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A New Methodology for Monitoring OSA Patients Based on IoT

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Abstract:
The Greek word "apnea" literally means "without breath". Sleep apnea is an involuntary cessation of breathing that occurs while the patient is asleep. Obstructive sleep apnea (OSA), also called obstructive sleep apnea syndrome, occurs when the upper airway suffers repeated episodes of complete or partial blockage during sleep. During an obstructive sleep apnea episode, the diaphragm and chest muscles work harder to open the obstructed airway and pull air into the lungs. Breathing usually resumes with a loud gasp, snort, or body jerk. These episodes can interfere with sound sleep. They can also reduce the flow of oxygen to vital organs and cause irregular heart rhythms. Left unmonitored and untreated, OSA can ultimately turn into a life-threatening disease. Today as Internet of Things (IoT) becomes a much needed reality, people have a desire to see their daily used smart-gadgets perform more and more tasks, especially in helping them live a healthier, active and better life. Gone are the days of the technologically challenged generation. People are now aware of different devices and applications that help track, monitor and analyze different health metrics which can prove really effective in diagnosing various life-threatening diseases. This paper proposes a new methodology based on the IoT to help monitor patients with Obstructive Sleep Apnea (OSA) and similar life-threatening diseases.

Keywords: *Internet of Things, Wearables, OSA*

1. Introduction

In today's world where time is more than a luxury, people, especially the working class, spend most of their day shuttling between various tasks and in the bargain ignoring their health and fitness. Imagine the time required to seek an appointment with the physician, visiting his clinic for consultation, running a set of diagnostic tests, waiting for the results of those tests, buying the prescribed medicines from the chemist. This puts off many people from regularly monitoring their health unless some serious ailment creeps up. Especially dangerous are sleep-related diseases which may not even be noticed by the patient but can prove to be fatal.

Obstructive sleep apnea (OSA) is one such sleep disorder in which breathing is briefly and repeatedly interrupted during sleep. The "apnea" in obstructive sleep apnea refers to a breathing pause that lasts at least ten seconds. OSA occurs when the muscles in the back of the throat fail to keep the airway open, despite efforts to breathe. When this happens, the patient may snore loudly or making choking noises as he/she tries to breathe. The brain and body becomes oxygen deprived and the patient may wake up. This may happen a few times a night, or in more severe cases, several hundred times a night. OSA can cause fragmented sleep and low blood oxygen levels. For people with OSA, the combination of disturbed sleep and oxygen starvation may lead to chest pain, irregular heartbeats, hypertension, heart disease, stroke, diabetes, depression and mood and memory problems. OSA also increases the risk of drowsy driving which can prove fatal. OSA often goes undiagnosed. Doctors usually can't detect the condition during routine office visits. Also, no blood test can help diagnose the condition. Most people who have OSA don't know they have it because it only occurs during sleep. A family member or bed partner might be the first to notice signs of OSA.

How about having just one device worn over the body which not only continuously monitors your sleep-patterns in real time but also provides timely insights on various health parameters to you as well as your physician, thus giving you the freedom to spend your time productively at other activities without worrying that your health is not being monitored. This is exactly what Internet of Things (IoT) is capable of doing in the health and fitness domain. Gartner [1] describes the IoT as the network of physical objects that contains embedded technology to communicate and sense or interact with the objects' internal state or the external environment. IoT describes a system where items in the physical world, and sensors within or attached to these items, are connected to the Internet via wireless and wired Internet connections [2]. These items (or "things") maybe smartphones, sensors, ATM kiosks, televisions, vehicles, security badges etc. and they all communicate with one another forming an interconnected superhighway of sharable data. In November 2014, International Data Corporation (IDC) forecasted that the worldwide IoT market is expected to grow from $1.3 trillion in 2013 to $3.04 trillion in 2020 with a compound annual growth rate (CAGR) of 13%. Also the installed and connected base of IoT units will reach approximately 30 billion in 2020 [3]. According to a 2015 survey conducted by Infonetics Research, 42% of survey respondents expected wearables to be connected to their networks by 2016 [4]. In April 2011 Cisco IBSG predicted that by 2020, 50 billion devices will be connected to the Internet with the number of connected devices per person going up to 6.58 from 3.47 in 2015 [5].

