Chapter 7
Monitoring Sleep with WISP Tags

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ABSTRACT

This chapter presents a sleep monitoring system based on WISP tags. The authors show that their system accurately infers fine-grained body positions from accelerometer data collected from the WISP tags attached to the sides of a bed. Movements, duration, and bed entrances and exits are also detected by the system. The chapter presents the results of an empirical study from 10 subjects on three different mattresses in controlled experiments to show the accuracy of the inference algorithms. The authors also evaluate the accuracy of the movement detection and body position inference for six nights on one subject, and compare these results with two baseline systems. Preliminary data investigating the correlation between sleep stages from the Zeo and movement is also presented.

INTRODUCTION

RFID is an important technology that has already experienced great success in several different application areas. With the advent of adding sensing to RFIDs, as found in WISP tags, many new applications are possible. One promising area for WISP applicability is in smart homes. The tags may be used for applications designed to save energy, automate homes, or to remotely monitor health. For monitoring many medical conditions, being able to assess the duration and quality of sleep plays an important role.

Because of its importance, many sleep-monitoring systems have been developed. These systems attempt to recognize sleeping disorders by providing healthcare providers with quantitative data about irregularity in sleeping periods and durations or the amount of agitation and restlessness experienced during the night. These
solutions vary in cost, comfort, and accuracy. In this chapter, we describe the main categories and characteristics of current solutions and then detail a new approach based on WISP tags.

The new system does not require any specific action from patients. In this system, we attach several WISP tags to the bed mattress and collect accelerometer data. Using the data we infer body positions, movements, and entries and exits from the bed. We compare the performance of our system with several baseline systems including using pressure pads, video, a popular iPhone based sleep monitoring application, and the Zeo.

**BACKGROUND**

To date, while there are many sleep monitoring systems there are very few low-cost, unobtrusive (comfortable) solutions. In this section we outline the major categories of solutions and describe their characteristics and limitations.

Physiological signals are regarded as the most accurate means to differentiate between awake and sleep phases such as light, REM, and deep sleep. The electroencephalogram (EEG) measures the frequency of brain waves to discern sleep and wake stages (Carskadon 1989). The electrooculogram (EOG) and electromyogram (EMG) are also standard technologies for sleep monitoring. The electrocardiogram (ECG) can be used to measure the heart rate, which is well known to decrease upon sleep onset. Some studies show that heart rate varies over different sleep stages (Redmond 2006, Shinar 2006) by use respiratory-derived features together with ECG-derived features for classifying different sleep stages automatically. These techniques have major limitations- they are costly since they require trained professionals in clinical environments to administer them and invasive since these techniques require equipment to be attached to patients, limiting their movement and causing discomfort. These physiological signals do not support monitoring body positions during sleep.

Temperature regulation in a body can also be used to monitor sleep quality. Skin temperature increases during sleep onset and decreases during wakeup (Krauchi 2004). But these temperature variations can only be measured under controlled laboratory conditions. (Yang 2006) uses an infrared triangulation distance sensor to detect movements of different body parts without attaching any device to the body. But it does not provide any information about body position.

To overcome the limitations of the above techniques, there are many systems that enable sleep monitoring in home environments. Actigraphy (Sadeh 2002) is a commonly used technique for sleep monitoring that uses a watch-like accelerometer based device attached typically to the wrist. The device monitors activities and later labels periods of low activity as sleep. There are many commercial products like the Philips Actiwatch that are designed based on actigraphy. The Zeo is another commercial product for sleep monitoring in home environments. It is a headband that users need to wear each night so that it can detect sleep patterns through the electrical signals naturally produced by the brain. There is also an associated display that shows a person’s sleep pattern for the previous night. These products are expensive and users need to wear the device.

Another method used for sleep monitoring is to instrument a mattress pad with sensors and passively infer body movements and sleep quality. The Bed Alarm Sensor Pad is such a commercial bed pressure-sensing pad that monitors change in body pressure on the pad to detect movements. In (Van der Loos 2001) the authors use pressure and temperature sensors laid out in a grid pattern in the mattress to determine quality of sleep. NAPS (Mack 2003, Mack 2006) is a low-cost physiological sensor-suite that can passively acquire important physiological and environmental characteristics. The NAPS suite allows subjects to simply lie on a mattress pad, embedded with vibration sensors, to obtain multidimensional data (e.g., body temperature, heart rate, respiration rate, positional mapping and movement). One might