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Using load cells under the bed as a non-contact method for detecting periodic leg movements

A.M. Adami [a,*], A.G. Adami [a], T.L. Hayes [b], Z.T. Beattie [b]

[a] *Universidade de Caxias do Sul, Rua Francisco Getúlio Vargas, 1130, 95070-560 Caxias do Sul, Brazil*
[b] *Oregon Health and Science University, 3303 SW Bond Avenue, 97239 Portland, USA*

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Abstract

Movement in bed may be an indicator of health problems, i.e., the alteration of the pattern or amount of motor activity can be a disease marker. It can reflect illnesses ranging from flu to depression, pain, or the side effects of certain treatments. There are also motor disturbances that are triggered by sleep such as restless legs syndrome and periodic limb movements during sleep that reduce sleep quality. The assessment of nocturnal motor disturbances in sleep is traditionally performed through overnight polysomnography or actigraphy. In this work, we investigate the use of unobtrusive load cells sensors installed under the supports of a bed to assess movements in bed. Body and leg movements are discriminated using a linear classifier with center of pressure trajectory features derived from load cell signals. Leg movements are scored as periodic leg movements using the criteria defined by The World Association of Sleep Medicine, and a periodic leg movement index is estimated. The system is validated against technicians' annotations of body movements and leg movements (scorings from EMG data) collected from 17 patients during a one-night polysomnogram exam. The classification rate is equal to 96.9%, and the Spearman's correlation coefficient between the periodic leg movement indexes estimated by the system and those obtained from polysomnogram is 0.927. These results demonstrate the feasibility of using load cells for movement classification and detection of periodic leg movements.

1. Introduction

Human sleep is characterized by episodes of immobility interrupted by episodes with different activity levels. The organization of the motor activity during sleep is related to sleep macrostructure, i.e., to the cyclic patterns involving non-rapid eye movement (NREM) and rapid eye movement (REM) sleep states. The normal motor phenomena during sleep includes hypnic jerks (abrupt flexion movements that are often felt as an illusion of falling) at sleep onset, postural shifts, body and limb movements, and sleep myoclonus (small bursts of movements) [1]. There are motor disturbances triggered by sleep such as restless legs syndrome (RLS) and periodic limb movements (PLMs). Patients with RLS report feelings of discomfort in the legs, and they feel compelled to move (for example, tossing and turning in bed) to relieve the discomfort [2]. Such symptoms disrupt sleep and cause daytime tiredness and sleepiness.

PLMs are involuntary and repetitive movements. A typical PLM consists of dorsiflexions of the ankle (bending the ankle upward to bring the toes closer to the knee), and is sometimes accompanied by flexions of the ankles, knees, and thighs. PLMs may be unilateral or bilateral. A PLM occurs about every 20–40 seconds, and lasts approximately 0.5–10 seconds. At least 4 consecutive leg movements must fulfill these criteria to be scored as a PLM event [1]. The criteria are defined by the World Association of Sleep Medicine (WASM). A PLM index (the number of PLM events per hour of sleep) above 5 per hour is often used as a cut off for differentiating normal from elevated values [3]. PLMs occur frequently in patients with RLS, narcolepsy, sleep apnea syndrome, insomnia, and REM sleep behavior disorder [4]. Periodic leg movements associated with repeated arousals can lead to excessive daytime sleepiness [5].

* Corresponding author.
E-mail addresses: amiorell@ucs.br (A.M. Adami), agadami@ucs.br (A.G. Adami), hayesta@ohsu.edu (T.L. Hayes), beattiez@ohsu.edu (Z.T. Beattie).

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Motor disturbances are diagnosed in a sleep laboratory, during a polysomnogram exam (PSG), by the recording of bilateral surface electromyogram (EMG) [6]. PSG is the gold standard for assessing disorders related to sleep, but issues of cost and inconvenience have motivated the development of devices capable of assessment in the patient's own home [7].

Actigraphy has also been used to diagnose PLMs [8]. Actigraphs are wristwatch-like devices that measure acceleration, and provide information on the activity level of the user. Because actigraphy captures activity even when the patient exits the bed (for example, when going to the bathroom), the patient has to keep a diary of the bedtimes and get up times to determine time in bed. Although it could be simple to detect when the patient is standing because the accelerations measured by the device are very distinguishable, it still requires patient's compliance because the person has to wear it every night.

