Sleep quality assessment by parameter optimization

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Abstract. Sleep quality measurement is a complex process requires large number of parameters to monitor sleep and sleep cycles. The Gold Standard Polysomnography (PSG) parameters are considered as standard parameters for sleep quality measurement. In the PSG process, number of monitoring parameters are involved for that large number of sensors are used which makes this process complex, expensive and obtrusive. There is need to find optimize parameters which are directly involve in providing accurate information about sleep and reduce the process complexity. Our Parameter Optimization method is based on parameter reduction by finding key parameters and their inter dependent parameters. Sleep monitoring by these optimize parameter is different from both, clinical complex (PSG) used in hospitals and commercially available devices which work on dependent and dynamic parameter sensing. Optimized parameters obtained from PSG parameters are Electrocardiogram (ECG), Electrooculogram (EOG), Electroencephalography (EEG) and Cerebral blood flow (CBF). These key parameters show close correlation with sleep and hence reduce complexity in sleep monitoring by providing simultaneous measurement of appropriate signals for sleep analysis.

KeyWords: Polysomnography (PSG), Electrocardiogram (ECG), Electrooculogram (EOG), Electroencephalography (EEG), Cerebral blood flow (CBF).

1. Introduction

Sleep is an essential biological function that occupy nearly one-third of life span of living organisms therefore sleep monitoring is needed for healthy life. Researcher shows that a poor sleep has an adverse effect on human system and their efficiency. These sleep disturbances have been described as sleep wake disorders. The vital parameters show significant changes during sleep as body and brain under goes relaxation and restoration process. The gold standard Clinical Polysomnography is considered as most authentic process to find types of sleep disorders and related problems by recorded sleep patterns. The problems associated with PSG are; its execution in an artificial environment at hospital in presence of medical staff, high cost, complexities and feel of obtrusiveness due to multiple physiological parameter monitoring and electrodes placed for it. The large number of variety of electrodes are attached at various positions of body to sense and study variations occurred during sleep. This attachment on body disturbs one’s natural sleep, so there is genuine need to select such fundamental parameters from PSG parameters, which can measure sleep unobtrusively and reduce the complexity of process by providing accurate sleep results. The aim of work is to optimize number of PSG parameters by applying elimination technique based on correlation between various parameters.
2. Parameter Optimization Method

The sleep is monitored by identifying the main stages of sleep and their time span as it changes due to brain activity and physiological functions of body during sleep. In Parameter Optimization approach, Gold standard PSG parameters Electroencephalography (EEG), Electrooculogram (EOG), Electrocardiogram (ECG), Electromyography (EMG), Pulse Oximetry, Actigraphy, Photo Plethysmogram, Capnometry, Snoring (Audio), Body Positions (Video) and temperature are considered as monitoring parameter. The measurement of these parameters makes PSG bulky and highly complex process. The goal is to optimise PSG sleep parameters by finding those key parameters whose changes are directly relates with sleep by eliminating the dependent parameters among PSG parameters that reduces number of parameter and results in less complex process.

In first step of optimization, the two parameters temperature and body movement sensing (actigraphy) among PSG parameters cannot be considered as a primary one since temperature is climate dependent provide no information about sleep stages and body movement based on actigraphy is dynamic and sensitive parameter and do not directly reveals information of sleep. These two parameters has been eliminated to reduce system complexities. In next level of optimization, all parameters of PSG are considered as independent parameters. The finding of correlation among these, will differentiate between fundamental and derived parameters. The study of sleep physiology shows the change in heart rate during different sleep stages. In second step, the focus is on Electrocardiogram to obtain information regarding heart rate. In human body, the cardiovascular system refers to heart, lungs and circulatory system, so the parameter ECG has close correlation with heart rate, respiration rate, oxygen saturation and blood pressure. A decrease in oxygen saturation results increase in heart rate as the body demands for more oxygen hence respiration rate also increases. ECG is used to measure the rate and regularity of heart beats. Researchers in their study used linear regression analysis to co-relate heart rate (HR) readings measurement obtained from general oximeter with standard ECG heart rate measurement. Data analysis revealed that heart rate by oximeter is significantly correlated with ECG showing correlation factor valuer = 0.91, P less than 0.0001 [1]. The study of ECG-derived respiratory rates are compared with chest strap derived respiratory rates by using autocorrelation method and zero crossing method. Both method shows strong linear relationship with correlation factor value $r = 0.86$, $p < 10^{-3}$ and $r = 0.88$, $p < 10^{-3}$ between respiratory rates estimated from ECG and chest strap. The result concludes that respiratory signals result obtained directly using chest strap have linear correlation with indirectly measured respiratory rates on the basis of the electrocardiogram (ECG)[2].

In circulatory system, the oxygen saturation directly affects the heart rate. The experimental results show inverse correlation $r = -0.865$, $p < 0.01$ between the heart rate with that of the oxygen saturation [3]. The heart rate increases with the rate of fall in the arterial oxygen saturation [4].

To find out the blood pressure (BP), the hemodynamic relationship [5] shows that blood flow in a blood vessel is directly proportional to pressure gradient. It is quite difficult to measure BP directly from ECG though number of methods are proposed by researchers like ECG Derived Respiration (EDR) which shows correlation value $r = 0.92$ between BP and pulse transit time [6]. There is inter-relationship between blood pressure (BP) and oximetry which is directly related with blood flow. Oxygen is the basic requirement for survival. The appropriate amount of oxygen consumption is needed for smooth functioning of the body. Brain requirement for oxygen is more in comparison to whole body. It consumes 20 percent of the body’s oxygen supply [7]. Further, there is a direct correlation between brain activity and blood flow. Cerebral blood flow (CBF) during sleep stage II is 3-10% below the level associated with wakefulness, whereas 25-44% reduction is for deep sleep stage III-IV [8]. On the other side, the extreme effect of oxygen deficiency results in increase blood flow and blood pressure. The correlation value
between CBF and cortical oxygenation is $r = -0.73$, $p < 0.01$ whereas the value of correlation $r = 0.88$, $p < 0.01$ is for CBF and mean arterial pressure[9], so to measure BP, the two parameters cerebral blood flow (CBF) and ECG are used together for accurate measurement.

