DETECTION OF DAILY LIFESTYLE CHANGE FROM PULSE RATE MEASURED DURING SLEEP

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Abstract: This study aims at detecting changes in daily lifestyle by using pulse rate measured during sleep. A convenient system for pulse rate measurement during sleep and an algorithm for detection of lifestyle changes were developed in this study. The data collection system consists of a home unit and a database server. The home unit includes a Bluetooth-enabled SpO_2 sensor and a relay station. The sensor measures pulse rate (PR) and SpO_2 beat-by-beat. The relay station receives the measured PR and SpO_2 data via Bluetooth connection with the sensor, and then transmits these data to the database server through Internet automatically. The database server manages the data and performs data analysis. Daily PR data were preprocessed to suppress spike-like noise and movement artefact. Changes in daily lifestyle were detected by a dynamic time warping (DTW) algorithm. Vital data were collected from a healthy college student during daily sleep time over one year, and were used to examine the prototype system. The results showed that unusual or irregular events, such as too much alcohol drink, physical illness and mental stress, could be identified successfully. The system seems promising in application of health care and management under daily life environment.

1 INTRODUCTION

Many chronic diseases, such as diabetes mellitus, hypertension, angiosclerosis, hypercholesterolemia and obesity, usually were conceived over a long period accompanying with poor lifestyle in daily living. Study showed that intensive lifestyle changes may lead to regression of coronary atherosclerosis after one year. More regression of coronary atherosclerosis occurred after five years than after one year (Ornish et al., 1998).

Positive changes in lifestyle are believed helpful in dealing with chronic conditions. Changes in diet and exercise are effective in curbing the development of diabetes in older people (NIH news, 2006). An active lifestyle with appropriate and sufficient physical activity was recommended beneficial in intervening body weight for obesity (Keim et al., 2004).

Monitoring of overt human behavior during normal daily life has become feasible. One of the most commonly used methods to assess daily activities is based on an ambulatory accelerometry (Welk et al., 2000); (Bussmann et al., 2001).

Further, a home-based system deploys a number of low-cost sensors within the home to continually monitor movement of older people, doors opening or closing, environmental temperature and appliance usage. By gathering these lifestyle data over a period of time, a template is created as an average of the client's daily lifestyle profile. This template is then used as a reference by which deviations of lifestyle can be detected (Barnes et al., 1998).

AMON, a wearable medical monitoring and alert system, continuously collects multiple vital signs, detects emergent situation for high-risk cardiac and respiratory patients by integrating the whole system in an unobtrusive, wrist-worn watch without interfering the patients daily activities and without restricting their mobility (Anliker et al., 2004).

A sensor vest was developed to monitor multiple vital signs, such as ECG, pulse, body temperature and acceleration, to transmit data via mobile phone, and to perform data analysis for early warning of lifestyle-related diseases (Chen et al., 2005).

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The purpose of this study is to develop an automatic system for collecting pulse rate (PR) conveniently during sleep, and an algorithm for detecting changes in daily lifestyle. We propose a method to define an initial template of average sleep pattern from daily PR profiles and to evolve on daily base. The template is used as a reference to calculate its similarity with the daily PR profile by the dynamic time warping (DTW) algorithm. We define a sleep index (SI) based on the DTW result to descrcibe daily lifestyle changes. The proposed method is examined by one-year's data collected from a healthy college student.

2 METHOD AND MATERIAL

PR data were collected during sleep using the scheme as showed in Figure 1. The system includes a wrist-type Bluetooth-enabled SpO_2 sensor (Model 4100, Nonin Corp., USA), a bedside box and a database server. Although the SpO_2 sensor collected both PR and SpO_2 data simultaneously, only the PR data were used in this study. The bedside box receives PR and SpO_2 data continuously from the SpO_2 sensor via the Bluetooth connection and transmits the data to the database server by an HTTP connection through a domestic LAN at home during sleep. The database server served for data management, analysis and visualization.

