# Comparative Study of Different Sleep Monitoring Methods

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***Abstract :*** World Sleep Society statistics show that disorders such as insomnia, sleep apnea, and narcolepsy affect up to 45 per cent of people, creating increased demand for home-based sleep monitoring system. These disorders mean that people do not get enough rest, or have a generally poor quality of sleep, raising the risk of heart diseases, high blood pressure, diabetes and stress. Lot of efforts has been made in the advancement of Sleep Monitoring systems. Various techniques have been implemented and attempts have been made in order to increase the precision and accuracy of sleep data, which can be further analyzed to produce a sleep score or efficiency.

In this paper, different sleep monitoring methods have been analyzed and their comparison has been done on the basis of their complexity, accuracy, output etc.

***Index Terms* – Non- Invasive, REM- sleep, Non-REM sleep.**

## I. INTRODUCTION

Sleep is a type of "brain activity" and this activity has the purpose of recovering from brain fatigue. Sleep plays a significant part in relieving tension and recovery. Sleeplessness takes a toll not just physically but also emotionally. A decent amount of sleep is pointless when the brain is restless all along the time. Quality plays an equal role in the maintenance of sound mental health.

Good sleep quality can lead to many beneficial outcomes including improved physical health, decreased daytime sleepiness and improved psychological wellbeing. Deprivation of sleep can cause memory issues, depression, increase pain perception and weaken your immune system.

It is a fact that humans are spending one-third of their lives in sleeping. Therefore, sleep monitoring is important because sleep accounts for a third of our lives and also affects the remaining two-thirds. Sleep monitoring and tracking plays an important part in the diagnosis and treatment of sleep disorders. It also helps to maintain a healthy lifestyle, and to recognize sleep patterns and sleep cycle. Deep Sleep parameters such as NREM and REM sleep detection play a vital role in monitoring sleep and measuring quality of sleep. Other parameters such as Breathing Rate, Pulse, Brain waves also give better insight into sleep surveillance.

Numerous researchers have proposed various approaches to monitor sleep, some of them are:

1. Polysomnography
2. Using Motion Sensing Mattresses
3. Ubiquitous Sensor System
4. Using Seismometer
5. Infrared Cameras
6. Sleep Masks
7. 3-D Cameras

Such approaches, however, are expensive and often require overnight treatment in clinics. And not all methods use all the parameters required to satisfy those conditions. This can result in different performance from one method to another. Therefore, in recent times, technology has developed a lot of state-of-the-art concepts such as machine learning can improve monitoring techniques.

In this paper we are comparing different sleep monitoring methods comprehensively based on the parameters and devices used, availability, complexity of system, use of technology and feasibility for daily life use.

## II. DIFFERENT SLEEP MONITORING METHODS

Different Sleep monitoring methods that have been analyzed are as follows: -

## 1. POLYSOMNOGRAPHY

Polysomnography is the gold standard method for sleep tracking. This is a screening procedure for sleep disorders. Polysomnography is typically performed at a sleep disorders unit within a hospital or at a sleep center. The test tracks patterns in your sleep.

The doctor will measure the following during a PSG to help graph a person's sleep cycles:

- Brain Waves
- Skeletal Muscle Activity
- Blood Oxygen Levels
- Heart Rate
- Breathing Rate
- Eye Movement

To record this data, the technician will position small sensors called "electrodes" on:

- Scalp
- Temples
- Chest
- Legs

It is a non-invasive, painless test but because of the adhesive used to attach sensors to the skin, it can cause skin irritation. Elastic belts around chest and stomach will record breathing patterns and chest movements. A small clip on finger will monitor the oxygen level of the blood. The sensors installed on small, flexible wires transmit the data to a computer. Technicians will set-up equipments for making a video recording at certain sleep centers. This will allow the doctor to check the night-time changes in your body position. You are probably not going to be as comfortable in the sleep center as you would be in your own bed, so you may not fall asleep or sleep as easily as you are at home, but the output does not differ much.