The use of an unobtrusive system for in-home assessment, which enables classification of movements in bed that include leg movements, could be very valuable for the evaluation of PLMs over multiple nights in a home environment [6]. Several devices have been proposed for monitoring of lower limbs motion. The PAM-RL device, based on leg actimetry, was proposed for ambulatory measurement of limb movements [9]. Wireless monitoring of leg movements by RFID technology equipped with motion sensors was proposed by Occhiuzzi [10]. Although both technologies can reliably detect leg movements, both are obtrusive because the sensors have to be attached to the patient's legs. Rauhala et al. [11] proposed the use of a electromechanical film called Emfit, placed under the bed-sheet, for detection of periodic movements. The sensor provides reliable information about movements and about screening of periodic movements.

Our research focuses on the unobtrusive assessment of movements in bed using data from load cells installed under each support of a bed. Load cell data can be collected continuously without interfering patient sleep. They have been successfully used in our laboratory to classify breathing events and detect sleep apnea [12,13], to determine lying position [14], and to detect bed movements [15]. In this paper, we extend our work by describing the use of load cell data to classify movements into two classes: body movements and leg movements. We present a linear classifier with features derived from load cell signals. The system is validated against technicians' annotations of body and leg movements (scorings from EMG data) collected from 17 patients during a one-night PSG exam. Furthermore, all classified leg movements are scored as a PLM event according to the WASM criteria. Based on the number of PLM events scored, a PLM index is calculated for each subject.

2. Subjects and methods

2.1. Load cells

Load cells are strain gauge transducers that convert applied force into a resistance change. They are widely deployed in industrial systems and are also commonly used in electronic scales. They are of relatively low cost, and represent a simple and durable technology. Although forces are not directly measured, but inferred from the resultant strain, the output is linearly proportional to force, with the relationship determined by calibration. This relationship was defined using a least squares regression line fit to the load cell output and applied force data pairs. The coefficients for a (slope) and b (intercept) from the least squares regression line $y = ax + b$, where x is the load cell output and y is the predicted load on the load cell, are found by minimizing the error $\sum_i (Y_i - y_i)^2$ where Y is the actual weight applied to the load cell [16]. After calibration the raw data is converted to force values (in Newton).

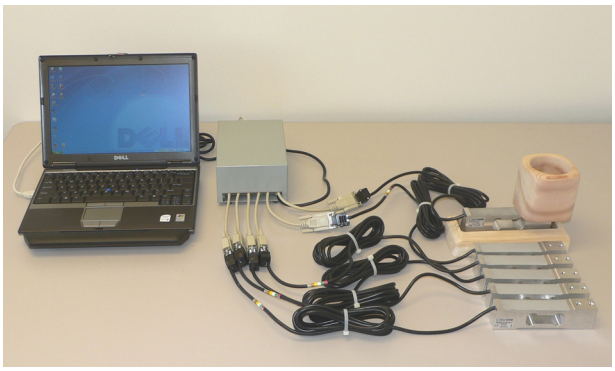

Fig. 1. Load cells used in the data collection.

The sleep laboratory bed used for this study is equipped with load cells under the bed supports. Given the number of bed supports, 6 load cells (AG100C3SH5eU, SCAIME Annemasse, France) with capacities of 100 kg each are used for data collection, as shown in Fig. 1. The load cell signals were collected at 2 kHz for the entire length of the patient's sleep study using a 16 bit A/D converter. Then, the signal is downsampled to 20 Hz to reduce the computational cost during analysis and because higher sampling rates are not necessary for the movements considered here.

For this study, 110.8 hours of data collected from the load cells, which included 2439 technician scored movements, were used for analysis. Fig. 2 shows an example of data collected from one subject. The highlighted portions of the signals mark the time intervals when the subject made a leg movement.

2.2. Subjects

Seventeen patients (10 men and 7 women) from the Oregon Health & Science University (OHSU) Sleep Disorders Program, with ages ranging from 29 to 74 years (mean age 50.4 ± 12.3 years old) participated of the study. Data were collected for each patient during regularly scheduled single-night PSG exam at the OHSU sleep clinic. Two patients that participated of the study had a PLM index above 5 events per hour and two above 15 events per hour. Table 1 shows patient demographics.

2.3. Movement classification

The goal of a movement classification method is to determine the type of movement (with respect to physical changes