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Stress detection and relief using wearable physiological sensors

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Abstract

The aim of the paper was to present a concept and to develop a prototype in the form of a cap which uses a combination of physiological sensors that work in concert to not only detect high stress levels in a person during his daily routine and working env ironment, but also initiate immediate relief measures. The parameters used to detect stress were compared with resting heart rate and brainwave activity to determine whether the person wearing the cap is in a stressed condition. Stress alleviation was achieved using Auditory Stimulation and a Scalp Massage. Early detection of stress and its immediate remedy or reduction can play an important role in preventing mental health disorders. In order to make the product cost effective, the concept of sensing optimum amount of data to trigger a remedial action was given more importance than extensive data collection using large number of sensors. Integrating an IOT device will further allow information to be recorded and transmitted to a caregiver/doctor to prescribe remedial action and thus prevent the condition to take a pathological form or get complicated. The detailed analysis of the collected data can help people identify the precipitating factors for stress and thus aims at reduction of stress related illnesses.

Keywords: *auditory stimulation, beats per minute, electroencephalogram, physiological sensors, wearable IoT*

1. Introduction

Medical literature suggests that stress can be a trigger to many medical, psychological and behavioural conditions [1]. Early detection of stress and remedial action can go a long way in preventing associated morbidity, mortality and economic loss. Advances in technology have made it possible to detect stress by the use of devices with physiological sensors that can be worn. These devices identify and decode bio-signals produced by the human body under both normal and stressful conditions. Further linking these devices with the internet can help gather, share and store information in the cloud for further analysis by a specialised decision-making system. Remote monitoring and analysis of stress patterns thus, becomes an integral part of the solution to stress elimination.

It is known that resting heart rate [2-5] and electroencephalogram [6-9] are the primary bio signals that can be analysed for stress diagnosis. While most of these devices detect stress, they do very little to alleviate the symptoms of stress and those that focus on alleviation, leave out the detection parameters. Once diagnosed, stress can be alleviated by methods of auditory stimulation and neuromuscular massage [10-16]. Further, in case of an emergency information needs to be transmitted to friends/relatives/doctors for immediate medical assistance: instances where a device of this type can be really helpful but there is little evidence of development of such a prototype in literature. This paper tries to address the aforementioned issues by:

a. Developing a prototype to integrate physiological sensors that work in concert to detect high stress levels in a person and provide stress relief.
b. Exploring the practicability of connecting the prototype on to an IoT network so that the users can be remotely monitored for health patterns and additionally sending alert messages to the users/caregivers/doctors for immediate action.

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2. Development of the Prototype

2.1. Physiological Parameters and Their Measurement

Physiological sensors can identify, measure and record physical, chemical and biological activity in the human body using transducers. Our prototype used sensors to assess two parameters: resting heart rate and brainwave signals to serve as optimum data points for detection of stress.

2.2. Resting Heart Rate

Resting Heart rate is the heart of person when he/she is calm, sitting or lying down. This is the parameter considered for stress detection. Normal heart rate varies according to age and gender, but the general range lies between 60-100 beats per minute [2, 4]. It is measured with the help of a PPG (photo plethysmography) sensor. Pulse rate above this value indicates a stressed person. However, a heart rate lower than 60 beats per minute is not of much concern. The normal range of heart rate is a function of age, body size, heart conditions, physical activity of the person, medication use, air temperature and several other factors. Emotions too can have an impact on heart rate; for example, getting excited or scared can increase the heart rate. The stress levels are easily detected with the help of the ranges in the Table 1 given below, PPG (photoplethysmography) sensors use a light-based technology to sense the rate of blood flow as controlled by the heart’s pumping action.