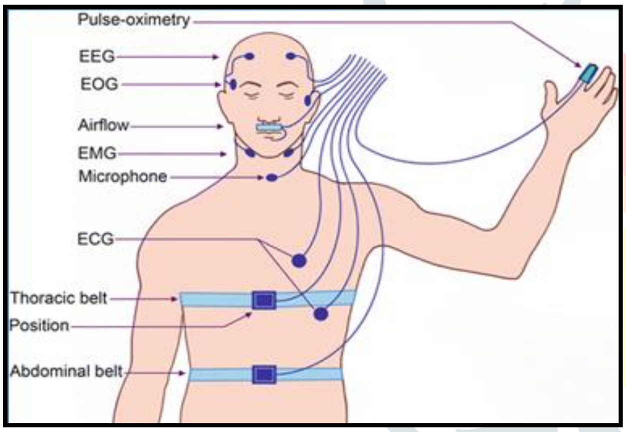


Fig.1.1: Connections in Polysomnography

| MEASUREMENTS | NO. OF CHANNELS |
|---|---|
| EEG | Minimum 3 |
| Air Flow | 1 or 2 |
| Chin muscle tone | 1 or 2 |
| Leg movements | 1 or more |
| Eye movements | 2 |
| Heart Rate & Rhythm | 1 or 2 |
| Oxygen Saturation | 1 |

Fig.1.2: Measurements and Channels required

Fig.1 shows the connections that are done in Polysomnography. It typically records at least 12 channels, and at least 22 wire attachments. Fig.2 illustrates the channels required for measuring various body elements. Wires lead from the patient into a central box for each channel of registered data, which in turn is linked to a computer network to capture, store and view the data.

PSG results can take up to about 3 weeks to obtain. A technician must compile the data to calculate sleep cycles from the night of the sleep test.

Polysomnography is a very complex test. It is a costly and uncomfortable sleep tracking test but its accuracy is high. It is also inaccessible, as the test can only be performed in hospitals or sleep centers and therefore does not give people the option to use it at home for sleep monitoring. It is a time-consuming test too.

## 2. Sleep Monitoring using a 3-D Camera

This non-invasive approach uses a 3D time-of - flight (TOF) camera to detect sleep stages from the respiratory motion recorded. After the patient sleeps his / her muscles relax and the degree of relaxation in each sleep stage is different. Abdominal muscle relaxation leads to slight variations in the movement of the abdomen in some regions. The signal of respiratory movement from all visible regions is extracted from 3D video recordings. It extracts the characteristic features of various sleep periods, comparing the correlation (coefficients) between different signals. Likewise, cases of obstructive sleep apnea are also observed.

The muscles become more and more relaxed during the various stages of sleep, and muscle tone is weakest during the Rapid Eye Movement (REM) stage. REM sleep is distinct from non-REM sleep, because at this stage the EEG is similar to the awakening stage, but at this point the body appears paralyzed. REM sleep also features the usual rapid eye movements recorded by the EOG. The 3D image recorded is broken down into twelve zones, shown in Fig. 2.1 and the average distance from the distance image to each zone is collected. The recorded signals are the variation of the mean distance to the chosen zones in time.

Fig.2.1: The distance image of the patient's body is divided into twelve zones;
Zone [1, 1] is darkened in the figure.

The measured distances change a lot when the body moves during the sleep period compared with respiratory motion. These body motions of high amplitude are greatly mitigated by filtering the signals.

A non-invasive diagnostic method is the sleep monitoring method, which is based on a 3D camera. The most significant result is the feature that establishes the transition from waking to sleeping. In general, belts with accelerometer sensors are used in PSG to monitor chest and abdomen respiratory effort. This 3D camera will be cheap and affordable for everyone in large scale production. The OSA algorithm for event detection is simple, and can be easily implemented. This can be enhanced by tracking the patient's movements during sleep. This method may also be used to screen for respiratory sleep disorders.

