Application of a wireless apnea monitoring device for crisis alertness and sleep diagnosis

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ABSTRACT

Over the past five decades, obstructive sleep apnea has been noted as a prevalent symptom in adults with escalated health conditions like stroke, obesity, high blood pressure, cardiovascular complications and chronic kidney diseases; to mention but a few. Apnea hypopnea index (AHI) is the average number of apnea or hypopnea events which occur during a complete sleep cycle per hour. It is a measure of determining the severity of sleep apnea, where an index range of 5 to 15 indicates mild, 15 to 30, moderate and above 30 denotes severe sleep apnea. In a bid to perform this diagnosis, several approaches have been considered. In this study vibrating sensor module and an Arduino Uno Rev3 microcontroller which retrieve breathing status data during sleep and identifies apnea events is proposed. The developed monitoring device displays the apnea count, effectively, which can be used to determine AHI. It also incorporates a Bluetooth module for wireless, real-time data monitoring which allows for more comfortable usability. The result is the successful implementation of an efficient, cost-effective system which can be used for sleep apnea diagnosis and provides preventive health care measures.

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1. INTRODUCTION

The oxygen is one of the essential elements for human existence. Without proper intake of oxygen, one becomes vulnerable to hypoxemia which can cause several conditions that are capable of affecting the normal performance of organs in the body such as the heart and brain. This lack of oxygen can be inaugurated by a wide variety of conditions, most of which are triggered by abnormalities centered around parts of the respiratory system, they could be organs (heart, lungs), inflamed tissues or even a combination of incompatible conditions in the body. In some such way, oxygen does not flow well through the system or not much of it comes in at all. When breathing is compromised during sleep, it is known as sleep apnea and prolonged subsistence with this condition can become even more burdensome. In recent times, electronic components are being integrated in a lot of systems to aid smart operation [1]-[4]. Several researchers have explored the potentials of electronic components to aid medical practitioners' works in terms of saving lives and preventing emergencies such as early detection of cancerous cells [5], [6], early risk detection of pre-eclampsia for pregnant women [7]-[9], type 2 diabetes [10]-[13], and cardiovascular disease [14]-[16].

According to the World Health Organization (WHO), "obstructive sleep apnea syndrome is a clinical disorder marked by frequent pauses in breathing during sleep usually accompanied by loud snoring" [17]. It is particularly common in children between 2 and 6 and in the older population of adults. Sleep apnea in adults is very few can lead to death, however it has a major hand in the inception and aggravation of health complications like diabetes, stroke, chronic kidney disease and heart failure [18]. In children, it can also lead to growth failure and cognitive distraction [19]. The condition is primarily diagnosed with a sleep study which is most effectively conducted in hospitals through polysomnography (PSG) [20]. This can be uncomfortable and expensive as it implies an all-night at the center-which is majorly situated in large urban areas.

Although several studies have been conducted on this topic in Nigeria, not much effort has been put into designing and employing effective solutions to aid in sleep studies. Statistics show that in fact, sleep apnea is not at all an unconventional disorder in Nigeria. According to Fawale *et al.* [20], aged people between 65 and 100 years were assessed and from their symptoms, their risks of suffering from obstructive sleep apnea (OSA) were evaluated. Over a quarter (26.7%) of the lower age range (65-74) manifested a higher risk of OSA, the percentage reducing at lower ranges with 19.3% for those within 75 and 84 and 10.7% for those above 80 [21]. Snoring, which is a prevalent symptom of the disorder has also been more associated with people of this age range [21]. However, many people are living with sleep apnea and are not aware of their condition, nor the predicaments that come with it.

Early recognition of OSA can help to improve the average adult's quality of life. According to Mbata and Chukwuka [22], it has proven to be one of the most common health issues with high morbidity and mortality, gradually rising in the past five decades. The need to design a reliable system for the detection of sleep apnea episodes cannot be ignored for long since it cannot be treated without a proper study. Several monitoring systems have been proposed to detect pauses in breathing, and initiate actions even such as sending vibrations to the patient to prompt breathing in cases of lengthened seizure [23].

