Measuring a patient's heart rate in an un-intrusive and non-disruptive way

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Sleep disorders are increasing within our society and they can have a detrimental impact on an individual's general health and quality of life unless treated. While the cause of many sleep problems can be easily identified or are temporary, such as stress at work or a family bereavement, there are those that need more detailed sleep analysis in order to properly investigate the root cause. The established method for this sleep analysis is by polysomnography (PSG) which takes place overnight in a specialist laboratory environment where multiple sensors are placed on the patient's body. Trained technicians and doctors undertake patient monitoring and data analysis, with the sleep pattern being visually analysed from the recorded data. The whole process is an expensive exercise in addition to it being intrusive and disruptive for the patient; we all would find it difficult to sleep in a strange bed at some stage.

Over the past few years a less intrusive and lower cost alternative to PSG has been developed. Ballistocardiography (BCG) works by measuring the mechanical forces originating from the body while the patient sleeps. Considered suitable for long-term use, BCG data is collected through an accelerometer which does not have to be physically attached to the patient. Recent clinical tests conducted by the Aalto University School of Electrical Engineering in collaboration with the University of Turku, Finland sought to validate that the data gathered via a BCG sensor compared to the standard PSG data is accurate enough so that it could be used as a sleep analysis tool in a home environment. The overnight tests were conducted in a clinical sleep laboratory with a sample of 20 healthy persons, 17 men and 3 women, all in the 24 – 46 year old age group. Persons with a pre-existing sleep condition, those consuming large amounts of alcohol or caffeine and those on medication were excluded from the tests.

Figure 1 – BCG and PSG clinical test set up

A Murata SCA11H BCG sensor node taped underneath the bed mattress gathered the BCG measurements see Figure 1a. Note that two sensor nodes were used during the tests, one provided processed vital sign data and the other raw accelerometer signal. In contrast, note the complexity of the PSG measurement sensors as can be seen in Figure 1b. This provided measurement data from a total of 18 sensors including six for electroencephalography (EEG) brain activity, measurement of eye movements with electro-oculography (EOG), measurement of muscle tension with electromyography (EMG) and measurement of respiratory rate with thorax belt and nasal prongs. Cardio function was also measured by electrocardiography (ECG). The key indicators of heart rate (HR) and respiratory rate (RR) were calculated from the ECG and thorax belt readings, respectively.