## 3. Sleep Monitoring using Pressure Sensor Mat

This method of sleep monitoring uses a low cost, disposable pressure sensor mat to monitor the user's sleep and movement. Fig. 3.1 shows Pressure mat tile. The design of the sensor mat is based on compressible foam sandwiched between two orthogonal conducting Paper (or C-paper) capacitance sensor arrays. C-paper is non-woven material where the loading of carbon fiber into matrix achieves electrical conductivity. The dielectric medium used between C-papers is foam. The combination of both is used as electrodes for the Capacitor sensor. A low-cost C-paper was designed for use as the electrode of the capacitance sensor. Typical mat design uses 3 mm thick foam with a 5 mm row / column grid pattern reveals it has a 0.1 PSI pressure measurement resolution. Both the changing properties of the conductive paper and the foam will control resolution.

Fig.3.1: Pressure Mat Tile

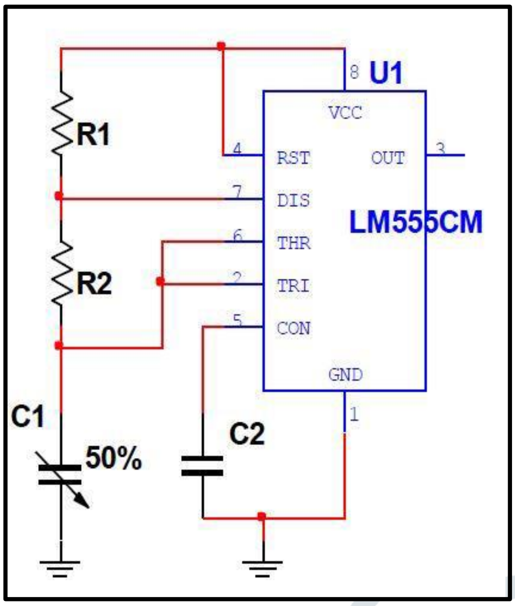


Fig.3.2: Astable Multivibrator Circuit

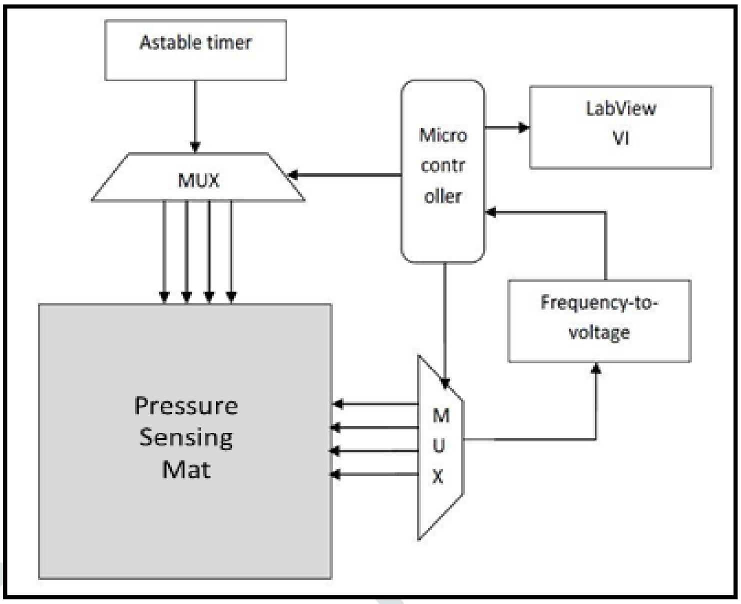


Fig.3.3: Block Diagram of the circuitry

Fig. 3.2 shows Astable Multivibrator Circuit and $C_1$ capacitance is the capacitance inside pressure sensing mat. When external pressure is applied, the foam compresses and capacitance changes due to electrode displacement at any point in the mat. Astable multivibrator output frequency changes due to capacitance change. The signal is amplified from an astable multivibrator and given to frequency to voltage converter. The micro-controller reads DC voltages and uses graphical interface to display outputs. Multiplexer scans with 20 Hz scanning frequency on rows / columns. Fig. 3.3 shows the block diagram of the circuitry of the sleep monitoring system.