The literature on apnea monitoring devices for crisis alertness and sleep diagnosis is almost in flux. Still, a common challenge confronting researchers for a long time is how to tackle inaccuracy in the apnoea-hypopnoea index (AHI) and provide effective cost solutions aid in sleep studies. For instance, Massaroni *et al.* [24] presented the achievement of non-contact monitoring using a single-camera video-based respiratory monitoring system. The use of pulse oximetry to observe breathing patterns is also seen in study conducted by Anderson *et al.* [11]. The two methods reflected factors such as the disparity in the AHI between polysomnography and sleep studies that do not include sleep stage measurements, in addition to the poor correlation between AHI and daytime symptoms such as sleepiness. In more recent times, apps on smartphones – incorporated with motion sensors – have been designed to provide low-cost sleep monitoring. The duration of the phone's clock is used to measure the length of sleep period [25]; this method is, however, not very efficient. The proposed apnea monitor in this study will retrieve data from respiratory movements in the abdomen during sleep which will also be displayed on a liquid crystal display (LCD) and sent real-time to a mobile device via Bluetooth. It can further be plotted for easier sleep assessment, displays the apnea count, effectively, which can be used to determine AHI, and saved for future analysis. The device is also equipped with an alarm system, which will be activated with different tones, once the ascribed length of exhalation time (10 seconds) is exceeded, depending on increasing duration of the crisis. This design allows for home automation, is more comfortable and cheaper compared to many other methods employed in sleep health diagnosis.

According to the study carried out by Fawale *et al*. [20], the criteria for the highest likelihood of OSA was found to be met by roughly one in four people (23.2%) in the sampled population. Furthermore, most people who experience this condition over time have proven to be at higher risks of other severe health issues [26]. Hence, the issue OSA must be given utmost attention.

This study will be of great assistance to those who cannot make out time for regular sleep diagnosis at a hospital, it also has capacity to alert individual or a caretaker whenever an apnea crisis occurs for too long. Cost is another limiting factor which is tackled by this design. PSG customarily costs between a thousand and two-thousand dollars a night [27].

PSG is the primary standard for diagnosing OSA and other sleep disorders. The sleep study is a test used to track record of brain waves, blood oxygen levels, eye and limb motion, breathing and heartbeat in the body. This information can be used to deduce the average number of AHI during sleep [28]. There is however, a general lack of resources and cost in its implementation because of the variations of data required. However, modern methods of sleep diagnosis are more simplified, incorporating fewer sensors which make them generally more comfortable for the users.

A report based on research of some home automated OSA examination devices reviewed their different approaches and performance. Due to changing technology, modern methods of diagnosing apnea can hardly be categorized following the approved American Academy of Sleep Medicine (AASM) parameters for portable OSA assessment which was published in 1994. For this reason, the paper discusses a more effectual approach; sleep cardiovascular oximetry position effort respiration (SCOPER) which is more suitable for classifying these methods into six different variables [13].

- Sleep: the sleep disordered breathing index largely depends on the basis of measurement (per sleep time or per recorded time).

– Cardiovascular: obtained physiological signals are used to determine the index used for identification of respiratory events.
– Oximetry: focused on detecting oxygen saturation in the blood.
– Position: can be visual (with the use of a camera) or non-visual (e.g.: ultrasonic) tracking of patient motion.
– Effort: indicates measurement of ease of respiration.
– Respiratory: any method involving quantification of airflow.

2. Materials and methods

Design, coding and construction are key concepts in the implementation of the wireless apnea monitoring system which is required to sound an alarm whenever a pause in breathing is detected and also transmit the sensor values wirelessly to a logging application. The breathing pattern is represented by voltage signals which can be sent to any appropriate device when the device is connected via Bluetooth. The system is sub-divided into four major functional blocks given in Figure 1. The sensor, control, the alarm system, and displays.