This paper seeks to propose a new methodology based on the IoT to help monitor patients with Obstructive Sleep Apnea (OSA) and similar life-threatening diseases.

2. Concept

Internet of Things (IoT) is a network of embedded sensors, usually, but not always, enclosed within wearable devices, that communicate wirelessly with different web-based services and also the cloud through a IoT gateway, such as a smartphone or a tablet. Sensors usually connect to the gateway via NFC, Bluetooth, ZigBee, USB or Wi-Fi and in the health domain they capture vital parameters like health, fitness, wellness and behavior of the user and send them to the cloud for further processing. The intelligence in the cloud computes analytical results based on these input parameters and presents them to the user in a series of well-defined stats and visualizations.

ABI Research has identified six kinds of wearable devices: smart glasses, cameras, smart watches, healthcare, sports and activity trackers, and 3D motion trackers [6]. Of these, fitness and health wearables often merge together many, if not all, device sensors and technologies to design a unique wearable that is small, easy to wear, comfortable, has good battery life and easily connects to the cloud and other online health and fitness services.

For example, a body-sensors network meant to monitor physical activity of aging people measures motion, vital signs, unobtrusiveness and a mobile unit collects, visualizes and records activity data which can be tracked by the relatives and the doctor. Or a patient-monitoring system with comprehensive patient statistics could be available for remote residential monitoring of patients with chronic diseases resulting in reduced medical center admissions, lower costs, and shorter hospital stays. Or vital signs monitoring of sportspersons which help measure exercise, steps, sleep, weight, blood pressure, and other statistics which can be tracked by the coach [7]. The possibilities are endless and the usefulness and adoption rate of such devices will only increase as the technology becomes more evolved and cost of sensors and processors reduce drastically and connectivity becomes a standard feature in these low-cost devices.

3. Architecture and Protocols

3.1. Architecture of Internet of Things

In the generalized IoT architecture in the health domain, the various wearable devices and sensors capture user body data and also external parameters in a secure manner and transfer this data to the cloud via the internet gateway. The "intelligence" in the cloud makes use of different complex algorithms and repository of health records to analyze this data and come up with analytical results which can be shared with the user and also with medical professionals for making critical and timely health recommendations.

3.2. Protocols Powering the Internet of Things

For IoT, wireless connectivity is very much essential if optimum performance is desired from them. This wireless connectivity can be achieved by utilizing several wireless protocols and standards powering the personal area network (PAN) devices like Wi-Fi, Bluetooth, ZigBee, USB, NFC etc. Among these, the most important is Wi-Fi. It is perhaps the most widely deployed wireless technology in homes and workplaces worldwide and provides easy cloud-based connectivity. It is also supported in various smartphones, tablets and PAN devices worldwide making it currently the most go-to standard for the IoT.

Bluetooth is widely used in devices which strive for power efficiency. But connectivity range can be an issue as the Bluetooth 4.0 technology has a practical range of approximately 30 meters. The cloud-savvy Bluetooth 4.1 specification, a recent update to the low-energy and IoT-friendly Bluetooth Smart, is meant for faster setup of connections and lesser manual intervention along with a higher bulk data transfer capacity thus greatly enhancing its usability. The reconnection time interval for Bluetooth devices is made variable and flexible [8]. Devices can now reconnect automatically, without user intervention, when they are in proximity of one another thus allowing IoT manufacturers and users to have better control over such devices. Along with bulk data transfer, this feature is very useful for people using health and fitness wearables who are constantly on the move. Once they reach their home or office, the wearable can automatically reconnect to the other devices to upload the captured fitness data or directly upload it to the cloud. This is possible by incorporating Bluetooth 4.1 into routers or set-top boxes, which can receive this Bluetooth data and redirect it to cloud services via a basic software layer in the gateway equipment. This eliminates the need for hubs like smartphones or tablets as the Bluetooth device can now function as a hub. Also Bluetooth Smart sensors can now use IPv6 [8], thus ensuring that Bluetooth will become the fundamental wireless connectivity standard for IoT.