This non-invasive sensor enables clinicians to collect data from in-home and community settings without disrupting the subject's routine sleep. The advantage of using C-Paper pressure sensors to monitor in-home sleep is that it can be used as a disposable mat that improves overall hygiene. Making large mats is easy by tiling different C-Paper mats, which is cost-effective, too. Usable and low-cost pressure sensors may also be used for imaging applications and general healthcare applications. This method uses only the pressure sensor and, therefore, only monitors the person's movement during sleep, so it is not an accurate method. In this process, only graphical analysis of sleep is performed, and output is not given in terms of sleep performance.

## 4. An Ubiquitous Sensor System for Sleep Monitoring

This design focused on reducing the number of sensors required, and utilizing non-invasive, feasible technologies. This approach presents ubiquitous architecture based on portability and interoperability principles in which a Smart Watch and a Smart phone are combined to incorporate a sleep monitoring system. This device incorporates heart rate, accelerometer, and sound signals into Smart watch. Smartwatch & Smartphone uses API to share data.

Audio signal is used to extract snore events during the sleep period. Heart Rate sensor is used to determine the heart beat rate of the user, which can be used further to predict sleep stages. Accelerometer is used to detect motion of the user during the sleep. The App provides graphical interface on the collected data including motion diagram including information on deep and light sleep period.

This study contributes to the concept of the sleep monitoring system architecture based on ubiquitous tools, i.e. Smartwatch & Smart phone, shown in Fig. 4.1. Smartphone includes a mobile app & a persistent database, while smartwatch includes a wear app for sensor data collection. Audio, ECG and accelerometer combine to sense simple sleep patterns such as amount of sleep hours, number of awakenings, and snore events etc. Fig. 4.2 shows the layers of the framework of API for communication and data exchange between the Smartwatch and the Smartphone .