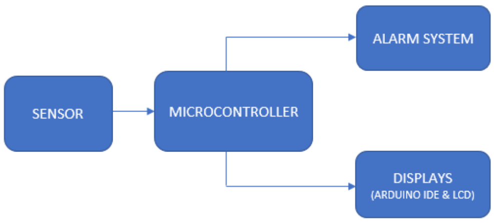

Figure 1. Design block diagram

The sensing unit is basically the vibration sensor module which generates digital high and low signals that are fed to the digital input on the microprocessor board. The alarm system is made up of the Arduino Uno Board, including the written code, the light emitting diode (LED) and the buzzer through which the alarm is sounded. The displays are interfaces which show the result of analysis in the microcontroller. The liquid crystal display shows breathing status and apnea count while the Arduino integrated development environment (IDE) serial plotter displays the graph in real-time. Communication is achieved to the LCD using an inter-integrated circuit (I2C) interface linked to the microcontroller. The Arduino Uno board also interacts with the mobile device using the Bluetooth module.

Using a vibration sensor module, the detected vibrations which are converted to voltage signals are transmitted and fed to an Arduino Uno microcontroller. A program is written on the Arduino Uno to monitor these values and determine when breathing stops which will be used to trigger the alarm. The microcontroller is also connected to a Bluetooth mod-ule which establishes connection with a mobile device hosting the Arduino IDE application to which the sensor values are also transferred them.

2.1. Mode of operation

The monitor was designed using the following steps:

1) The sensor detects vibration which represents either inhalation and exhalation or when the user is not breathing.
2) This data is fed to the microcontroller digital inputs.
3) A code is written on the microcontroller to analyze the data.
4) On the LCD, the breathing as status of the user is displayed, as well as the apnea count. The apnea count is necessary for sleep diagnosis and can be used to determine AHI.
5) Apnea crisis is specified to begin at 10 seconds after breathing has stopped. So once this limit is crossed, the buzzer begins to sound a monotonous alarm and the red LED lights come on. When this interval crosses to 20 seconds, the alarm tone changes to signify that the user’s condition is critical. The disturbance is not necessarily loud enough to wake the user, but is capable of rousing them in order to trigger breathing. As soon as the person begins to breathe again, current the buzzer and LED is shorted.
6) For better monitoring and record keeping, a Bluetooth module is connected to the microcontroller to enable devices connect to it. This data can then be extracted from the serial monitor and the graph can also be seen in real-time showing the apnea count and breathing rate. The flow chat diagram and circuit diagram of the design are given in Figure 2 and Figure 3 respectively.