ZigBee is another PAN-based specification of a group of wireless communication protocols that has enabled many implementations of wireless sensor and control networks. Unlike Bluetooth, however, ZigBee does not come with native support on smartphones, tablets and laptops. ZigBee also requires a relatively sophisticated software stack, meaning node costs could be higher. On the other hand, ZigBee offers the advantage of being part of a large mesh network with architected arbitration and identification. A mesh network can talk to many other devices in the network, not just one. The result is that each data packet communicated across a wireless mesh network can have multiple possible paths to its destination. The result is that if one device fails, the others can continue their communication without any sort of interruption. In fact devices bearing the ZigBee logo can work together without any hassles even if they are from different manufacturers. Also power consumption is very low for ZigBee devices and sensors. But what could perhaps revolutionize the IoT domain and in turn, IoT, is ZigBee Green Power [9] which works for battery-less devices running on harvested energy like switches, sensors etc. which can securely connect to the existing ZigBee networks without any complications. These sensors and devices can harvest energy [10] from various sources like motion, light, vibration etc. Without a need for battery replacement, these

sensors can now be used in various health and fitness wearables especially for aged people who may find the process of replacing batteries tiresome and complicated, especially when such devices are supplemented with a poor and incomprehensible user manual.
Then there are higher level protocols that focus on application data transfer and processing that data, like, the Constrained Application Protocol (CoAP), Message Queue Telemetry Transport (MQTT), Data-Distribution Service for Real-Time Systems (DDS), Extensible Messaging and Presence Protocol (XMPP), Advanced Message Queuing Protocol (AMQP) etc. Each protocol has a specific design objective. CoAP is meant to connect a large number of devices and sensors to a lossy network using a request/response approach. MQTT is designed and developed to collect data from devices and send it to the server. DDS connects a diverse set of devices using a fast bus offering detailed quality-of-service (QoS) control, multicast, configurable reliability, and pervasive redundancy. XMPP connects devices to people using XML text format as the native type and runs over TCP. AMQP connects servers to one another by means of transactional messages. A detailed and analytical description of all these protocols is beyond the scope of this paper.
Among all these protocols, one of the most widely used IoT higher level protocol is MQTT which is a light-weight, publish/subscribe protocol intended to replace the high bandwidth requiring HTTP thus providing a better user experience, lower running and development costs and higher scalability and flexibility. The idea behind it is to collect data for many mobile devices and transport it to the existing data processing infrastructure. Thus monitoring and controlling such small devices and sensors from the cloud becomes easier and a large network of many such sensors can be easily supported by one MQTT server. What also makes MQTT ideal for mobile devices is due to of its small size, low power usage, minimized data packets, and efficient distribution of information to one or many receivers in devices having low bandwidth and low battery power [11].
One of the more recent protocol is Thread developed by Google Inc's Nest Labs. It is a IPv6 wireless networking protocol which does away with the drawbacks of older protocols like lack of interoperability, no support for IPv6 communications and high power requirements reducing battery life. Some advantages of the Thread mesh network over its counterparts include its low energy consumption, its secure infrastructure and the fact that it is IP-based, meaning it uses existing IPv6 technology to connect devices together. Thread can also support over 250 devices per network with easy cloud access [12].

4. Internet of Things: Helping OSA Patients

Major health and fitness wearable and device manufacturers are now providing innovative sensors and SDKs for designers and developers. This enables them to design and implement new breakthrough applications which can provide revolutionized ways to monitor and diagnose different health, fitness and wellness parameters of both, the young and old. This is especially useful for people who are health-conscious and want to keep a close track of the vital health statistics of themselves and their dear ones. Proposed below is a new methodology that can guide the future direction of the IoT, making it a life-saving system.

