AUTOMATIC MONITORING OF SLEEP BEHAVIOUR IN NURSING HOME RESIDENTS

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ABSTRACT
In this paper, we propose a completely unconstrained method for automatic monitoring of sleep behaviour and health status in nursing home residents using an Internet-based automatic sleep monitoring system mainly composed of a pressure sensor and a data server. When a nursing home resident lies in bed, his/her pressure variations due to heart pulsation, respiration, and body movement are sensed by a pressure sensor under a pillow or mattress. Then the corresponding digital signal is sent to a data server via Internet and processed by a background program to obtain heart rate, respiration rhythm, and body movement information in bed. 231 whole days’ data from 5 subjects in a nursing home were obtained by this system for evaluation. Through comparing with records provided by nursing home staff, we found our system can accurately and reliably estimate heart rate, respiration rhythm, and body movement during sleep for the analysis of circadian rhythm and sleep quality. It is concluded that our method may serve as an effective and convenient tool for automatic monitoring nursing home residents’ casual lifestyle, circadian rhythm, and health status. The introduction of this system may also lessen the burden of nursing home staff and help to realize personal specific healthcare service.

KEY WORDS
Automatic monitoring, nursing home resident, pressure sensor, sleep disturbance, and circadian rhythm

1. Introduction

Based on a report issued by Japan Ministry of Health, Labour and Welfare [1], it is estimated that 13.1% of Japan’s population will be over 75 years old in 2015 and this percentage will continue increasing to 26.5% in 2055. Furthermore, 11.7% of Japan’s population over 65 years old is expected to have dementia diseases and cannot live independently in 2015. However, the support from other family members is unreliable because it is found that 64.4% of elderly families in Japan will only be composed of 1~2 members at that time. Nevertheless, Japan’s elderly healthcare and life support facilities are not enough and could only provide healthcare service to 4.4% of elderly over 65 years old currently. After the modification of Act on Social Welfare Service for Elderly in Japan, the number of private residential home has increased at an annual speed of 16.2%. Simulations have shown that the number of healthcare staff in 2025 should be raised to 2.12~2.55 million, about twice of that in 2008 [2]. With the increments of nursing home and requirement for long term care, an objective measurement is required to evaluate the service, quality and outcome of healthcare in nursing home [3]. Furthermore, because most of nursing home residents have chronic diseases and mental disabilities, a long term and convenient health monitoring method is required to confirm the health status of nursing home residents. Moreover, because the lack of qualified staff is also puzzling most nursing home, an automatic monitoring system is needed to reduce the labour burden of staff and therefore increase their efficiency.

To date, in response to these requirements, many healthcare monitoring systems have been developed especially for monitoring sleep in nursing home residents because sleep disturbances are frequently found in elderly with dementia diseases [4][5]. The sleep monitoring system can provide evidence for effective diagnosis, therapy, and healthcare of nursing home residents’ sleep disturbances [6][7]. Fetveit and Bjorvatn used actigraphical measurements to detect sleep onset latency, long mean wake time, and sleep efficiency among 29 nursing home residents [6]. Through comparing with nursing staff’s observations, they found that the subjects have a mean sleep onset of 1 hour, a mean wake after sleep onset of over 2 hours, and a mean sleep efficiency of 75%. Alessi and Schnelle found that common lifestyle characteristics, i.e., inactivity, long time in bed, lack of bright light exposure, and poor hygiene, and nursing home environments may interfere with sleep as well as pathological factors [8]. Jacobs et al. observed that sleep patterns of nursing home residents were fragmented and it might be attributed to compensation for lost sleep, increased total time in bed, weakening of social constraints, and deterioration of the circadian sleep-wake rhythm [9]. Ancoli-Israel et al. used wrist activity for monitoring sleep/wake in demented nursing home patients [10]. Paavilainen et al. employed a telemetric actigraphy method for long-term monitoring of sleep/wake and circadian activity patterns in the elderly in nursing home and at home [11]. Chee et al. developed an air mattress sensor system with balancing tube for unconstrained measurement of respiration and heart beat movements [12][13]. Watanabe et al. used a thin, air-sealed cushion
and a pressure sensor placed under the bed mattress to measure heartbeat, respiration, snoring and body movements of a subject in bed [14]. Brink et al. also used actigram to realize a contact-free measurement of heart rate, respiration rate, and body movement during sleep [15]. Kortelainen et al. used FFT averaging of multichannel BCG singles from bed mattress sensor to improve estimation of heart beat interval [16]. Bu et al. developed a respiration and heartbeat monitoring system using a flexible piezoelectric film sensor and empirical mode decomposition [17]. Our research team has developed an automatic sleep monitoring system for home healthcare [18]. In this research, we used this system to monitor sleep behaviour in 5 nursing home residents and recorded a total of 231 whole days’ data. Through comparing with nursing home staff’s records, it is shown that our system can serve a low-cost and convenient tool for long term sleep quality and casual lifestyle monitoring of nursing home residents.