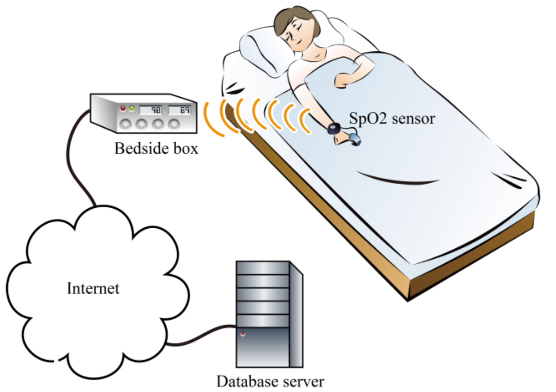

Figure 1: Schematic of PR and SpO_2 data collection during sleep.

2.1 Data Collection

The bedside box is always on a standby status waiting for the SpO_2 sensor to initiate. The Bluetooth connection between the bedside box and the SpO_2 sensor device will be established automatically after the subject lies down to sleep and inserts the SpO_2 sensor into a finger to trigger the SpO_2 sensor switch. The bedside box receives the measured PR and SpO_2 data from the SpO_2 sensor via Bluetooth connection, and then transmits these data to the database server through Internet once a minute. When the subject gets up and removes the sensor from the finger, the Bluetooth connection is closed, the bedside box goes into standby mode again, and the data collection procedure is terminated.

The subject involved in data collection was given the explanation of the task and study purpose, and was asked to sign a consent agreement prior to the data collection. The subject was a male college student in twenties of age, and was allowed to live in usual lifestyle completely over one-year period. The subject was asked to insert the finger into the SpO_2 sensor every night as possible as he could, but occasional skip in measurement in some nights due to personal reason or temporary leave are permitted. Information of the actual daily activities is collected by subject's diary.

2.2 Data Preprocessing

Data preprocessing for noise suppression was implemented using two digital filters in two steps. A median filter was used in the first step to remove spike-like noise, and a Savitzky–Golay filter was used in the second step to smooth the PR profile.

The main source of noise in the raw measurement during sleep is spike-like noise, which is perhaps due to movement artefacts, or misinterpretation of the transmitted data package. Such noise is suppressed in the first step.

The Savitzky–Golay filter was used to smooth the signal that was outputted from the median filter in the first step.

One night sample of PR profiles, raw and preprocessed, are shown in Figure 2.

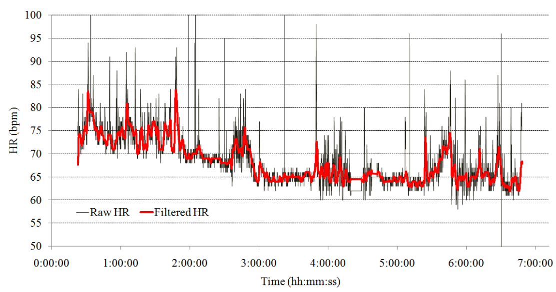

Figure 2: Pulse rate profile during sleep. Raw PR data (thin black trace) and filtered PR data (bold red trace) in single night's sleep.

2.3 Detection of Lifestyle Change

Lifestyle change is detected by the dynamic time warping (DTW) algorithm, which is used to measure the similarity between two data sequences that may generally vary in temporal span and rhythmic tempo.

A similarity measure for the reference pattern R and the test pattern T is determined by the overall minimum distance $D(T, R)$. A smaller distance value indicates a higher similarity.

A template of PR profile was initialized by averaging five regular nights' PR data measured during sleep. Because daily data differs in length, the data lengths in all five nights were normalized to six hours. The initial template adapts evolution on daily base gradually to reflect intrinsic biorhythmic change.

The preprocessed daily PR profile was used in the detection of daily lifestyle change. The template of PR profile was used as the reference pattern, and the daily PR profile was used as the test pattern.

The sleep index (SI) S is defined by normalizing the similarity measure, or the overall minimum distance between two patterns, $D(T, R)$ as below:

$$S = \left(D(T,R) - D_{min}\right) / \left(D_{max} - D_{min}\right) \tag{1}$$

where the value S is between 0 and 1, D_{min} and D_{max} indicate the minimum and maximum similarity values, respectively. The smaller the value S is, the more regular the sleep is.

3 RESULTS

The results by analyzing daily PR data over one year from a healthy male college student in his twenties are presented in Figure 3. The value S was calculated using the DTW method from daily PR profile and the template of PR profile. The lower the value S is, the higher the similarity is with usual daily lifestyle. The higher values of days, whose values are greater than 2SD, indicate the days when the subject had a heavy intake of alcohol, gotten illness or mental stress or other unusual events. It can be observed that 2SD is a proper threshold for detecting irregular lifestyle changes in the proposed method.