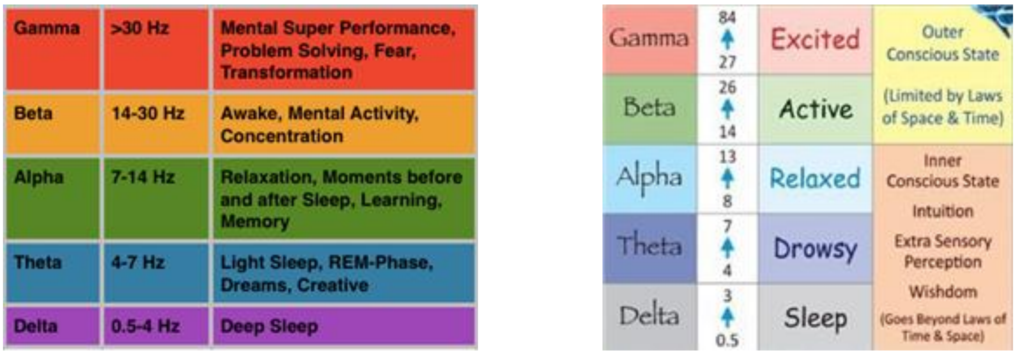
Table 1. Resting Heart Rate Values for Men and Women, Courtesy: NIH

				Males			
Age in years	Athlete	Excellent	Good	Above Average	Average	Below Average	Poor
18-25	49-55	56-61	62-65	66-69	70-73	74-81	82+
26-35	49-54	55-61	62-65	66-70	71-74	75-81	82+
36-45	50-56	57-62	63-66	67-70	71-75	76-82	83+
46-55	50-57	58-63	64-67	68-71	72-76	77-83	84+
56-65	51-56	57-61	62-67	68-71	72-75	76-81	82+
>65	50-55	56-61	62-65	66-69	70-73	74-79	80+
				Females			
Age in years	Athlete	Excellent	Good	Above average	Average	Below average	Poor
18-25	54-60	61-65	66-69	70-73	74-78	79-84	85+
26-35	54-59	60-64	65-69	70-73	74-78	79-84	85+
36-45	54-59	60-64	65-69	70-73	74-78	79-84	85+
46-55	54-60	61-65	66-69	70-73	74-77	78-83	85+
56-65	54-59	60-64	65-68	69-73	74-77	78-83	85+
>65	54-59	60-64	65-68	69-72	73-76	77-84	85+

2.3. Electroencephalogram (EEG) Signal

An EEG can track and record brain wave patterns. Brain cells communicate with each other in the form of electrical impulses. Electrodes in the form of metal discs are attached to the scalp. The electrodes analyse the electrical impulses in the brain and send signals for recording the results. Brain waves are further divided into alpha, beta, gamma, theta, delta depending upon the frequencies they exhibit. Stress detection is closely related to the study of the beta waves that lie in the frequency of 12-30 Hz [6, 7]. Whenever the brain focuses on cognitive tasks and the outside world Beta brainwaves dominate our normal waking state of consciousness when attention is directed towards cognitive tasks and the outside world. The brain shows high beta wave activity when we are alert, attentive, engaged in problem solving, judging, decision making, or involved in mental activity as shown in Figure 1 [16]. The electroencephalogram gives a meditation value, in the range 0 to 100. If this meditation index value is below 40, then person is said to have a lower meditation or alertness level, thus suggesting a stressed state of mind.

The values keep fluctuating with every action the body does. This includes breathing, concentrating or even blinking. Statistical methods are used to determine whether the person is actually stressed. So, instead of focussing on one value, the focus is on the number of times the value falls out of range before concluding that a person is stressed.



Gamma	>30 Hz	Mental Super Performance, Problem Solving, Fear, Transformation
Beta	14-30 Hz	Awake, Mental Activity, Concentration
Alpha	7-14 Hz	Relaxation, Moments before and after Sleep, Learning, Memory
Theta	4-7 Hz	Light Sleep, REM-Phase, Dreams, Creative
Delta	0.5-4 Hz	Deep Sleep

Gamma	84 ↑ 27	Excited	Outer Conscious State (Limited by Laws of Space & Time)
Beta	26 ↑ 14	Active	
Alpha	13 ↑ 8	Relaxed	Inner Conscious State Intuition Extra Sensory Perception Wishdom (Goes Beyond Laws of Time & Space)
Theta	7 ↑ 4	Drowsy	
Delta	3 ↑ 0.5	Sleep	

Figure 1. Human brain waves frequencies and pattern

3. Prototype Working and Architecture

This section describes the components used in the prototype and their contribution to the module. It also describes the reasons why certain parameters or components were preferred over others.