2. Methods and Materials

2.1 Subjects

Total 231 whole days’ data were obtained from 5 female subjects in a nursing home in Aizu-Wakamatsu, Fukushima, Japan. Their average age is 87.4 years old. 4 of them have dementia of the Alzheimer’s type, and 4 of them have hypertension. We have obtained the records with detailed behaviour information about these 5 subjects written by nursing home staff. Table 1 lists the details about the 5 subjects.

Table 1

<table>
<thead>
<tr>
<th>Recording date</th>
<th>Age</th>
<th>Main diseases</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011/12/01~2011/12/31</td>
<td>89</td>
<td>dementia of the Alzheimer’s type, hypertension</td>
</tr>
<tr>
<td>2011/05/31~2011/07/23</td>
<td>76</td>
<td>dementia of the Alzheimer’s type</td>
</tr>
<tr>
<td>2012/01/01~2012/03/11</td>
<td>87</td>
<td>dementia of the Alzheimer’s type, hypertension, congestive heart failure</td>
</tr>
<tr>
<td>2012/01/01~2012/02/29</td>
<td>90</td>
<td>dementia of the Alzheimer’s type</td>
</tr>
<tr>
<td>2012/05/19~2012/05/31</td>
<td>95</td>
<td>hypertension, angina pectoris, cardiac hypertrophy, heart failure</td>
</tr>
</tbody>
</table>

This research has been approved by the University of Aizu, and Keiwakai, a social welfare service corporation in charge of the collaborative nursing home. Informed consent and signed agreement forms were obtained from the subjects’ guardians after this research’s details were explained directly by nursing home staff.

2.2 Methods

The details of automatic monitoring system used in this research have been described in [18], and therefore we only give a brief introduction about it in this paper. Fig. 1 illustrates the schematic of automatic sleep monitoring system, which is composed of a sensor board, environmental sensor box, bedside box, and servers. The sensor board can be placed under a pillow or mattress to sense the heart pulsation, respiration activity, and body movement. And the sensor board can automatically detect whether a subject is in bed or not [19]. When the subject’s pressure variation is sensed, the raw signal is amplified and digitized in the bedside box at a sampling rate of 100 Hz and transmitted to servers via Internet for storage and further processing. Then, heart rate, respiration rhythm, and body movement are estimated in an interval of 1 minute. When the signal is free of body movement or is not too low to estimate useful information, heart rate and respiration rhythm are calculated in a

Figure 1. Schematic of automatic sleep monitoring system modified from [12].

Figure 2. Raw pressure (a), extracted pulse waveform (b), and extracted respiration waveform (c). Characteristic points detected in pulse and respiration waveforms are marked with red circles for the estimation of heart rate and respiration rhythm.
wavelet transform based method [19]. Fig. 2 illustrates the raw pressure signal and the corresponding pulse and respiration waveforms extracted from the raw signal. Characteristic points detected in pulse and respiration waveforms are marked with red circles in Fig. 2 for the estimation of heart rate and respiration rhythm.

3. Results

Fig. 3 illustrates the “in bed” and “out of bed” detection results of 5 nursing home residents. Data from the left to right are recorded from 18:00 of the preceding day till 17:59 of the current day. The “in bed” and “out of bed” status are shown with white and black colors, respectively. It is observed that all subjects have a circadian rhythm but demonstrate fragmented sleep, which was in consistent with nursing home staff’s records. Fragmented sleep is manifested by constantly toilet visiting, meaningless wandering, early waking up, sleeplessness, and etc. And fragment sleep is more apparent in day sleep compared with night sleep. This might indicate that day sleep is not so efficient as night sleep.

Table 2
Each subject’s everyday average “in bed” time and stable “in bed” time calculated from data illustrated in Fig. 4 and 5, and each subject’s corresponding sleep efficiency.

