Poster Abstract: Accurate Monitoring of Circardian Rhythms using Wearable Body Sensor Networks

Carlo Alberto Boano†, Matteo Lasagni†[*], Kay Römer†, and Tanja Lange‡
†{cboano,lasagni,roemer}@iti.uni-luebeck.de, ‡lange@kfg.uni-luebeck.de
†Institute of Computer Engineering
University of Lübeck, Germany
‡Department of Neuroendocrinology
University of Lübeck, Germany

ABSTRACT

Monitoring the impact of sleep deprivation on thermoregulation requires a careful measurement of skin temperature across the human body to have precise knowledge and understanding of the stability of circadian rhythms, the 24-hour cycles of biological activity. However, medical measurements and clinical trials are often carried out in controlled lab settings, which limits the realism and the duration of data collections, and increases significantly their costs. We aim to provide medical researchers studying the stability of the circadian rhythms with a tool for higher quality data collections. We design and develop a wireless unobtrusive monitoring system for accurate body temperature measurements to be worn by patients for several weeks while they live their normal life. Obtaining a long-lasting highly-accurate measurement system is challenging, as energy and computational resources are severely constrained in miniaturized wearable sensor nodes. We develop a prototype of an active temperature measurement system with 0.02°C accuracy, a lifetime of up to 3 weeks, and real-time feedback to a remote medic. Our preliminary experiments show that we can identify the circadian rhythms also in non-ambulatory environments, indicating that our tool could become a valuable asset for medical research.

Categories and Subject Descriptors

J.3 [**Computer Applications**]: Life and Medical Sciences

General Terms

Design, Experimentation, Measurement.

Keywords

Body Sensor Networks, Circadian Rhythms, Skin Temperature.

1. INTRODUCTION AND MOTIVATION

Chronobiologists can derive from long-term skin and core body temperature measurements an accurate profile of the circadian system, which is essential to understand the time-dependent regulation of brain and body functions.

Body core and skin temperature follow strong circadian rhythms over the 24-hour day: in the evening, as a result of vasodilatation, an increased blood flow to the periphery leads to a sharp increase in distal skin temperature (i.e., skin temperature at the extremities), while proximal skin temperature (i.e., skin temperature at the trunk) shows only slight changes. The resulting increase in distal-proximal skin temperature gradient is a very good indicator of heat loss that in turn leads to a drop in core body temperature [1].

Sleep is tightly connected to the circadian system and sleep deprivation induces a substantial decrease in core body temperature and, as shown in animal experiments [2], can lead to thermoregulatory failures with marked heat loss. It is an open research task to monitor the response of temperature rhythms to prolonged sleep restriction. To achieve this goal, having precise measurements of the phase, amplitude, and stability of circadian temperature rhythms is fundamental. This requires frequent and continuous sampling of temperature over several days in different body areas, such as core (inner) body temperature, distal (extremities) skin temperature, and proximal (abdominal) skin temperature to exactly monitor the redirection of blood flow from the shell to the core and viceversa.

Medical researchers typically gather their data in ambulatory environments, but their measurements often suffer from the ”White Coat Syndrome”: patients being monitored in hospital environments do not behave as in their daily life, due to the stress associated with the clinical visit and due to the exposure to a different environment. Unobtrusive 24/7 pervasive monitoring in non-ambulatory environments using miniaturized body sensors would more accurately reflect the true values for a given parameter, improving the quality of data available to medical researchers.

We exploit the flexibility, low cost, and uninterrupted operation of wearable Body Sensor Networks (BSNs) to obtain highly-accurate realistic data collection. Our goal is to monitor patients with a prescribed sleep schedule (including prolonged sleep restriction) for several weeks while they live their normal life, and enable the medical staff to remotely check in real-time the impact of sleep restriction on their circadian rhythms. Towards this goal, we design and develop a non-invasive wearable wireless body sensor node that measures the body temperature with high accuracy. Our first step is to prove the usability of our tool in non-ambulatory scenarios. In such environments, body temperature fluctuates due to several factors, such as movements and activities, food intake, environmental temperature changes, and weather conditions. A simple change of room can cause a significant change in skin temperature, especially when measuring with a precision in the order of hundredths degrees Celsius. Our preliminary experiments show that circadian rhythms can also be successfully identified through measurements in non-ambulatory environments, indicating that our tool could indeed become a valuable asset for medical research.

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[*] M. Lasagni is also affiliated with the Dipart. di Scienze e Metodi dell'Ingegneria, University of Modena and Reggio Emilia, Italy.

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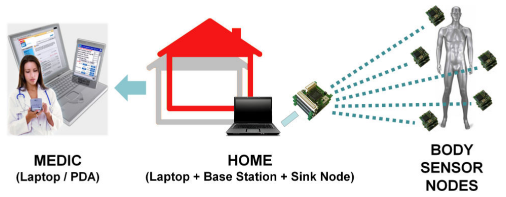
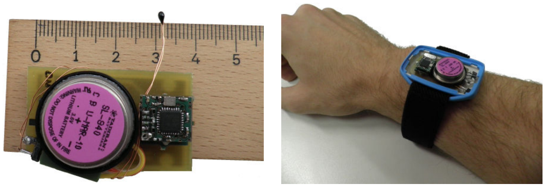


Figure 1: BSN architecture and back-end infrastructure.