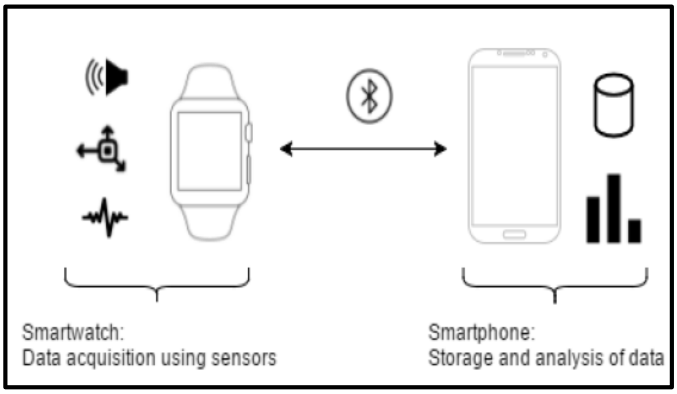


Fig.4.1: Ubisleep System Architecture

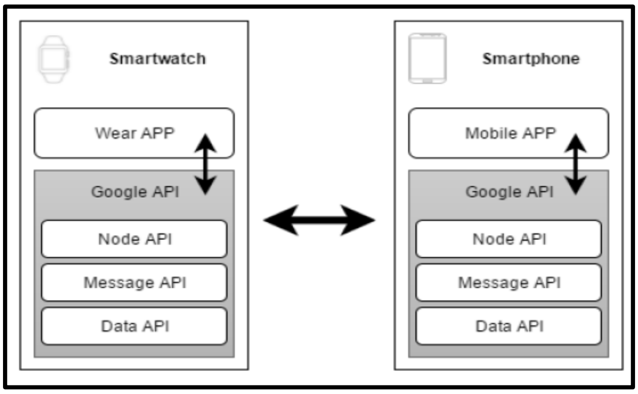


Fig.4.2: Framework Layers

However, some difficulties were observed, namely in designing and implementing the multi-tiered framework, mainly due to the challenge of putting all the different methods and concepts together. In addition , the development of both the wear app and the smartphone app posed many challenges not only in terms of system requirements, but also in terms of usability and user interaction due to the smartwatch's small screen dimension. This indicates the sleep monitoring system is very complex. Certain concerns that need to be discussed are: data transmission protection policies, the summary and/or optimization of storage data, and usability principles with a special emphasis on the user-friendliness of the smartwatch interface due to its reduced dimension. Such challenges and difficulties make this approach quite expensive.

**5. Sleep monitoring system using infrared cameras and motion sensor**

This approach includes developing and implementing a novel sleep monitoring device that analyzes respiration, head position and body posture at the same time. The system consists exclusively of cost-effective vision-based devices, operating in a quiet and non-contact manner with little natural sleep disturbance. Specifically, the sleep process is recorded via an infrared camera. The region of breathing motion is automatically determined from the infrared video, and the intensity is calculated, resulting in a waveform showing respiratory rhythms. Five additional infrared cameras are used to record the face of the subject from multiple orientations, and the matching of models is used to conduct head tracking. A Kinect motion sensor is often used to obtain skeleton description of body posture that is resilient to self-occlusion, and machine learning techniques are applied for classification of body posture after the noise is filtered.

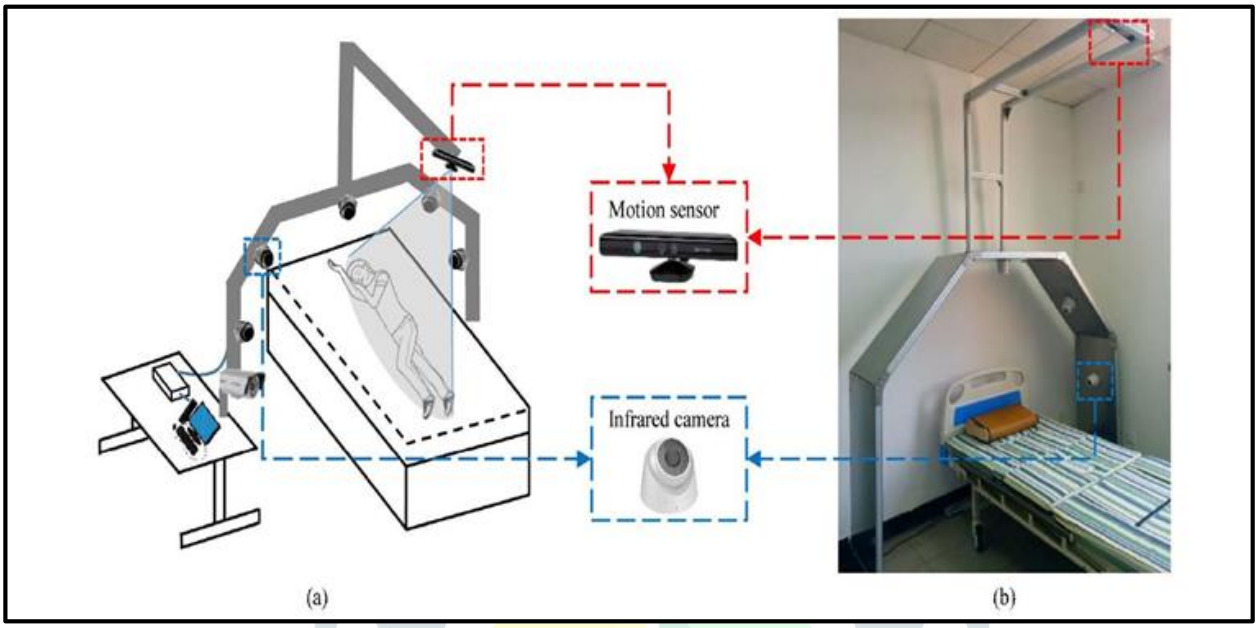


Fig.5.1: Overall Architecture of the monitoring system. (a) Blueprint of the system hardware. (b) Real scene.
The infared camera of the monitoring system is shown in blue rectangle, and the motion sensor Kinect is shown in the red one.

