Sleep Disorder Recognition using Wearable Sensor and Raspberry Pi

Vinay Kumar Chandna[1],
Senior member, IEEE
Prof. and Head Electrical
JSS Academy of Technical Education
Noida,

Sagar Narang[2]
Student Member IEEE
Final Year, MAIT Delhi

Yash Bansal[3]
Student Member IEEE
Final Year, MAIT Delhi

Abstract- Sleep analysis is usually done inside a sleep laboratory under close supervision of doctors with the help of cardiac rhythm using electro cardiography (ECG), breathing patterns, brain activities using electro encephalography (EEG), eye movement using electrooculography (EOG) and muscle activity during sleep. The data collected through these devices is thus utilized for further analysis and has uncertainty and noise. In this paper, a novel approach for sleep analysis is discussed with Raspberry Pi. Sample data is collected during night with the sensor attached to the patient's pillow and observations are made during various sleep stages. The data is also utilized for the calculation of sleep efficiency that is further divided into awake, light sleep and deep sleep percentage as shown by the hypnogram. This methodology helps us in easy analysis of quality of sleep and calculation of sleep debt. The methodology is useful for the patients who are unable to go to the hospital.

Index Terms— Accelerometer, ECG, EEG, Gyroscope, NREM sleep, Raspberry Pi, REM sleep, Sleep Analysis, Sleep Debt, Sleep Apnea ,Sleep disorder, Wearable sensor.

I. INTRODUCTION

Sleep is an essential natural activity that is useful to avoid fatigue, stress and keeps people healthy. One fourth of a life time is spent sleeping, approximated to 2,500 hours per year. Lack of sleep can affect the memory, immune system, cognitive functioning, learning abilities, and alertness and thus lead to poor work performance of an individual. Furthermore, researchers have found correlations between sleeplessness and certain diseases, such as heart disease and diabetes. [1]

There are several technologies made by the researchers for monitoring human sleep. Some of them require an artificial stimulated environment where in a patient is analyzed under several factors, for instance, cardiac rhythm using electrocardiography [ECG], breathing patterns, brain activities electroencephalography [EEG], eye movement electrooculography [EOG] and muscle activity during human sleep. These techniques are based on physiological signals from the human body [9] .However with as many as 55 sensors on a human body, the natural sleeping patterns of the patient is disturbed. Some of the methods are based on the patient's medical history and surveys. Thus, there is a need of an efficient way to remotely monitor human sleep in a natural environment. [4]

The normal human sleep is broadly categorized as:
1. Rapid eye movement (REM sleep) [3]
2. Non-Rapid eye movement (NREM or non-REM sleep).

Each type of these categories have distinctive set of physiological and neurological characteristics associated with it. Fig.1. shows the typical hypnogram that shows the average human sleep cycle with various stages viz. awake, REM, light, medium, deep and very deep[2] .The characteristics of the human sleep cycle is as shown in table-I.

Table-I: Typical characteristics of the common human sleep stages

Sleep Stages	Behavior
Awake	Conscious state of mind
REM Sleep	Dreams occur, muscles are turned off, provides energy to brain and body
Light non-REM Sleep	Occasional muscle twitching, Light decrease in temperature
Deep non-REM Sleep	Slower breathing rates.

The above table depicts various sleep stages in a human sleep cycle with their characteristic behaviors.
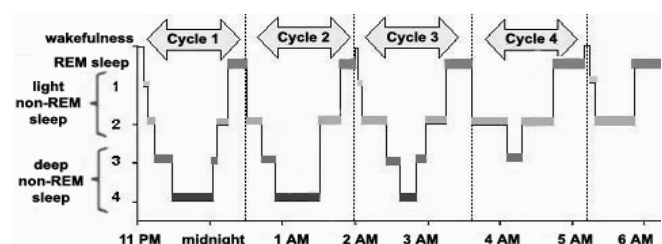

Fig.1. A typical Hypnogram representing various sleep cycles of a 7 hour sleep.