4 DISCUSSIONS

Many lifestyle-related chronic diseases threaten human beings. Better lifestyle is believed to be significant in dealing with such diseases. A healthy lifestyle requires a balanced nutrition diet, regular physical activities and proper coping with mental stress. Lifestyle improvement needs to persist. Therefore, it is important to monitor routine lifestyle and its change by a sustainable means.

A daily lifestyle can be considered consisting of a series of physical and mental activities. A variety of wearable devices, such as a wrist-watch or an earphone-like device, an arm belt or a vest, for daytime use usually impede routine activities more or less. Convenient and comfortable monitoring methods are rarely available. It is indispensible to monitor daily lifestyle in a convenient way yet sensitive enough to detect any lifestyle change whenever occurs.

Physical and mental conditions are affected by various endogenous and exogenous factors. The former includes emotional, psychological, and

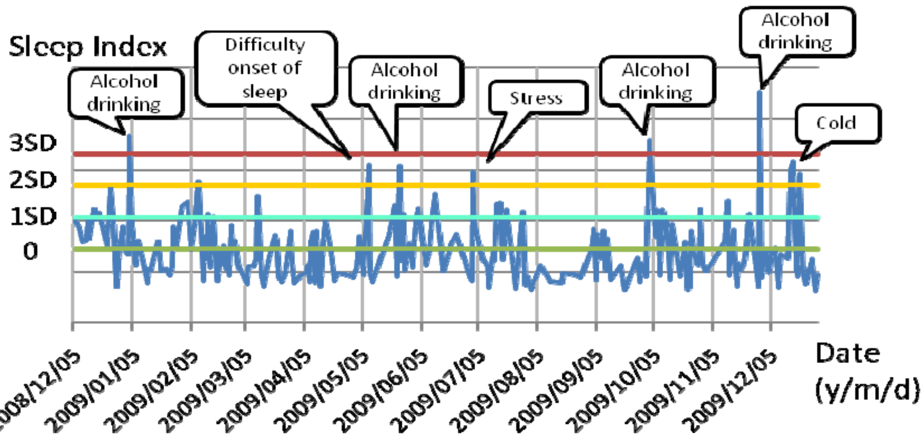

Figure 3: Variation in SI over one year period. Balloon boxes indicate some special events recorded by the subject, and correspond to the higher SI values calculated by the proposed method.

behavioural aspects, and the latter includes meteorological, environmental, geographical, and temporal factors. Human body has to levy upon immune system and auto regulation mechanism to adapt various regular and irregular stimulants physically and mentally. Activities in daytime often preserve memories for a certain period physiologically and psychologically, and usually can be reflected as a physiological response at night.

On the other hand, sleep insufficiency or disorder may cause unpleasantness even illness. Good sleep can help to not only secrete growth hormone and recover human body's physiological functions, but also relieve mental aspect from stress and build up immune system.

Instead of identifying every detail of daily activities in daytime, we believe that it is possible to monitor physiological condition during sleep at night to reflect the lifestyle change in daytime indirectly.

Standard polysomnography method provides an accurate approach to monitor multiple parameters and perform comprehensive sleep analysis, but requires professional intervention and is highly expensive, therefore is unsuitable for daily application at home.

We developed a convenient device for automatic collecting PR data during sleep and an algorithm to detect lifestyle change from these PR data. Various specific events, such as alcohol drink, mental depression and physical illness, and other commonly non-routine epochs in daytime are confirmed often bringing disturbance or disorder in sleep at night, and are probably reflected on night-time PR profiles. This study demonstrated availability to detect these daily behavioural changes during waking hours by the PR data collected during sleep.

This method is recognized feasible for a user over one year test. However, more data from more users in different age groups and longer period of data collection are desirable in further validation of the proposed method. More sensitive and robust algorithms are also worth to be explored in depth.

5 CONCLUSIONS

In this study, we developed a convenient system to measure PR and SpO_2 data during sleep, and a DTW-based algorithm to detect lifestyle change using daily PR profile. The proposed method was examined by one-year data and confirmed sensitive in detecting lifestyle change due to various incentives. It suggests a promising method for daily health management and chronic disease prevention.

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