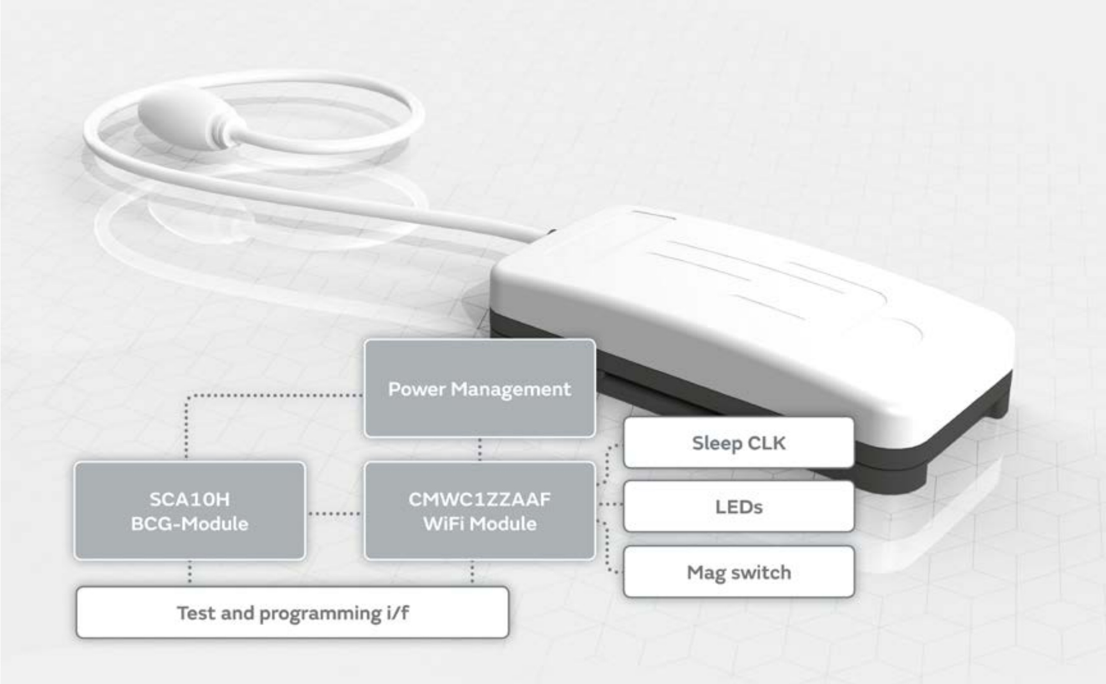

Figure 2 – Murata SCA11H BCG sensor node and its block diagram

The contactless Murata SCA11H BCG sensor consists of a Murata SCA10H BCG sensor module, including a 1-axis accelerometer, an IEEE 802.11b/g/n compliant Wi-Fi communication module and a host microprocessor see Figure 2. The accelerometer operates with a 1 kHz sampling frequency and has a 90 µg detection resolution. Using a proprietary Murata algorithm the detected signal can be processed to report multiple parameters every second. These include heart rate (HR), respiratory rate (RR), relative cardiac stroke volume (SV) and heart rate variability (HRV). In addition several other non-clinical values are reported such as bed occupancy status, signal strength and timestamp.