The recent innovations in technology has enabled us to decrease the size of the embedded devices with increased processing speed. To reduce stress, sound sleep is essential. Thus, making it necessary to monitor the sleep with the help of motion sensors. This paper aims at discussing a novel approach for the analysis of sleep disorder in a setup, at the patient's premises with the help of wearable sensor and Raspberry Pi. Sample data is collected throughout the

night with the sensor attached to the patient's pillow and observations are made. The data is also utilized for the calculation of sleep efficiency that is further categorized into awake, light sleep and deep sleep percentage.

In our study of sleep disorder, we collected 20-days subjective sleep-movement data which is considered as a parameter for sleep efficiency calculation. Then, efficiency report was prepared and further investigating if the data would allow us to recognize whether the patient suffered from sleep disorders or not. The Sleep Analysis Algorithm is based on the hypothesis that quality of sleep is directly related to the motion of patient during the sleep [10].

Sleep study and analysis has a lot of applications. Some serious ailments related to human sleep are as follows:
1. Sleep-related breathing disorders: Central Apnea Syndromes, Upper Airway Resistance Syndrome.
2. Sleep-related movement disorders: Restless Legs Syndrome (RLS),Periodic limb movement disorder
3. Sleep-related seizure disorders.
4. Common sleep disorders: Insomnia, narcolepsy.
5. Sleep-related night-time behaviors: Sleepwalking, Night Terrors, or bed-wetting.[6]
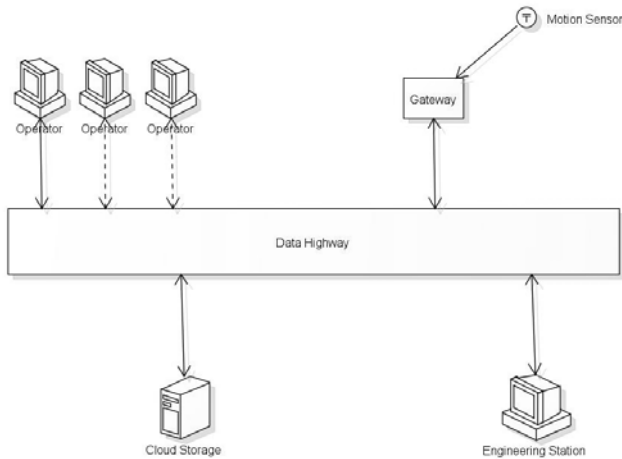
II. SLEEP ANALYSIS ALGORITHM

Fig.2. Typical architecture implemented in sleep analysis algorithm.

Data Collection:
The Raspberry Pi in combination with the gyroscope and accelerometer collects data from the motion of the patient. The motion sensor is attached to the pillow or the mattress of the sleeping person under observation. It gathers movement data throughout the course of sleep. The data collected during typical human sleeping cycles is stored on a cloud database using engineering station through a data highway.

Data Processing:
Precision tracking of both moderate and minuscule level motion is performed on the Operator machine. The output range of the wearable motion sensor (±1000) is transformed to an appropriate scale for computation. The sensor collects data on the 3-dimensional axis and the reading of these

individual axis is saved in to the database. The x, y, z axis values are intelligently analyzed and assimilated into a single float point entity using generalized mean. The algorithm classifies the sleep on the basis of degree of motion.
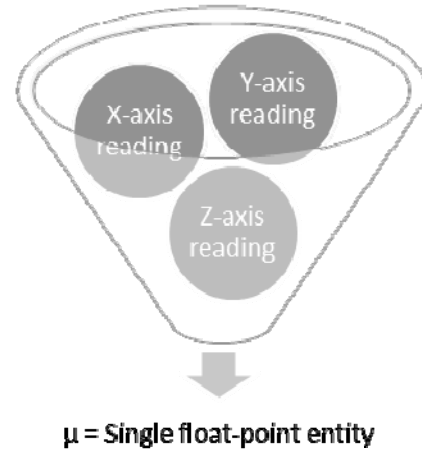

Fig.3. Assimilation of 3-dimensional axis reading into a single float point entity (μ) using generalized mean.