3.1. Working

Data is acquired from the wearable physiological sensors which are connected to the micro controller unit. The employed processing algorithm matches real time information with predefined validated values to check for deviations to conclude whether a person is stressed. The controller sends a signal to coin vibration motor located at strategic points to relieve stress. In addition, signalling is done to DF Media Player (DFMP) which stores binaural beat music on an SD card and plays it when triggered and thus, causes auditory stimulation to alleviate stress. This sensor data can be seen on a screen or can be transmitted to the cloud for monitoring and analysis via the Wi-Fi transceiver module attached to the controller as shown in Figure 2.

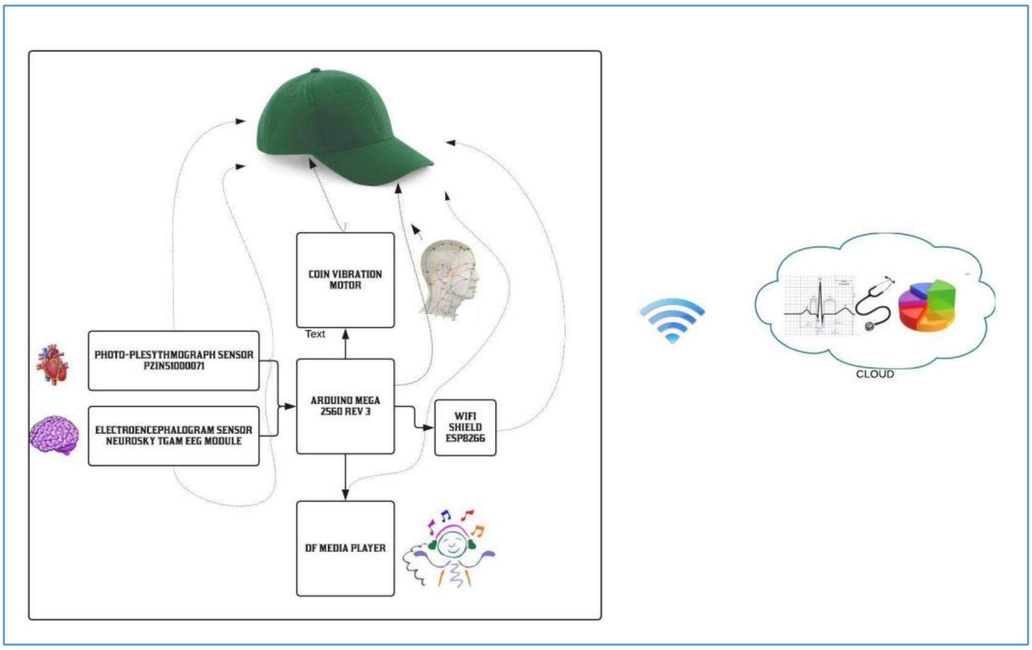


Figure 2. Prototype block diagram

3.2. The Micro Controller Unit and Architecture

The micro controller unit (MCU) used is the Arduino Mega 2560 REV 3. It is responsible for sensor data collection, decision making and activation of remedial functionality. The MCU is also responsible for providing an interface to Cloud/IoT as shown in Figure 3. It has 54 digital input/output pins (of which 15 can be used as PWM outputs), 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. The Mega 2560 board is compatible with most shields designed and back compatible with boards that existed formerly which was the basis of the choice.

The prototype is powered by SUNCA 6v 4.5ah. It provides extra proof against corrosion, overcharging, gassing, water usage, and self-discharge, all of which shorten battery lifestyles. It has a large electrolyte reserve area above the plates. Possesses better cold Cranking Ampratings and requires little or no protection.

