Beddit Sleep Monitor and the Science Behind It

The established practice of medical sleep monitoring, polysomnography, involves wearing multiple electro-physiological sensors for a single night, at a sleep laboratory or at home. It provides clinically valuable information, but is expensive and uncomfortable. More long-term and comfortable measurements can be done with actigraphy, where the overall sleep patterns of a patient are measured with a wrist-worn movement sensor.

Beddit measures sleep with unobtrusive force sensors. The idea is to measure the forces caused by the body on the bed with a flexible film sensor that is placed below the bed sheet.

Each ECG heartbeat signal consists of a clear spike (the QRS complex), which is followed by an impulse in the BCG around 80 ms later. The ECG spike precedes the impulse in the BCG, because electrical activity causes the mechanical contraction of the heart.

Respiration
Beddit Sleep Monitor is also capable of measuring respiratory activity as respiration causes the chest to move measurably. Figure 2 shows how the respiration cycles and heart rate events appear in the sensor signal:

There are three main motivations for measuring respiration unobtrusively during sleep. First, respiration conveys information about the general condition of the patient, so the deterioration of health can be detected with respiration monitoring. Second, sleep-related breathing disorders (SRBD) such as sleep apnea represent a major share of sleep problems. Third, the structure of sleep can be analyzed based on respiration, because sleep stages have differing effects on respiration.

The respiration measurement is a 4-step process where first the parts of the signal that contain gross movements are discarded. Then the respiration signal is low-pass filtered on 4 distinct F Hz frequencies with potentially disturbing phenomena taken into account at around 2xF Hz. Therefore, at least one of the filters will result in an output signal that has the respiration frequency intact but the disturbance removed.

Then the respiration cycles are detected from each filtered signal. A respiration cycle begins at a local maximum and ends at the next local maximum in the signal. In addition, the amplitude of each respiration cycle is calculated by taking the difference between the signal value of the local maximum that starts the cycle and the minimal signal value in the cycle. Lastly, the first sequence of respiration cycle lengths is compiled from the four signals based on the stability of respiration cycle amplitudes in each signal.

The correct signal is typically selected, because the signal that contains frequencies up to the respiratory frequency is more stable in its amplitude than a signal that also contains higher-frequency disturbing phenomena.

Movement
As sleep correlates with a low level of motility, circadian rhythmicity can be estimated with a method called actigraphy. An accelerometer sensor is worn on the wrist 24 hours a day, which allows estimating the daily alternation between sleep and wakefulness. Due to its limited accuracy, actigraphy is typically used for the overall characterization of sleeping patterns over a period of at least a week.

The Beddit Sleep Monitor detects the gross movement of the person sleeping. Even if Beddit is not a medical device and shouldn’t be used for any kind of medical diagnoses, the excessive movement during the night could potentially be a sign of, for example, periodic limb movement disorder. In such a case, the user should be in contact with an appropriate doctor.

The movement information is analyzed by detecting discrete events of movement from the BCG signal. That is done by dividing the high-pass filtered (cut-off frequency 5 Hz) signal into three-second windows. Each window is detected as movement if the difference between signal minimum and maximum in the segment is above a fixed threshold.

Validity of the measurements
The measurement data provided by the Beddit Sleep Monitor has been tested against results from ECG and polysomnography (PSG).

The heart rate data has been tested in a clinical study conducted in 2012 in cooperation with the VitalMed Research Centre together with the renowned sleep researcher and expert, Prof. Markku Partinen, M.D. The study consisted of 46 test subjects whose ages varied between 20 to 74 years. The study focused on measuring beat-to-beat heart rate. Out of all the detected beat-to-beat intervals, a maximum precision of 99.94% was achieved with the Beddit Sleep Monitor compared to the reference ECG-signal.

The measurement methodology poses scientific challenges because physiological information (heart rate, respiration, etc.) that are vital for analyzing sleep cannot be readily extracted from the sensor’s signal, but requires sophisticated signal analysis methods.

Ballistocardiography
The measurement of mechanical cardiac activity from the platform supporting the body is called ballistocardiography (BCG). Each time the heart beats, the acceleration of blood generates a mechanical impulse that can be measured with a proper force sensor, such as the Beddit Sleep Monitor.

Heart rate
Measuring the heart rate from BCG or similar mechanical signals requires much more complex procedures than measuring the heart rate using electrocardiogram (ECG), the most common place cardiac measurement method. Individual heartbeats can be detected from an ECG signal relatively easily, by locating a clear spike (called the QRS complex, from the consecutive named spikes Q, R, S of the ECG heartbeat) that accompanies each heartbeat.

However, with BCG, the cardiac impulses are less pronounced and more variable than the salient shape of the QRS complex. The differences between the ECG and BCG-signals are shown in Figure 1:

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[Diagram of sensor signal]

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[Diagram of ECG and BCG signals]

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Sources