Data Classification:
 Based on the motion of the patient, the output values of the gyroscope are segregated into the following categories [7]:

1. *Awake*: Wakefulness is an everyday recurring state of consciousness in which a human being is conscious and engages in clear cognitive behavioral responses to the external world
2. *Light Sleep*: Lasting from 10 to 25 minutes, this is the first stage of factual sleep. The eye movement stops, heart rate slows, and body temperature decreases. About 70 to 90 minutes after falling asleep, humans enter REM sleep. The eyes move speedily, the heart rate and blood pressure increases and breathing patterns shallows. In this category, there is occasional muscle twitching.[3]
3. *Deep Sleep*: Sleep is a naturally recurrent state characterized by altered consciousness, inhibition of nearly all voluntary muscles and relatively inhibited sensory activity. It is differentiated from category-2 by a decreased ability to react to stimuli.

Data Aggregation:
The float point value (**μ**) is separated into its respective sleep categories (Awake, Light Sleep and Deep Sleep). These results are fed into the data operator for result formation, efficiency calculation and sleep disorder recognition.
Data Analysis:
Intelligent Algorithm
    Variables Used:
1.   X = Y-axis reading
2.   Y = Y-axis reading
3.   Z = Z-axis reading
4.   th1=Deep Sleep Motion Threshold
5.   th2=Light Sleep Motion Threshold
6.   β1 = Sleep_type_deep

7.   β2 = Sleep_type_light
8.   β3 = Sleep_type_awake
9.   α = Total value count
10.   TST = Total sleeping time
11.   TRT = Total recording time

$$\mu = \frac{1}{3}(\sqrt[3]{(\sum (x^3 + y^3 + z^3))})$$

if (μ>0 or μ<=th1)
          β1 = "DEEP SLEEP"
else if (μ>th1 or μ<=th2)
          β2 = "LIGHT SLEEP"
else if (μ>th2)
          β3 = "AWAKE"

The ratio between the total sleep time (TST) and the total recording time, or TRT, is called the sleep efficiency.

Total sleep efficiency $= \frac{TST\ (\sum \beta 1 \sum \beta 2)}{TRT} * 100$

Deep sleep efficiency $= \frac{\sum \beta 1}{\alpha} * 100$

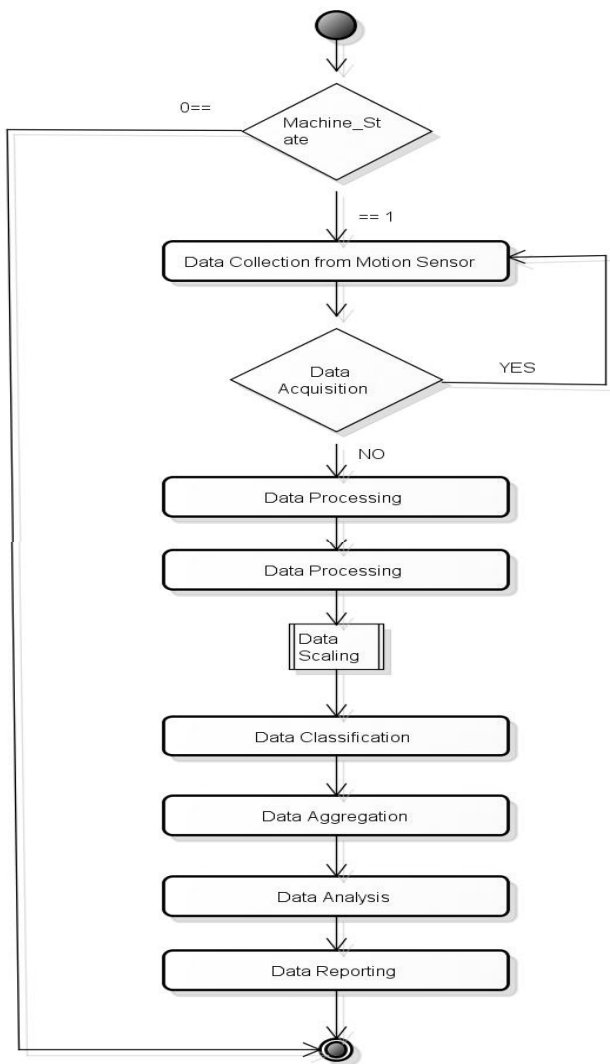Light sleep efficiency $= \frac{\sum \beta 2}{\alpha} * 100$

Fig.4. Procedural flow of Intelligent Algorithm

Data Reporting:
Data was collected over a period of twenty nights and it was represented as a graph (Movement V/S Time) for each night. The graphs represents motion of the patient during the night with respect to time, which is known as *Hypnogram [8]*. It graphically depicts the stages of sleep during the course of each night. After efficiency calculation for each night, a sleep disorder report for the patient was generated. The final report displays quantitative comparison among the each day sleep efficiency for the patient.