Fig. 5.1 shows the overall architecture of the sleep monitoring system. Blueprint of the system hardware is shown in Fig. 5.1(a). An arrangement of the infrared camera and Kinect motion sensor in real scenario is shown in Fig. 5.1(b).
Breathing and Body and Head Posture Analysis algorithms have been implemented in this method and data analysis software has also been used. Simulation Data set has also been collected from subjects in order to apply analysis algorithms.

This simple and efficient architecture allows the device to work properly and stably. Since no physical contact between the sensor and the subject is required and no precise targeting is assumed, the system is robust to the unconscious movements of the subject during sleep, and can be deployed in a regular home environment. Therefore, the subject can sleep peacefully and naturally without interruption from the monitoring device thanks to its peaceful and non-contact mode of activity.
True breathing anomalies with complex properties would require more sophisticated detection algorithms, however. The device will also fail if a thick blanket completely covers the subject. The breathing action under such condition would be too subtle for the algorithm to detect. The Kinect sensor also can not acquire accurate data about the skeleton. The system proposed is not cost-effective and the setting of apparatuses is very complicated. As visual assistance is needed, there is a lighting necessity that can cause disruption in sleeping for the patient.

**6. Sleep Monitoring with bed-mounted Seismometer**

During the sleep, a bed-mounted seismometer system was used to monitor heart and respiratory rates, and body movement and posture. An groundbreaking local maxima statistics approach and instantaneous property-based method for estimating heart and respiratory rates have been developed to efficiently monitor sleep status.

The body motions and movement can be registered and analyzed for determination of sleep quality by using Amplitude Abnormalities in the seismometer. The seismometer was mounted to the frame of the bed, which is non-intrusive and non-contact to the body. Raspberry Pi 3 was connected to the seismometer to process the data in real time. The bed-mounted seismometer is non-intrusive and non-contact, showing great potential for tracking sleep quality and status. Viewing the respiration and heartbeat are different human body rhythms; oscillatory components were extracted to estimate those body parameters. Instant property analysis method based on oscillatory analysis technique Synchro Squeezed Wavelet Packet Transform (SSWPT) and novel local maxima statistics was designed to estimate heart and respiratory rate.