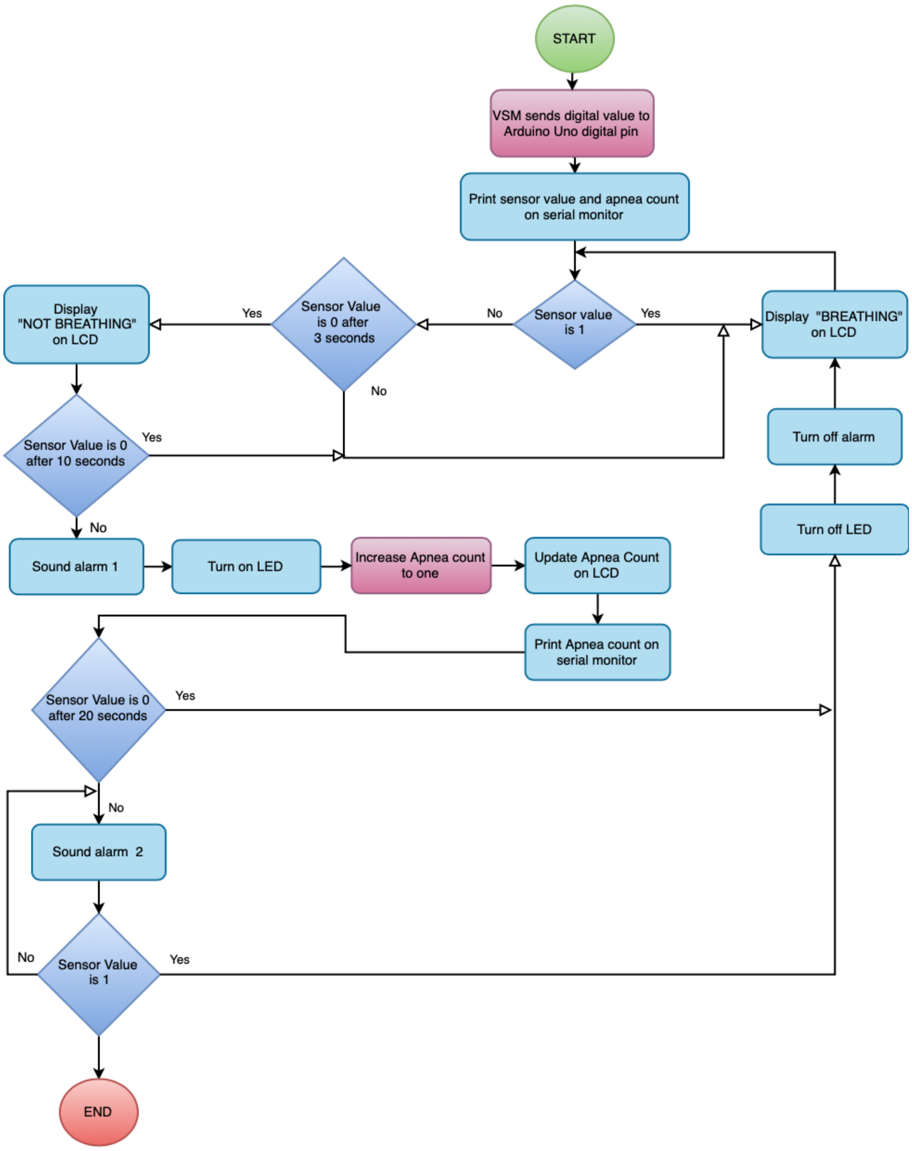

Figure 2. Flow chart of the proposed apnea monitor

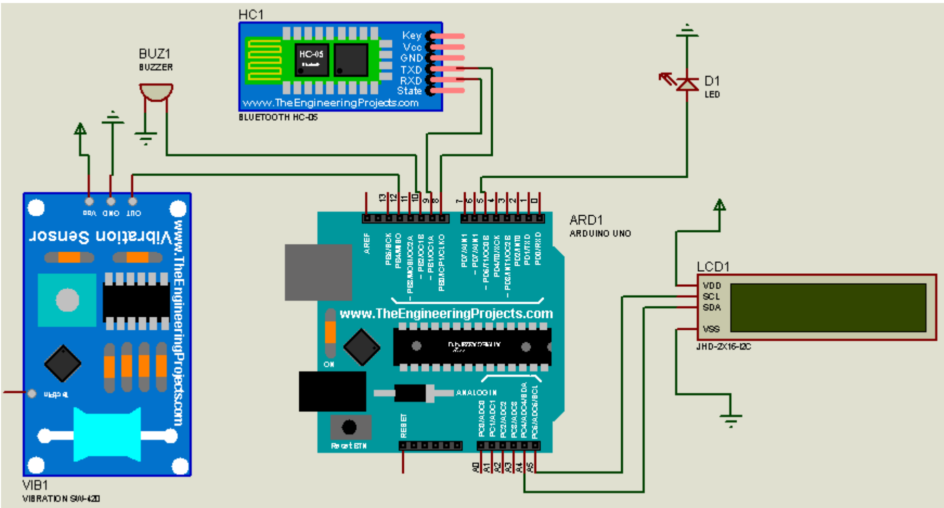

Figure 3. Circuit diagram of the proposed system

3. RESULTS AND DISCUSSION

The circuit of the apnea monitor was first patched on a breadboard and the code was written and uploaded to the Arduino. Several resistors were placed in series with the buzzer until a suitable volume was reached. After the code was tested and adjusted, the circuit was moved to the vero board where the necessary components were soldered as shown in Figure 4. The butts of the hardened lead, as well as exposed metallic ends were insulated with black plastic tape.