III. HARDWARE AND SOFTWARE DESCRIPTION
The Raspberry Pi B+ is a credit card-sized single-board computer, developed by the Raspberry Pi Foundation. Linux is the primary operating system supported by Raspberry Pi. The MPU-6050 is a 6-axis Motion tracking device consuming low power and providing high performance requirements of wearable sensors. The MPU-6050 sensor combines a 3-axis gyroscope and a 3-axis accelerometer on the same silicon die with an integrated Digital Motion Processor (DMP).

The sleep disorder analysis system uses Python for software code, R for statistical analysis and graph sketching, and SQLite3 as a database. R is programming language and software environment for statistical computing and graphics. The architecture stack for the system has been shown in figure 6.

The system constraints of the sleep disorder analysis system have been enumerated below:
1. System Power specification :Micro USB socket 5V, 2A
2. System CPU specification: 700 MHz Low Power ARM117
3. System Memory specification: 512 SDRAM
4. Wearable Sensor full scale range : ±1000
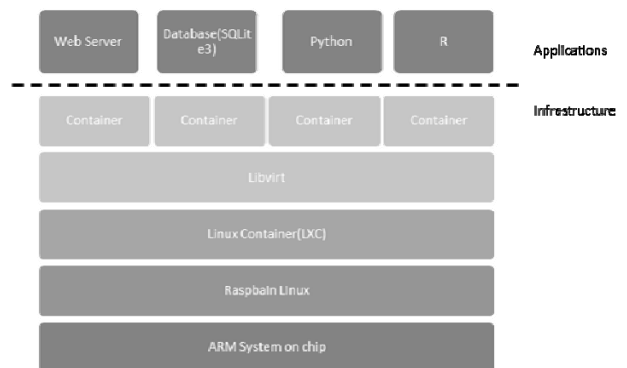5. Wearable Sensor power supply range: :2.375V-3.46 V

Fig.6. Architectural Stack for Sleep Disorder Analysis System

IV. RESULT AND ANALYSIS
The algorithm is implemented using the specified hardware and software system. The experiments were conducted for ten patients over a period of same twenty night. The Efficiency readings for each patient is computed

using the above algorithm. The *Hypnogram* (Time v/s Movement graph), as shown in fig.7 is plotted using a single night data for a patient (Day 1) [8]. The efficiency table (Table-II) stores the computed efficiency of the 5 patients over a period of 20 days.
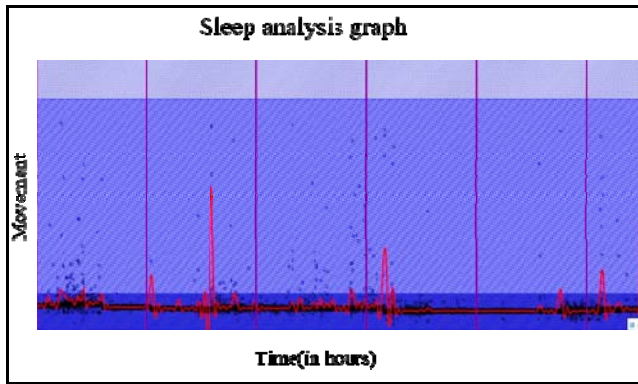

Fig.7. Hypnogram depicting sleep effectiveness for every hour.

Table-II: Sample data depicting the efficiency calculation of 5 patients for the duration of 20-days.