Table 2. Relationship between X and Meditation Level [6, 9]

Value	Attention State	Result
X>=25	Poor Attention	Stressed
10<=X<25	Medium Attention	Calm
X<10	High Attention	Very Calm

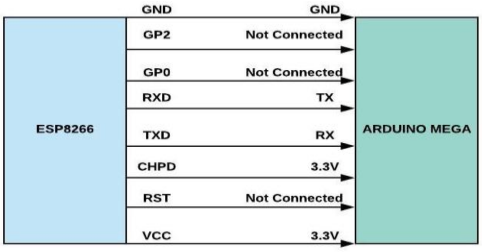


Figure 3. Wi-Fi Interface Schematic

3.3. Decision Making Algorithm

The inputs from the two sensors were checked for deviations from their mean values to check if a person is stressed. Data from the PPG sensor is analysed for resting heart rates given in beats per minute. The value is compared against a look up table that is mapped to the respective class and age group. The data from the EEG sensor was analysed for a parameter known as the meditation value. This value lies in the range of 0 to 100. When below 40, it becomes a cause of concern as shown in Table 2. Since the statistical approach is used to be sure of the results, the logic evaluates the number of times the meditation value falls below 40. If this count is greater than 25, then it is safe to conclude that the person is in stress. The algorithm flow chart can be seen in the Figure 4.

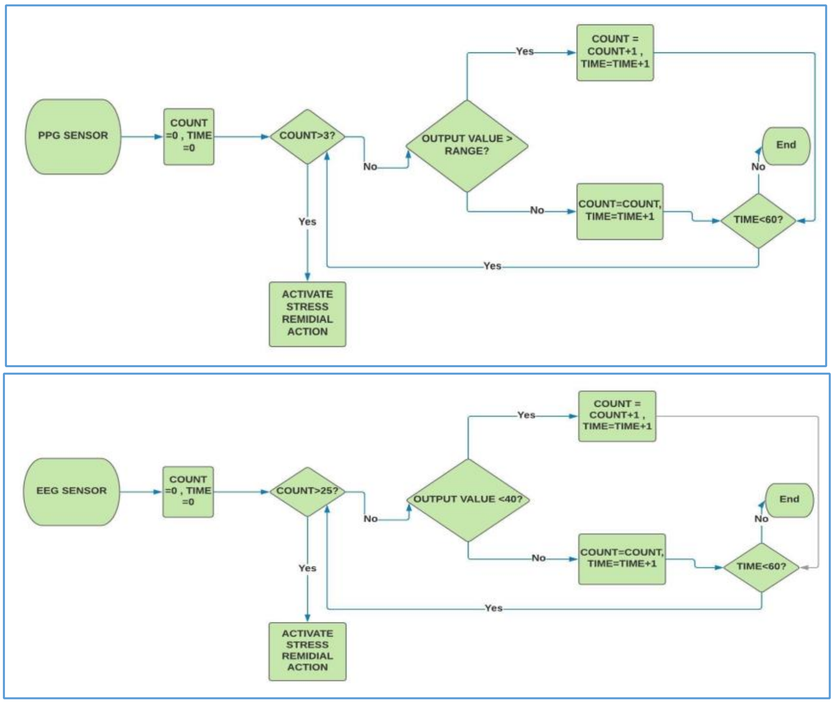


Figure 4. Decision making algorithm

3.4 Sensors

Physiological sensors acquire real time bio medical signals from the body. The photo plethysmograph and the Electroencephalogram sensors formed the basis of data collection as shown in Figure 5.

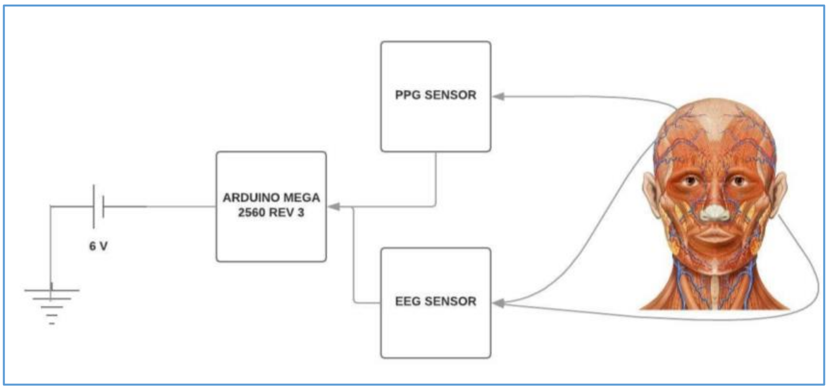


Figure 5. Input bio-signal sensors

3.4.1. Photoplesythmograph (PPG)

The PPG Sensor used was the PZIN51000071. It detects the resting heart rate in beats per minute. The value should approximately lie between the respective ranges for different age groups. A value lying outside this range more than thrice for the same subject indicates stress and mitigates errors due to fluctuations caused by error sources.