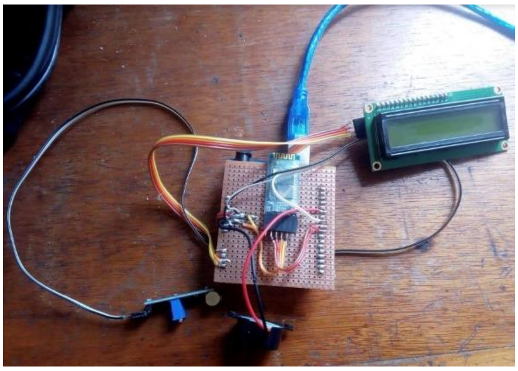

Figure 4. Complete soldered circuit

3.1. Testing

Testing is important to ensure that the circuit is functioning properly and can serve its intended purpose. Several tests were carried out on the individual components using the Arduino IDE software. The entire circuit was also tested.

3.1.1. Testing the 801 s vibration sensor module

This test was carried out by checking the sensitivity and delay of the vibration sensor. After applying from high to low vibrations, the serial monitor displayed the results using a simple test code. The sensor showed acceptable response time and detected all vibrations as shown in Figure 5.

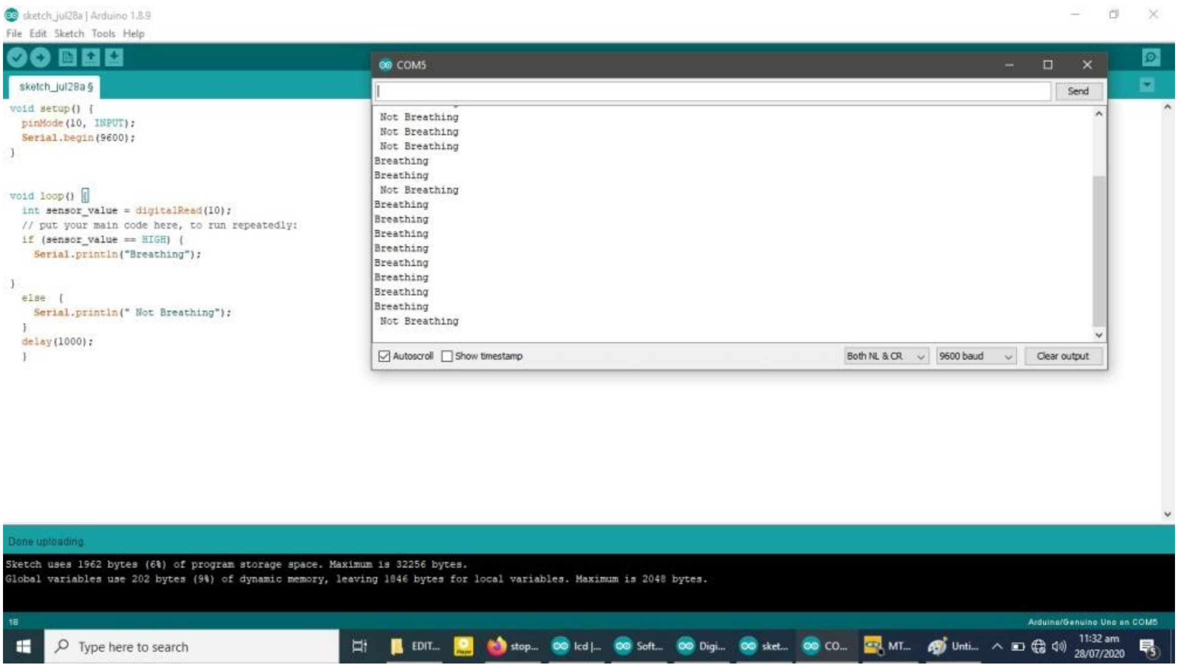

Figure 5. Arduino IDE test on the 801S VSM

3.1.2. Testing the LCD
Shorter intervals were used in the range of 3 to 6 seconds. The intervals greater than 7 seconds were used to test the response of the LCD. The overall test was carried out to confirm the functionality of the LCD as shown in Figure 6.

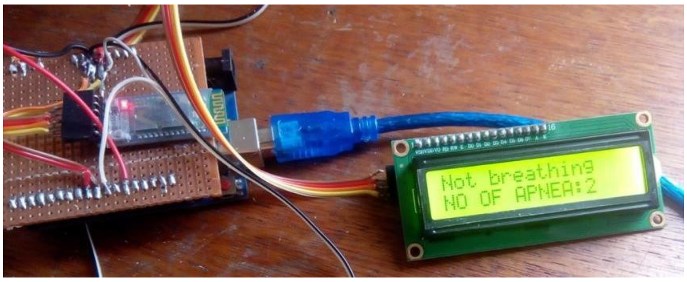

Figure 6. LCD showing correct output

3.1.3. Testing the completed circuit
After confirming the functionality of module, all the modules were properly assembled as shown in Figure 7. The entire circuitry was tested to confirm desired output. Thereafter, assembled was properly packaged together in a suitable case.

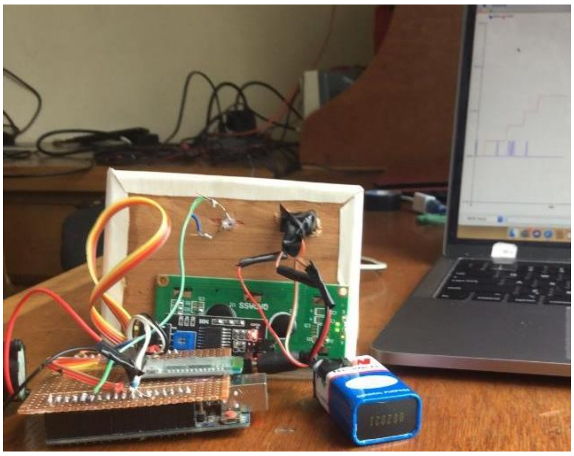

Figure 7. Final circuit testing prior to packaging

3.2. Packaging
The circuitry was packaged in a thin, wooden box laid with Formica. The lid was etched with holes to carry the LCD, LED and switch. The packaging gives allowance for switching ON and OFF as shown in Figure 8.

Figure 8. Fully packaged apnea monitor

4. CONCLUSION

This study is aimed at designing an effective low-cost solution to apnea monitoring, and the proposed approach was a successfully implemented monitor device, which is efficient and cost effective, for sleep apnea pre-diagnosis and provides distress measures in event of prolonged apnea crisis. It is generally made for domestic use as a preventive measure before deciding to undergo costly, long sleep hours in hospitals. It also gives the user a general idea of his/her OSA status, a good indicator of sleep health. The report covered basic information on OSA monitoring and diagnosis; introduced the work, discussed previous works closely related to the topic as well as the methods used in achieving the design and finally, explained the tests carried out to ensure proper functionality of the implemented system.

The designed system is capable of calculating AHI to a reasonably accurate degree. The system offers answer to whether further treatment is required by the user. As AHI increases, the person is more likely to develop other health challenges. Real-time data logging was achieved for further analyses. The system can be improved by including internet of thing to achieve remote access to data. Likewise, sensors like pulse oximeters can be incorporated to improve the quality of resolution assessment.

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