Day No.	Patient 1	Patient 2	Patient 3	Patient 4	Patient 5
1	79.85437	59.2815	55.1256	76.98767	35.1625
2	61.98531	64.83051	65.14629	78.98786	45.1565
3	69.57602	57.29577	58.4621	79.98769	54.63214
4	67.82065	63.97173	70.46132	74.5469	45.32555
5	58.21636	67.53699	50.16495	82.8754	50.4158
6	54.0575	71.21418	80.7652	81.9097	60.6316
7	57.81651	75.92418	60.73156	78.8954	52.6425
8	64.90366	73.497365	75.13246	75.7656	54.79654
9	69.80144	74.498265	45.1326	83.8754	59.43258
10	67.53622	78.65119	87.9809	85.9876	65.1254
11	70.56842	80.31279	68.8754	87.76557	57.6421
12	71.83502	80.24959	72.9876	67.9878	61.26547
13	76.83408	84.458764	85.09876	90.87986	68.1326
14	81.379	83.210358	88.90876	87.6568	63.162
15	76.88331	88.536811	76.98769	85.76789	66.1254
16	77.83654	91.773326	62.9876	88.8712	60.1325
17	83.50238	95.476898	81.98765	90.0981	60.1546
18	84.5308	93.452104	82.09876	91.1299	68.84236
19	82.883351	92.86735	69.09876	94.5429	67.1265
20	83.9345	94.86735	53.0975	95.43256	64.13654

The next step would be analyzing the efficiency report of each patient and comparing them to other patients. Two types of analysis were done here:

1 .Qualitative Analysis: The sleep efficiency gives us the quality of the sleep the patient is getting. Now, on carefully analyzing Fig.7. , Patient ID 3 and Patient ID 8 have the maximum discrepancy in their efficiencies.
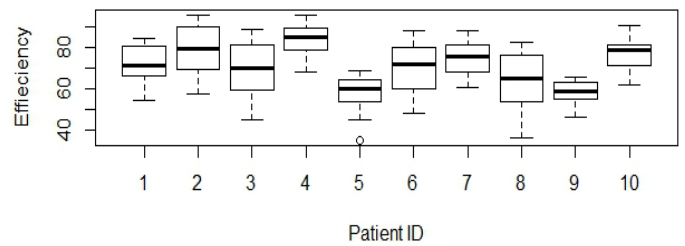

Fig.7. Boxplot comparing the sleep efficiency of 10 patients (Qualitative Analysis)

2. Quantitative Analysis: Effective number of sleeping hours were calculated using the following formula:
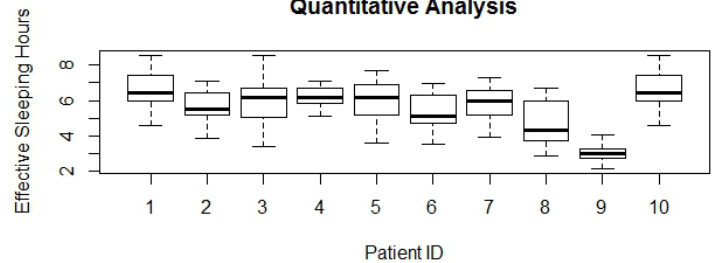*Effective Sleeping Hours = (Sleep Efficiency*Total Recording Time)/100*

Fig.8. Boxplot comparing the Effective Sleeping hours of 10 patients (Quantitative Analysis)

Analyzing Fig 8 quantitatively, Patient ID 9 and Patient ID 8 have the minimum average Effective sleeping hours.

V. CONCLUSION

The above sections shows two types of analysis done on patients for sleep disorder recognition. The qualitative analysis shows that Patient ID 3 and Patient ID 8 have the maximum discrepancy in their efficiency thus concluding that they have a very erratic quality of sleep.

The qualitative analysis shows that out of all the patients Patient ID 8 and Patient 9 were getting below average number of hours of sleep.

Thus, combining the results from both the analysis, it can be concluded that Patient ID 8 has confirmed sleep disorder and Patient ID 3 and Patient 9 have high risk of developing a sleep disorder.

Although these results are preliminary with limited number of participants, it revealed an effective technology for the analysis of sleep disorder with the help of wearable sensor and Raspberry Pi. While, the paper discuss the methodology for the calculation of sleep efficiency that is much more effective and can be used in a real time environment for detection of sleep disorder. With more extensive data and patient base from real time environment, people will soon be able to investigate their sleeping deficiency times and quality of sleep.

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