Electroencephalogram (EEG).

EEG sensor used was the NeuroSky TGAM EEG Module. It has a myriad of use cases including wearable sensors as it consists of dry electrodes as opposed to conventional medical wet electrodes. It contains two main electrodes out of which one is placed at the forehead and one at the earlobe for most effective data collection. Output from this sensor is a frequency spectrum that is analysed for characteristics of brain waves. The developed algorithm used the statistical approach for making conclusions. It counts the number of times the frequency of the output falls below a threshold value 40 for 25 number of times to make deductions from complex signals.

3.5 Stress Alleviators

The process of stress alleviation starts once it has been established that the subject is under stress. Deductions are made based on the algorithms that count on how many times sensor data deviates from the mean validated values for each bio-signal. The stress alleviation Schematic can be seen in Figure 6.

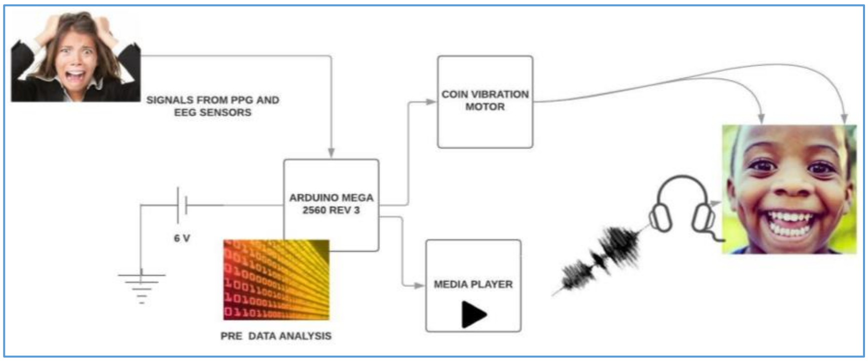


Figure 6. Stress alleviation schematic

3.5.1. Coin Vibration Motors

Neuromuscular massage at appropriate acupressure locations as shown in Figure 7 helps in relieving stress [15]. The coin vibration motors are used to mimic massagers. The massage point was identified one and half inch below the base of the skull on the ropy muscle one and half inch outward from spine. Massages at these strategic locations help in increasing brain circulation and thus driving the brain into a relaxed state Coin vibration motors of size 12 mm have an operating voltage of about 3V. Vibration specifications include a displacement of 1.5mm (p-p), frequency: 10~55 Hz, Acceleration: 22 m/s2 and a Period: 10 Minutes log sweep (10~55~10 Hz).

3.5.2. Auditory Stimulation

Auditory simulation has been proven to relieve stress. When sounds of two different frequencies fall on either ear, the difference of the frequencies is understood by the brain. This beat is known as a binaural beat as shown in Figure 7. The brain tries to synchronise with this beat and resonates with a frequency equal to the difference of the two frequencies falling on the ear. While this is done, the brain attains a calmer state that is the beta state [10-14]. Care must be taken that the difference between the frequencies falling on either ear should be in the range of 14-26 Hz for the brain to resonate to beta state. The DF Media player with a SD card contains binaural beat tracks that effectively relieve stress.

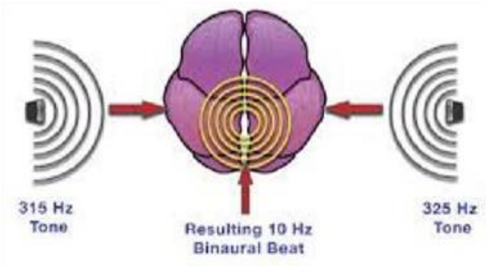


Figure 7. Auditory simulation using binaural beats

3.6 Data Transfer to Cloud and Analysis

The information is mounted on a Wi-Fi carrier to be uploaded on the cloud server [17,18] or an application that sources data from the cloud. Users can be monitored professionally and can seek medical help in no time. Furthermore, user information is analysed with the help of MATLAB algorithms to check for patterns that need to be corrected as can be seen from Figure 8 .Thingspeak was an open source IOT analytics platform that we used for our testing purposes.