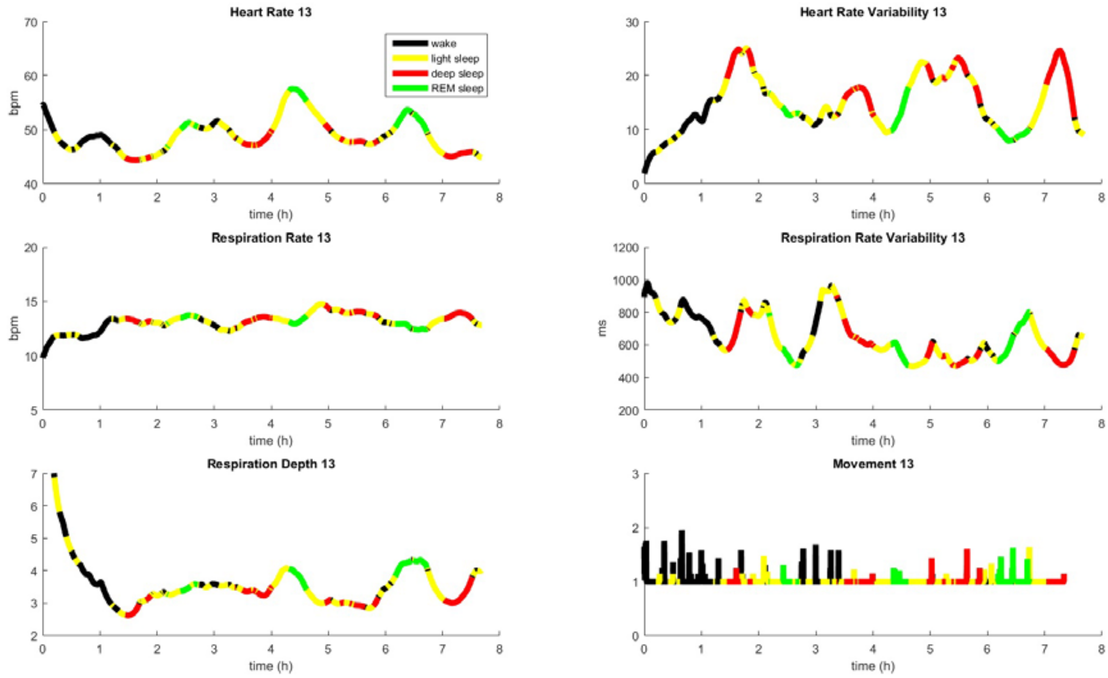

Figure 3 – Example results from a single night's test

The results of the tests concluded that the BCG results were accurate and correlated well with the PSG results. An example of one night's HR and RR data can be seen in Figure 3. It was agreed that BCG was a reliable approach to be used for sleep analysis. From Figure 3 it can be seen that the HR was typically at a high level during wakefulness and REM sleep compared to deep and light sleep. HRV was highest in deep sleep and lowest during wakefulness and REM sleep. There was no clear difference between the RR between the sleep stages and respiratory rate variability (RRV) was typically at the lowest level during deep sleep and increased in REM and wakefulness. The BCG sensor also was able to record movement of the person during the measurement process, something that the PSG approach could only do by visual observation. These sleep stages were scored from the recorded PSG data and categorized according to the American Academy of Sleep Medicine (AASM) criteria.

Measuring just 83.7 x 40.7 x 17.6 mm the SCA11H node is housed in an IP55 waterproof plastic enclosure from a nominal 9 VDC supply. The firmware is capable of being remotely upgraded over-the-air (OTA). The node can be accessed locally via TCP/IP or it can be configured to send data directly to customer’s cloud service.

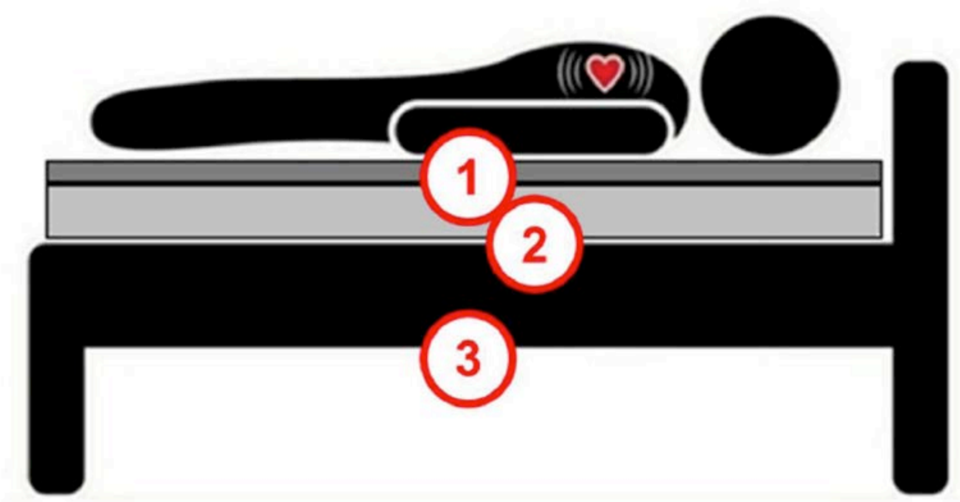

Figure 4 – Attachment options for BCG node

Figure 4 illustrates the recommended attachment locations for the BCG sensor node. Position 1 is underneath the mattress, perhaps between a “toppy” layer and the main mattress. Position 2 indicates the top part of the bed frame and Position 3 the side of the bed frame.

At the heart of the SCA11H sensor node is a Murata SCA10H accelerometer module that contains a single-axis MEMS accelerometer. Communication with the MEMS module is via a standard UART interface. A detailed binary protocol specification document highlights the data and message frame formats that the module uses for UART communication. Both SCA11H node and SCA10H module are already available. SCA11H is targeted for system manufacturers whereas the main interest towards SCA10H module product is mainly from various device manufacturers.

Figure 5 – Murata SCA10H module

The comparative clinical tests between PSG and BCG heart measurement methods concluded that using a BCG-based approach for conducting a sleep analysis was an inexpensive and unobtrusive way to measure sleep over multiple nights, something that can take place in the home for example. According to the results, the HR & HRV parameters measured by BCG were accurate and correlated with the PSG data. The conclusion is that Murata's BCG products are reliable enough for sleep analysis.