

# UNOBTRUSIVE VITAL SIGNS MONITORING FROM A MULTISENSOR BED SHEET

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## ABSTRACT

Chronic sleep disorders affect more than 50 million people in the U.S., and there are numerous clinical populations, such as spinal cord injury patients, cognitively-impaired elderly persons living at home, and infants at risk for Sudden Infant Death Syndrome, who could benefit from unobtrusive, long-term monitoring. The prototype SleepSmart sheet is a thin, full-length, multi-sensor mattress pad. It is controlled by software to detect heart rate, breathing rate, body orientation, and index of restlessness. A spectral analysis module is combined with an event detection module to accumulate nightly reports and signal alarms when appropriate. Lab bench testing has confirmed the effectiveness of the sensors and software algorithms; clinical testing is expected to confirm the ability of the SleepSmart sheet to detect vital signs to within  $\pm 10\%$  of conventional, wired clinical devices.

## BACKGROUND

There are many methods of monitoring sleep by putting sensors on the sleeper's body. Polysomnography [1] uses wired sensors to measure vital signs (breathing and heart rate, blood pressure), chest wall expansion, airway pressure changes and exhaled air CO<sub>2</sub> content, electroencephalogram (EEG) and body orientation. While this provides a rich data set for the diagnosis of severe sleep disorders such as obstructive sleep apnea, it is expensive, can only be done in the unfamiliar environment of a clinic over one or two nights. A second mechanism to collect sleep data is surveying people who have sleep disorders or their guardians/parents. While the easiest methodologically, this is the least powerful. Actigraphy [2,3] unobtrusively measures gross body movement with a wrist-watch-type data logger that can be worn for weeks. An increase of restlessness has been shown in some cases to correlate to a decrease in sleep quality. In a similar manner, an experimental ring that performs blood oximetry and measures heart rate optically has been developed to send data to a bed-side receiver via telemetry [4]. Another experimental device is the SmartShirt [5,6], an undergarment with woven-in wires and snaps to connect to sensors and a wearable computer for telemetry to a base station. The sensors can measure vital signs such as breathing and heart rate.

While these sensor systems are person-based, another class of sensors are bed-based. Many devices have been developed and patented for body position, breathing rate, and heart rate [e.g., 7] using force sensitive resistors, capacitive sensors, piezo-electric sensors, and microphones. However, they can be expensive and may require wired electrodes for many of the sensing functions [e.g., 8,9].

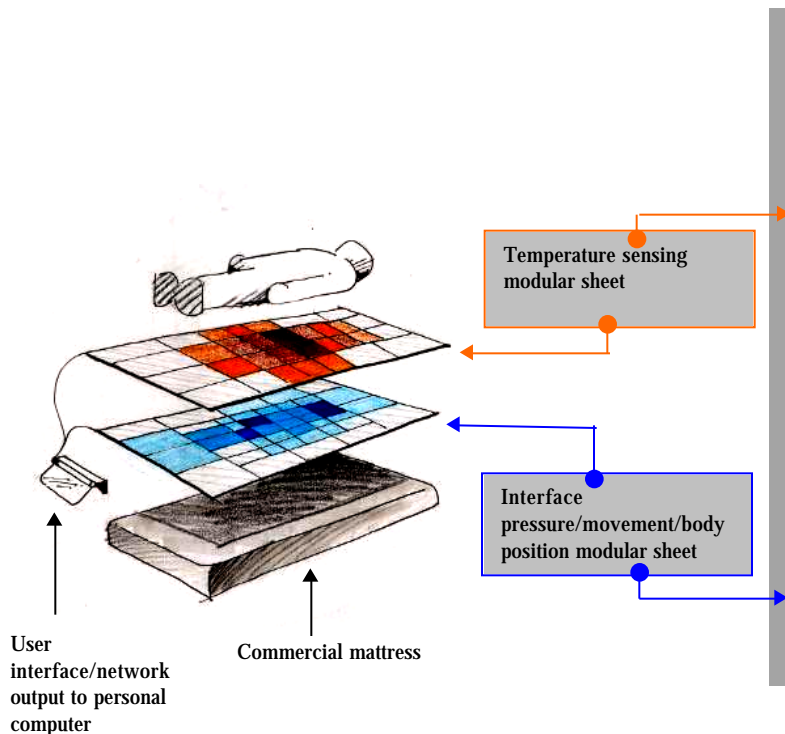
## RESEARCH QUESTION

The goal of the SleepSmart Project was to develop a low-cost, multi-sensor, modular, unobtrusive bed sheet that was breathable, impervious to liquids and washable. The frequency-based software algorithms requirements included heart and breathing rate, body position and motion, and