(a) Prototype Board (b) Packaging (top removed)

Figure 2: Our body sensor node prototype and its packaging.

2. CONTRIBUTION

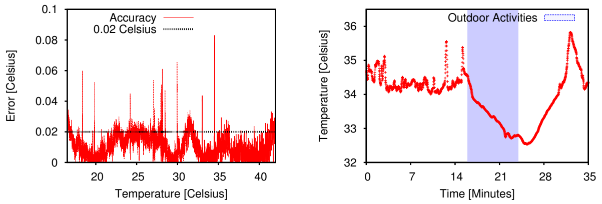
Architecture and Prototype. The architecture of our BSN is illustrated in Fig. 1. The subject wears small-size body sensor nodes, which are limited in their energy supply, storage, and computational resources. Whenever the subject enters the range of a base station installed at home (a sensor node wired to a laptop connected to the Internet), the nodes forward the collected samples to the base station wirelessly. Each node samples the skin temperature and groups readings in packets of 30 bytes. We use ACKs to monitor connectivity: if the patient is not in the range of the base station, the packets are timestamped and stored in the local 4kB EEPROM, and are retransmitted as soon as the patient returns in-range. In case the EEPROM is filled before the communication is restored, new sensor readings are discarded. To minimize the amount of retransmissions and save energy, we use a linear truncated backoff [3].

Fig. 2(a) shows the body sensor node prototype: the hardware consists of MF51E high-precision NTC thermistor, precision amplifier, conditioning circuitry on a custom PCB to connect the thermistor to the Tyndall 10mm node [4], and a Lithium Thionyl primary battery. All the electronics are packaged in an OKW Minitec Enclosure (Fig. 2(b)) and are fixed to arms or legs with a strap.

Accurate Temperature Measurements. Using high-precision thermistors is not enough to guarantee accurate readings. We built an active conditioning circuitry using a precision amplifier in order to exploit the full resolution of the ADC by mapping the temperature range of interest $[16, 42]$°C to the full input voltage range of the ADC. Due to the tolerance of the components, we need to perform a calibration of the thermistor and the conditioning circuit. We place the probe of a reference thermometer and each thermistor within 1 cm distance inside a glass filled with one liter of water. The water cools down naturally from 42 to 16°C in 2 hours time, and the response time of our calibration thermometer is enough to characterize the thermistor with an accuracy up to 0.02°C (Fig. 3(a)).

One important aspect that affects accuracy is the self-heating of the thermistor, as the current flowing through it depends on the supply voltage. We use a Torex XC6215 voltage regulator to produce a constant supply voltage of 3.3V with a swing smaller than ± 0.01V, and make sure that the inaccuracy of temperature measurements due to self-heating variations is two orders of magnitude smaller than our target accuracy. Using a Tadiran SL-840 battery with a capacity of 420 mAh, the lifetime of the system is roughly 3 weeks.

Preliminary experiments. We instruct a 24-years old male subject to wear our BSN and monitor the skin temperature of his non-dominant hand over 24 hours. Fig. 4 shows the raw data collected at a sampling rate of 1 Hz (the small interruption of connectivity at 6 AM is due to a communication failure). As the patient is not constrained to a specific environment, his skin temperature varies due to user mobility, emotional state, and changes in environmental temperature. Fig. 3(b) highlights how user mobility can affect skin temperature causing a variation by up to more than 2°C when the patient spends a few minutes outdoors. Nevertheless, filtering the data using a moving average over 5000 samples, we can see in the evening, as a result of vasodilatation, an increase of temperature, followed by a decrease as soon as the patient goes to bed. In the following morning, the temperature starts rising again, proving that our sensor node does a commendable job in detecting the circadian rhythms through hand temperature measurements.



(a) Accuracy (b) Impact of user mobility

Figure 3: Accuracy of our prototype after calibration and impact of environmental temperature on temperature readings.

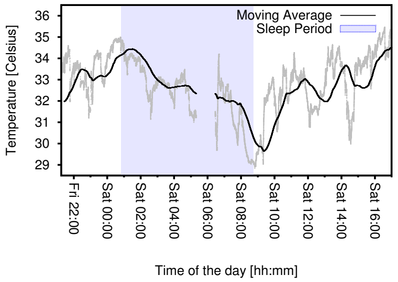


Figure 4: Monitoring of the circadian rhythms through a continuous measurement of the hand temperature.

3. CONCLUSIONS AND FUTURE WORK

Long-term non-invasive and accurate measurements of body temperature in realistic environments can substantially improve the quality of data available to medical researchers. We design a BSN node that can seamlessly and accurately measure the body temperature: our preliminary studies show that starting from measurements of skin temperature in non-constrained environments, we can identify the circadian rhythms over 24 hours. We are currently testing a prototype of portable ear thermometer for non-invasive 24/7 monitoring of core temperature, and our next focus will be on advanced functionalities such as automatic compensation for environmental conditions, and automatic generation of a diary of activities.

Acknowledgments

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