cases of sleep apnea can vary between 10 s and 2 min, thus, the sensitivity that this sensor possessed, allows such stops to be identified in the data collected. In the proposed solution, this sensor, together with the Arduino, is positioned and centered with the patient's chest at a height of 90 cm. The frequency of sending data, which are sent using Narrowband-IoT (NB-IoT), is minute by minute and begin to be sent by Arduino to the cloud, from the time defined by care, as will be detailed in section refma. The use of NB-IoT is justified by the fact that there is no stable connection to the internet in the homes of users, and the simplicity in configuration that is, so that the solution works as expected is not necessary a connection to home networks. In addition, one of the key points of this technology is to enable the ease of connection that exists in smartphones can be used in the IoT world, namely ultra-low consumption communications, allowing to remove the need for battery recharges by its users. The selection of the Arduino MKR 1500 [11,12] is due to the fact that it is the first and only one of the Arduino family compatible with LTE Cat M1 and NB-IoT [13–15].

Listing 1.1. Example of JSON string sent by Arduino board to cloud

```
{
    "user_id":123,
    "data":[0,0,1,0,1,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,1,1,1,1],
    "timestamp": 1662887046
}
```

Another point that supports the use of NB-IoT is the size of the transmitted data. In the Listing 1.1, you can see the data frame that is sent to the Cloud. The field *user_id* represents the user identification and can be changed via mobile application. In the field *data* it is possible to analyze the data collected from the sensor, and represent the variation of the reflection waves of the previous 30 s. It is by processing the data in this field that background tasks (see Sect. 3.2) can detect possible stops. Finally, the *timestamp* represents the Unix time of the actual message sending.

3.2 Background Tasks

The background tasks are composed by two components:

- A model that is responsible to identify the number of respiratory arrests that a person has in a night of sleep.
- A process that is responsible for the diagnosis of people by analysing the values returned by the model.

For a model to be trained, a dataset is needed. But, since the authors of this paper didn't find a dataset that could be used to be applied to this solution, before this model can be trained, a dataset needs to be generated using the system of this solution. When the system of this solution generates enough data, a dataset will be built with data of people who have been diagnosis with sleep apnea and people who have not. With this dataset built, the model will be trained using this data to identify the number of respiratory arrests that a person has in a night of sleep. Then, the model will be fine-tuned and tested in order to increase the capacity of generalization and the accuracy rate of it. When the performance of this model is satisfactory, it will start to be used to process data generated by the system. The model will process this data, once per day, when everyone finishes this exam.

When the model [16] has just processed the data of all the people who took the examination in the current day, the process is called. Depending on the values returned by the model, the process will give a diagnosis of the people who took the examination in the current day. The result of the diagnosis can be positive mild, positive moderate, positive severe or negative. The process reaches these results using the algorithm that has been mentioned in the Sect. 2. When the number of respiratory arrests is less than 5 per hour, then the test is considered negative. If the number of respiratory arrests is more than 5, the test is considered positive, but depending on this value, the result can be a positive mild (5 to 15), positive moderate (15 and 30) and positive severe (more than 30).

When the results of the examinations of everyone are calculated, the resulted data is then saved on the database of the system. This will allow this data to be accessed by the mobile application.

3.3 Mobile Application

In Fig. 3 it is possible to analyze the layout of the built mobile application. This application has an important role in the built architecture, since, through it, caregivers/doctors can consult the results of the data processing from the sensors.

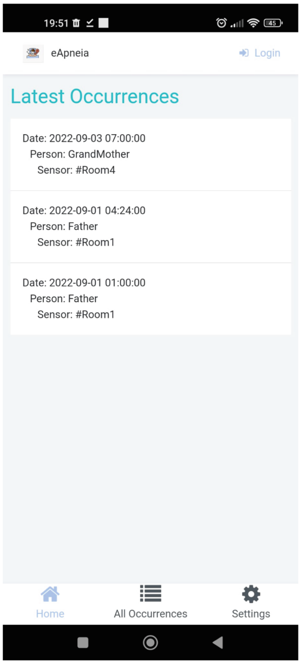

Fig. 3. Mobile Application Layout

Although it is not represented, the Arduino is connected to a BLE sensor [17], allowing care to change the time that the readings of the sensor values start. In addition, it is using the mobile application that it is possible to obtain the *user_id* field. This field is the serial number of Arduino and is necessary to then request the result of data processing to the existing restfull API [18]. This process is only performed once at the time of system configuration.

4 Conclusion

At the current stage, the solution is already at an advanced stage of development and testing. As mentioned, detection of sleep apnea is often a complicated process given the lack of perception of symptoms by patients. The simplicity of configuration, the need not to place devices external to the body of patients, makes the solution presented a solution with some potential to function as a first line of screening in the detection of sleep apnea. In addition, one of the secondary objectives of this solution is to make the results produced, only in cases where stops are detailed, lead the patient to do the diagnostic confirmation tests of apnea.

However, although the solution is well underway and necessary to recognize that there are several contexts that have not been validated. The initial context of tests, emphasizes on the assumption that the person under evaluation sleeps all night on his stomach, however, this assumption is not transversal to all people, but you can be cautioned in this solution by placing more microwave sensors to monitor other sleeping positions. Another context that has not been validated and in the opinion of the authors it is necessary to validate is the amount of bed linen that patients use daily, because this quantity can have a negative influence on the data produced by the sensors, making it difficult to detect respiratory stops.

4.1 Future Work

Despite the great potential, the solution still has a long way to go. The following points have been left for future work:

- Validate the solution built for scenarios where patients do not sleep on their stomach.
- Optimize the sending of data by Arduino, in order to ensure the best balance between the number of submissions and the captured information.
- Confirm the impact on data collection with the presence of large amounts of bed linen on the patient.
- Perform studies to understand the difference between the results produced by this solution and the diagnostic tests for sleep apnea (e.g. polysomnography).

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