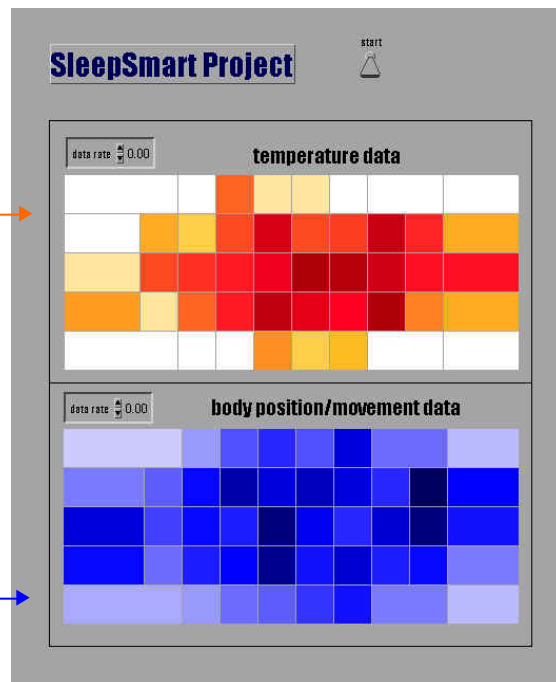
surface temperature (also used as a redundant sensor for body presence). The event-based diagnostic module would reduce and store data to allow 24-hour reporting as well as recognizing and alerting the medical staff in the case of clinically-derived alarm conditions.

**APPROACH**

The SleepSmart system (patent application filed September, 2000; see figures 1 and 2) uses an array of 54 force sensitive resistors (FSRs) and 54 resistive temperature devices (RTDs). The array is denser (10 cm spacing) under the torso than the legs (20 cm spacing). All of the sensors have 10-Hz cutoff low-pass filters. Twelve of the torso FSRs have an parallel high-gain AC-coupled signal conditioning circuit to facilitate heart rate detection. All 120 channels are recorded at a 100 Hz scan rate. Digital wavelet transformation software measures average heart rate at a resolution of 0.5 beats per minute using 5-second data sets. Breathing rate is measured every 5 seconds using 25-second data sets. Body center of mass is measured using moment calculations of the low-pass-filtered FSR and RTD signals. A restlessness index is calculated by integrating the absolute change in body center of mass over the duration of sleep at 25-second intervals.



**Figure 1; prototype concept demonstrating layered sensor approach; each layer can be updated /removed depending upon the users' needs or new technological innovations**



**Figure 2; graphical user interface concept for clinical studies; pressure/temperature information is displayed chromatically and recorded for analysis**

**RESULTS**

Bench testing has shown that heart rate can be measured reliably if an FSR sensor is within 2cm of the projected location of the heart on the mattress and is not significantly affected by body orientation. The wavelet transformation software computes the heart rate at the 12 torso sensor locations

and selects the sensor with the strongest amplitude. Breathing rate software uses a similar algorithm, but the chest wall movement is readily measured at a number of the sensors due to its gross nature.

## DISCUSSION

While bench testing of the hardware configuration and the major software modules has been completed, the current effort of the project is devoted to system integration and clinical testing at the VA Palo Alto Sleep Disorder Clinic. Clinical tests (March, 2001) are expected to show that wired, state-of-the-art, breathing and heart rate detection devices have a higher resolution than SleepSmart. However, this is not critical due to the function of each of the devices. SleepSmart is expected to have an equal or better performance in the event of the sleeper rolling over, which may cause electrode detachment with a wired sensor or a temporary loss of signal for SleepSmart.

Further work in this area will focus on developing advanced software to correlate SleepSmart sleep profiles with the results of polysomnography data, and the incorporation of fabric-based sensing technologies to further reduce costs of the SleepSmart system.

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## ACKNOWLEDGMENTS

This study was funded by a grant from the Paramount Bed Corp., Tokyo, Japan, and from the National Trust Corp., Tokyo, Japan. We are grateful for the help of Prof. Cleto Kushida, MD, of the Stanford Sleep Disorder Clinic, Prof. Ware Kushner, MD, and James Canfield, BS, CCPT, of the Palo Alto VA Pulmonary Service, Roy Sasaki, MD, of the Palo Alto VA Spinal Cord Injury Service, and Prof. Kos Ishii, PhD, of the Stanford University Dept. of Mechanical Engineering.

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