Eyes are closed during the sleep and shows direct relation with sleep stages. The eye movement is a kind of muscular activity of eye muscles measured by EOG. EMG for eye muscles is referred as EOG which shows close correlation value of the eye EMG as $r = 0.98$, $p < 0.01$. EOG provides a confirmative information about various sleep stages like non rapid eye movement (NREM) and rapid eye movement (REM). Hence we have selected subpart of EMG that is EOG for our research.

The last step includes the study of EEG. It measures electric potential change caused by a large number of electric dipoles formed during neural excitations of body activity. All muscular signals of body like limb movement, body positions and snoring be a part of EEG waveforms. Body movement affects EMG and EEG signals that are referred as motion artifact. The correlation value between EMG and EEG is $r = 0.78$, $p < 0.01$ [10] and that of snoring is $r = 0.84$, $p < 0.01$ [11]. These artifact signals will be used to notify body movements during sleep as sleep disturbance. The parameter EEG provides information for brain activity during sleep by generating brain electrical signals standardized as beta (>13 Hz), alpha (9-13 Hz), theta (4-8 Hz) and delta (0.5-4 Hz).

In this manner, all independent parameter with their relationship with each other has been studied. The most significant parameters are find out by correlation factor matrix with which other parameters can be measured directly or indirectly.

3. Result
The study of all sleep parameters of PSG shows that some parameters are primary while other are derived parameters. The value of derived parameter can be obtained from primary parameter means that derived parameter has significant correlation with primary parameter. The final results obtained from parameter optimization has been summarised in below Table 1. showing correlation factor of optimize primary parameter with derived parameter.

| Parameter | HeartRate (HR) | Respiration Rate (RR) | Oxygen saturation level (O2) | Electro-myography (EMG) | Snoring | Blood Pressure (BP) |
|-----------|----------------|-----------------------|-----------------------------|-------------------------|---------|---------------------|
| ECG       | 0.91           | 0.88                  | -0.865                      | x                       | x       | 0.92                |
| EOG       | x              | x                     | x                           | 0.98                    | x       | x                   |
| EEG       | x              | x                     | x                           | 0.78                    | 0.84    | x                   |
| CBF       | x              | x                     | -0.73                       | x                       | x       | 0.88                |

The above matrix gives clear information that these four parameters, cerebral blood flow, EEG, EOG and ECG are Primary parameters with the help of these we can derive other dependent parameters.

4. Conclusion
In Parameter Optimization method, PSG parameters are considered for optimization. We can conclude on the basis of experimental values of correlation factor among various PSG parameter
that Cerebral blood flow (CBF), Electrocardiogram (ECG), Electrooculogram (EOG) and Electroencephalogram (EEG) found as four key parameters to monitor the sleep while dependent parameters, can be obtained from these to reduce complexity of monitoring process. Since these four key parameters are significant in sleep assessment, can provide the closer readings to the clinical trials for sleep monitoring. Monitors based on this technique could be more accurate in comparison to other commercially available system based on actigraphy or heart rate alone.

References
[1] Iyriboz Y, Powers S, Morrow J, Ayers D and Landry G 1991 Accuracy of pulse oximeters in estimating heart rate at rest and during exercise. Br J Sports Med 25 (3) 162-4
[2] Schrumpf F, Sturm M, Bausch G and Fuchs M 2016 Derivation of the respiratory rate from directly and indirectly measured respiratory signals using autocorrelation. Current Directions in Biomedical Engineering 2 (1) 241-5
[3] Amare Y E and Haile D 2020 Evaluation of pulmonary function tests among pregnant women of different trimesters in debreberhan referral hospital, shoa, Ethiopia. International Journal of Women’s Health 12 1135-43
[4] Mathers J A L and Levy R L 1950 Correlation of the oxygen saturation of the blood and changes in the electrocardiogram, blood pressure and heart rate during the anoxemia test. Circulation AHA journals 1 (3) 426-32
[5] Richard E Klabunde 2007 Cardiovascular Physiology Concepts 3rd edition Text book published by Wolter Kluwer
[6] He X, Goubran R A and Liu X P 2013 Evaluation of the correlation between blood pressure and pulse transit time. IEEE Int. Symp. on Medical Measurements and Applications (MeMeA) doi: 10.1109/MeMeA.2013.6549697
[7] Marilyn J. Cipolla. 2009 The Cerebral Circulation Text book Morgan and Claypool Life Sciences Publishers
[8] Madsen P L and Vorstrup S 1991 Cerebral blood flow and metabolism during sleep. Cerebrovasc Brain Metab Rev. 3 (4) 281-96
[9] Lucas S J E, Tzeng Y C, Galvin S D, Thomas K N, Ogoh S and Ainslie P N 2010 Influence of changes in blood pressure on cerebral perfusion and oxygenation. Hypertension 55 (3) 698-705
[10] Liang H, Yu Y, Mochida M, Liu C, Ueda N, Li P and Zhu C 2020 EEG-based EMG estimation of shoulder joint for the power augmentation system of upper limbs. Symmetry 12 (11) 1851
[11] Alencar A M, Silva D G V, Oliveira C B, Vieira A P, Moriya H T and Filho G L 2013 Dynamics of snoring sounds and its connection with obstructive sleep apnea. Physica A: Statistical Mechanics and its Applications 392 (1) 271-77