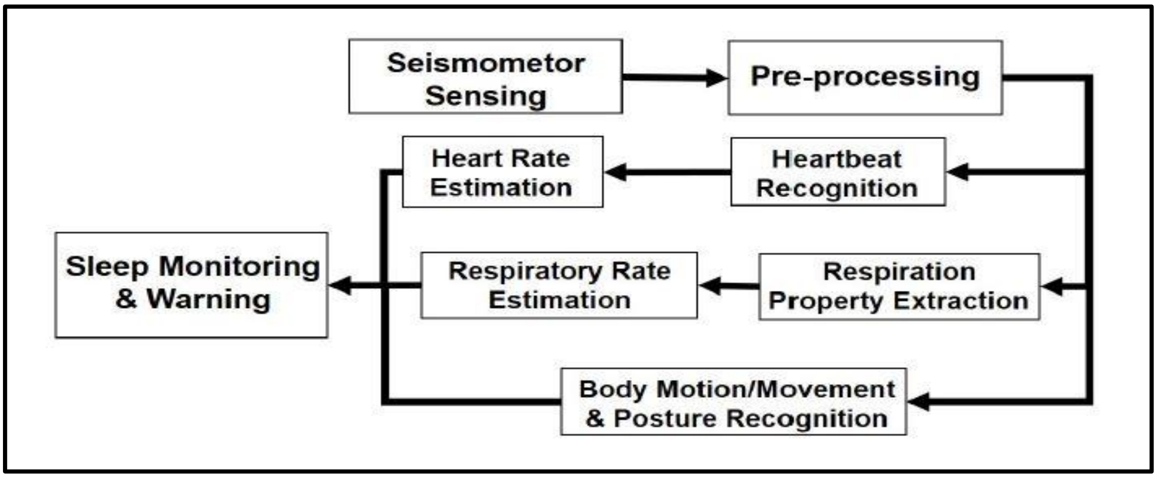


Fig.6.1: Sleep Monitoring system workflow

Fig.6.1 shows the workflow of the Seismometer based Sleep monitoring system. This method is more robust than others because it uses only one device i.e. seismometer for sensing heart and respiratory rate, as well as body movement and posture. This approach is relatively costly, though. To make the present program more sophisticated, Machine Learning & Deep Learning can be introduced.

## 7. Graphene-Based Sleep Mask for Sleep Tracking

This method has been basically devised to measure eye movements during sleep. In this method, Sensing electrode is placed into a commercially available eye Mask. To prepare the conductive material, a sending material is coated with Graphene Oxide and reduced. Conductive textiles are on a scoured and bleached nylon knitted fabric. The first step in this process is reducing a solution of Graphene oxide, functionalizing the solution, and then coating the textile material with this. Electrodes are created by sewing processed nylon fabric into a standard, off-the-shelf eye mask using non conductive polyester thread.

To investigate the output, two masks (Mask A and Mask B) were made. For horizontal movements, the second mask (mask B) uses two larger electrodes sewn on either side of the eyes, and one smaller reference electrode. Mask A has a hole cut into it to allow the participant to see a screen to follow the instructions given in the experiment, while the second one has been left as received. Fig. 7.1 shows the picture of prepared masks A & B.


Fig. 7.1: Sleep masks with grapheme-based nylon sensors sewn in, showing the view from back of the mask.

Electrical tape has been used to prevent the metal back of the snap connectors touching the skin.

(a) Mask A (note V+ and V- electrodes were not used in this paper) (b) Mask B

Using Unity, an eye-tracking experiment is set up on a PC to test the device. The program instructed the user to perform a series of voluntary blinks, as well as smooth eye pursuit movements that are accomplished by instructing the user to follow a moving ball with their eyes on the screen. The program also manages the timing of each of these acts to enable repeatable participant measurements.

This device can be used for EOG tests, and can detect eye blinks with a high SNR above 16 dB consistently. It has also shown that in certain situations, it can detect smooth eye movements of the pursuit. It has been found that the smooth pursuit eye movements were difficult to detect in many situations, possibly due to the difference in tightness of the mask strap between participants with different head diameters. Such electrodes, however, are only held in place with a regular elastic band, as opposed to conventional electrodes which are held on with an adhesive pad, providing greater comfort and ease of use for masks. The findings suggest that this material could be much more convenient than traditional methods for monitoring eye movements in REM sleep.

**8. Machine Learning Based Sleep-Status Discrimination Using a Motion Sensing Mattress**

This approach introduces a new paradigm of sleep-status discrimination by introducing a motion-sensing mattress that senses the movements of the user on the bed including the movement of head, arms, legs and feet. Unlike conventional methods such as Polysomnography (PSG) requiring user-connected electrical equipment, or like wrist actigraphy requiring user contact, the proposed system distinguishes sleep states in an unconscious and non-contact manner. The proposed system is developed in offline stage using a machine learning method, and by using designed sleep-status discrimination algorithm, it distinguishes sleep states in the online level. The experimental findings show that the proposed approach effectively differentiates sleep status without using a monitoring interface communication with the body or using hospital treatment of PSG.