4.1. Monitoring and Analysing Sleep Patterns of OSA Patients

During sleep, various physiological changes occur in our body. Many physiological variables, like, temperature, blood pressure, and levels of oxygen, carbon dioxide, and glucose in the blood, are controlled when the person is awake at levels that are optimal for the body's functioning. During non-rapid-eye-movement (NREM) sleep, increased parasympathetic tone and decreased sympathetic activity cause a decrease in the heart rate, blood pressure, and cardiac output [13]. Obstructive sleep apnea (OSA) is a type of sleep-disordered breathing (SDB) that is caused when the soft tissues around the upper airway collapse leading to halting of air flow during sleep despite a increased ventilatory effort. Studies have shown that people diagnosed with OSA are likely to die from a sudden cardiac arrest between 12 AM to 6 AM due to a pronounced decrease in heart rate [14], [15], [16]. In fact 14.6% of the deaths in sudden cardiac arrests occur in the said time period [17]. OSA can also cause a rise in the patient's blood pressure due to depletion of oxygen levels in the blood and may eventually lead to a stroke [18]. Myocardial Infarction (MI), better known as heart attack, is another cause of sudden death during sleep whose vital signs include increase in heart rate, blood pressure and body temperature [19], [20].
A monitoring and preventive methodology, meant for early and timely diagnosis of such medical cases, can be designed based on the IoT, as shown in Figure 1. The OSA/MI patient can be made to wear a small health monitor which can be modeled as a wrist band or a sticker, before going to sleep. This monitor accurately measures vital human body parameters such as heart rate, blood pressure, body temperature among others. This band can now be connected to various other devices and sensors such as the patient's, physician's and caretaker's smartphones and the online cloud-based health records and profile via Bluetooth and Wi-Fi. When the heart rate of the patient falls below a certain threshold during NREM sleep or when the blood pressure rises abruptly, the sensors in the wrist band detect this and can sound off an alarm or start vibrating in order to completely wakeup the patient or at least bring the patient to the consciousness level so as to stabilize the breathing rate. A similar effect can also be achieved by increasing the brightness in the room. The patient's physician and caretaker can also be promptly informed of the fall in the patient's heart-rate and spike in the blood pressure to enable them to take emergency medical action and necessary precautionary measures. Periodic updates can also be uploaded into the patient's health profile on the cloud thus providing easy access to all pre-authorized persons interested in the patient's well being. Even medication prescriptions, dosages and timings can be programmed into such wearable devices.
Similarly, by studying the correlation between a patient's heart rate and body temperature while asleep and the room temperature at that moment, IoT can help in understanding the effects of the room temperature on the sleeping patterns of the patient. As the patient goes into deep sleep, his body's core temperature drops. Keeping this in mind, the recommended sleeping temperature is around 65-72 degrees Fahrenheit [21]. It has also been observed that a cold weather results in disturbed sleep due to a reduction in the duration of the REM stage [22]. This can be made possible by interconnecting the sensors of the air conditioner (AC), room heater, dehumidifier and/or the fans in the room and the heart rate monitor with the cloud via the smartphone gateway. This helps in finding the optimum room

temperature and humidity level during the different phases of sleep for the patient from the patient's cloud-based health profile. Also the quality of sleep can be ascertained by the physician after interacting with the patient and the gathered information can be stored in the patient's profile to form a correlation between sleep quality, heart rate and room temperature. This helps in determining the right sleep-inducing temperature for the patient. Next time the heart rate monitor detects the heart rate and immediately sends periodic updates to the cloud via the gateway. This update period can be dynamic and decided by the healthcare professionals. The intelligence on the cloud recognizes the shifts in the sleeping phase based on the heart rate and breathing pattern and sends a real-time instruction to the device or smartphone, who then adjusts the AC temperature via an IR blaster so as to bring the temperature of the room to a predefined level without waking up the patient.