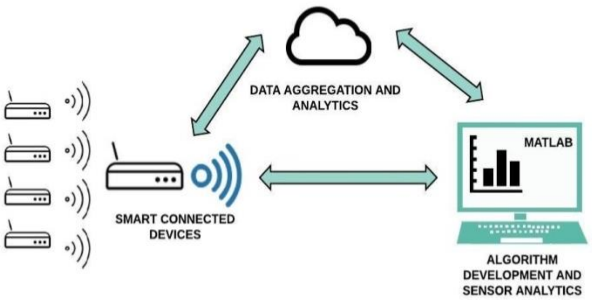


Figure 8. Cloud and Data Analytics

3.6.1. ESP8266 Wi-Fi module

This module was programmed as a shield to the micro controller to increase its data communication capabilities in a cost-effective manner. This couldn't be directly connected to the

MCU despite the presence of a 3.3 V pin in the micro controller. Direct connection would have yielded insufficient current to power the Wi-Fi module. Thus emerged a need for another higher power source that could be stepped down as per the requirements using a voltage regulator. A 5 V or a 10 V source could be easily stepped down with the help of AMS1117 chip in voltage regulators. The design has been shown in the Figure 9.

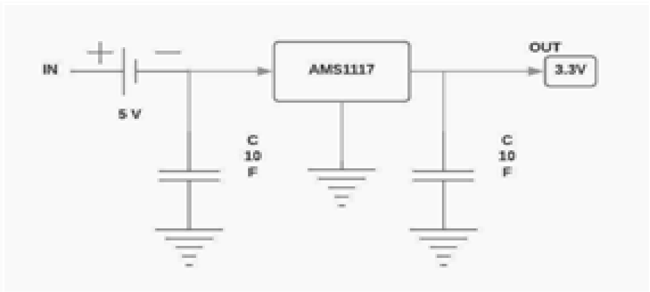


Figure 9. Voltage Regulation using AMS1117

4. Discussion

Stress measurement has been given significant importance and technological advances can help identify the most prominent factors that can precipitate stress under different conditions. Various Algorithms and computing techniques employing time domain and frequency domain measurements and sparse or nonlinear analysis can be applied for identifying different type of stress. Resting heart rate and EEG, being simple and non-invasive, have become one of the most popular methods for detecting stress [1-9, 17, 18]. The use of dry electrodes in the EEG sensors instead of conventional wet electrodes enhances the usability in simple devices, is very user-friendly, with low maintenance for mobile and wearable sensors. The concept of gathering and utilising specific data instead of accurate absolute large data resulted in not only cost reduction, faster, easier data analysis but the concept can be extended to local storage of data of longer duration in absence of IoT infrastructure or connectivity [19-25]. The monthly data can be downloaded as per requirement.

Due to use of optimised data collection and thus lower power needs, these modules can eventually be solar powered. Use of FPGA and similar technologies can help in not miniaturisation of these devices but also allow for deployment of newer derivatives, algorithm and implementation if more efficient sensors as the technology evolves. After the development of product, all that the users would have to do is have the cap on and the rest would be taken care of by the reliable and robust engineering [19] that constitutes sensors controllers and analysers.

5. Conclusion

The concept of development of a prototype with an embedded IOT device is an attempt to help people identify factors that trigger stress so that they can avoid them if possible or seek professional help.While most of the currently available devices detect stress, they do very little to alleviate the symptoms of stress and those that focus on alleviation, leave out the detection parameters. The focus of the developers is now to develop devices that can make more accurate measurements and more data processing capability.

This will lead to a significant increase in cost of such devices. Given that stress affects a large proportion of the population, simple low-cost solutions are needed. The authors feel that these devices need to be more sensitive than specific and should focus early identification and early action

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