Fig. 8.1: The test bed for field measurement

Fig.8.1 shows the test bed arrangement for sleep monitoring. Motion sensing mattress is adopted and called WhizPad, which is imbedded with 4 pressure sensing units to monitor the user 's movements on bed including head, arms, legs and feet movement. Once WhizPad senses a movement, it registers the event and outputs digital value ranging from 0 to 30 where 0 & 30 represents the lowest and highest values, respectively. Operation of the four parts is registered every 30 seconds and then transmitted to the server. PSG is often used to track the brain waves of the patient to differentiate between two sleep states: "Wake up and Sleep."

WEKA (Waikato Environment for Knowledge Analysis), is the machine learning tool used in this process. The proposed system of sleep discrimination can be divided into two levels, Offline and Online.

The priori awareness of user activities (recorded by WhizPad) and sleep states (identified by PSG) passes in the J48 Decision Tree (J48-DT) classifier for training and testing in the Offline process. In the online process, the findings in the offline stage from the machine learning framework are used to develop our algorithm for sleep discrimination. The output of J48-DT is used in the algorithm for compiling the table of decisions. The program must analyze the decision points in order to achieve the sleep condition "Awake" and "Sleep", according to the compiled decision table. In the online process, the activity signals reported by WhizPad are going through the mechanism of sleep discrimination to discern the present sleep state of the user.

The system's accuracy is high, but because it uses PSG to discern users' sleep cycles, this process is very costly and people may find it difficult to use this tool, because the whole system is not readily available. For rigorous performance field research , the proposed scheme will be applied with various machine learning techniques, such as Hidden Markov Model (HMM) and Long Short-Term Memory (LSTM), in future.

## III. COMPARISON

All the sleep monitoring methods mentioned above have been analyzed on the basis of parameters and devices used, availability, complexity of system, use of technology and feasibility for daily life use etc.

A comparison table (Table 1) is formed discussing all the parameters stated above.

Table -1: Comparison Table

| Parameters | Output Response | Complexity | Accuracy | Technology | Manufacturing Cost | Reliability | Feasibility | User Comfort during Sleep |
|---|---|---|---|---|---|---|---|---|
| **Poly-somnography (PSG)** | Graphical Output, Needs Experts analysis | Very High | High | Invasive / Non-Invasive | Very High | Very High | Low | Low |
| **3-D Camera** | Graphical Output | Low | Very Low | Non-Invasive | Low | Low | High | Moderate |
| **Pressure Sensor Mat** | Graphical Output | Moderate | Moderate | Non-Invasive | Moderate | Moderate | High | High |
| **Ubiquitous Sensor System** | Graphical & Numerical Output | High | High | Non-Invasive | High | Moderate | High | High |
| **Infrared Cameras & Motion Sensor** | Graphical Output | Moderate | Low | Non-Invasive | Moderate | Moderate | Moderate | High |
| **Bed-mounted Seismometer** | Graphical Output | High | High | Non-Invasive | High | High | Low | High |
| **Graphene based Sleep Mask** | Graphical Output | Moderate | Low | Non-Invasive | Moderate | Low | Moderate | Moderate |
| **Machine Learning Based Motion Sensing Mattress & PSG** | Graphical & Numerical Output | High | High | Non-Invasive | Very High | High | Low | Low |

By referring to the parameters in the above table, it was seen that every method has some advantages and disadvantages. Hence, in order to get a user-friendly, feasible, reliable and cost-effective system, trade-off should have to be done between reliability, ease of access and manufacturing cost. It is also concluded that Machine Learning algorithms can definitely increase the accuracy of the system.

## IV. RESULTS AND DISCUSSION

Different methods of Sleep monitoring have been studied and a comprehensive comparison of these methods was made. The conclusions from these methods are framed in a Table of Comparison. Comparison has been made on various parameters such as output response, complexity, accuracy, technology, manufacturing cost, etc.

Sleep monitoring is a very important part of human life, as sleep is a very important part of human life and accounts for one third of our lives. Such forms of tracking certainly benefited the current mankind. Nonetheless, Research is being conducted in the area of sleep monitoring, and in the near future, we will receive the best possible solutions.

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