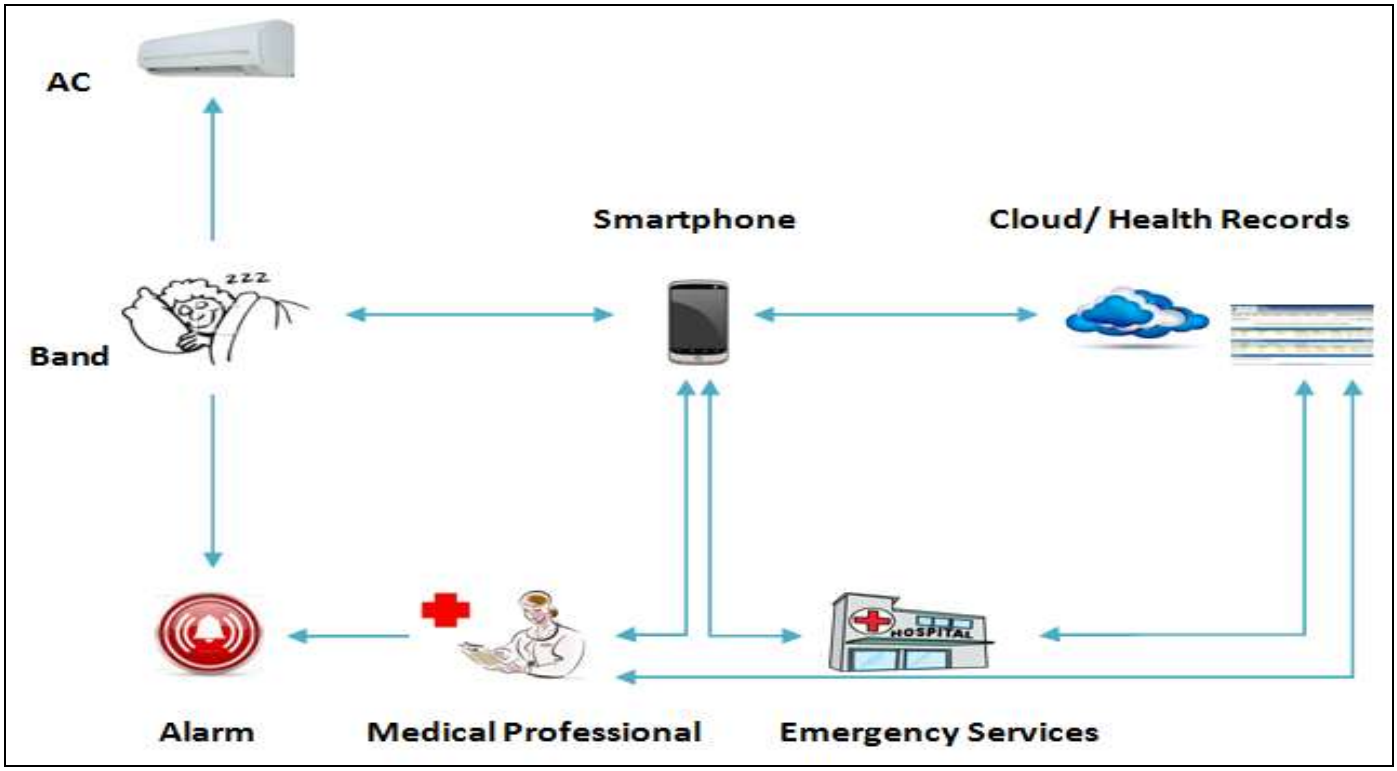

Figure 1: OSA-Patient monitoring and preventive system using IoT

The above mentioned methodology can also be extended in the case of Sudden Infant Death Syndrome (SIDS), one of the leading causes of death in babies aged between one month to one year. This happens suddenly when the baby is in sleep. Poor sleeping practices and environments such as overheated rooms and increased body temperatures due to excessive clothing are one of the leading causes of such infant deaths [23]. In fact the American Academy of Pediatrics in its guidelines to reduce the risk of sudden infant death syndrome (SIDS) has suggested that the infant's body and room temperature should be at a comfortable level [24].
Fatal Familial Insomnia (FFI) is a rare hereditary and incurable disorder causing difficulty in sleeping, motor dysfunction, and eventual death. The early stages of this disease are an increase in the body temperature, breathing and heart rates, and systemic blood pressure. By using the proposed methodology along with other medical tests, early diagnosis of this disease is possible which can prove beneficial in increasing the lifespan and quality of life of the patient [25].

5. Conclusion

Internet of Things (IoT) is now fast emerging in the health and fitness sector as a force to reckon with. It caters to not only the youth in achieving their fitness goals, but also to the old, especially in cases to severe ailments. By putting all sensor data to proper use, we can come up with various health visualizations and statistics that can be beneficial to all concerned. As sensors and devices are getting cheaper by the day, and SDKs are becoming freely available, manufacturers are encouraging developers and designers to come up with unique health and fitness apps and devices that can revolutionize the health industry. Governments and MNCs can also play a very crucial role here by investing in IoT R&D and thus ensuring the smooth and gradual transition of IoT from a premium and luxury device to an essential and affordable one.

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