<table>
<thead>
<tr>
<th>ID</th>
<th>Average “in bed” time in a whole day</th>
<th>Average stable “in bed” time in a whole day</th>
<th>Sleep efficiency*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>14.4 h</td>
<td>10.8 h</td>
<td>75%</td>
</tr>
<tr>
<td>2</td>
<td>12.5 h</td>
<td>7.9 h</td>
<td>63%</td>
</tr>
<tr>
<td>3</td>
<td>9.5 h</td>
<td>5.6 h</td>
<td>59%</td>
</tr>
<tr>
<td>4</td>
<td>16.8 h</td>
<td>10.1 h</td>
<td>60%</td>
</tr>
<tr>
<td>5</td>
<td>13.6 h</td>
<td>6.7 h</td>
<td>49%</td>
</tr>
</tbody>
</table>

*Sleep efficiency = Average stable “in bed” time in a whole day/ Average “in bed” time in a whole day.

Fig. 4 illustrates the average “in bed” and “out of bed” profile of each resident. The value of the profile is in [0, 1] and corresponds to the possibility of “in bed” status. It is observed that subjects 5 usually go to bed after 18:00 earlier than subjects 1~4 subjects. However, if we removed “body movement” and “low signal” status from “in bed” status as shown in Fig. 5, subject 5 had frequent and irregular body movement during the night’s sleep. We also observed that subject 4 showed rather long sleep latency by comparing her “in bed” profiles in Fig. 4 and 5. These phenomena are consistent with nursing home staff’s records about subjects 4 and 5: subject 4 often got up for toilet at night, and subject 5 has frequent movement after going to bed in the evening. The profiles in Fig. 4 and 5 can also be regarded the percentage of “in bed” and stable “in bed” at each minute within a whole day. Table 2 lists each subject’s average “in bed” time and stable “in bed” time in a whole day calculated from data illustrated.
in Fig. 4 and 5, and each subject’s sleep efficiency defined by the ratio of the previous two indexes. It is clear that subject 5 has the lowest sleep efficiency value.

Besides the circadian rhythm as shown in Fig. 3-5, day-by-day circadian rhythm variation can also be found by daily “in bed” and “out of bed” information. Fig. 6 illustrates the correlation coefficient of “in bed” and “out of bed” patterns with the average “in bed” and “out of bed” pattern in subject 4. The lower correlation coefficient on Feb. 25th, 2012 is due to long time in bed on that day as shown in Fig. 7, which illustrates the time in bed profile from Jan. 1st, 2012 till Feb. 29th, 2012.

What’s more, heart rate and respiration profile can be estimated when a subject is within a stable status in bed. Fig. 8 illustrates the heart rate (black dots), respiration rhythm (red dots), body movement (magnet dots), “out of bed” (blue dots), and “low signal” (green dots) information detected by this system from subject 5 from 18:00 of May 19th, 2012 till 17:59 of May 20th, 2012. It is observed that subject 5 had frequent body movement in bed before about 00:10, when she got up for toilet. The heart rate gradually decreased with the reduction of body movement after that time. This indicates that deep sleep is accompanied with less body movement and reduced heart rate. Furthermore, time in bed between 14:00 and 17:00 was nearly occupied by body movement and therefore the day-time sleep might be of low efficiency for subject 5.

Figure 6. Correlation coefficient of “in bed” and “out of bed” patterns with the average “in bed” and “out of bed” pattern in subject 4.

Figure 7. Time in bed of subject 4 from from Jan. 1st, 2012 till Feb. 29th, 2012.

Figure 8. Heart rate (black dots), respiration rhythm (red dots), body movement (magnet dots), “out of bed” (blue dots), and “low signal” (green dots) information detected by this system from subject 5 from 18:00 of May 19th, 2012 till 17:59 of May 20th, 2012.

Figure 9. Heart rate (black dots), respiration rhythm (red dots), body movement (magnet dots), “out of bed” (blue dots), and “low signal” (green dots) information detected by this system from subject 4 from 18:00 of Jan. 29th, 2012 till 17:59 of Jan. 30th, 2012.
dots) information of subject 4 from 18:00 of Jan. 29th, 2012 till 17:59 of Jan. 30th, 2012. Although time in bed was even longer than half of a day, body movement was frequently detected and heart rate didn’t reduce a lot at night. Her sleep quality might be dissatisfying at that night. However, the frequent body movement in bed at night is not recorded by nursing home staff’s records. Subject 4’s body movement at that night might be too unapparent to be noticed by nursing home staff.

4. Discussion

In this research, we used an automatic sleep monitoring system to obtain sleep-related information such as time in bed and physiological indexes including heart rate, respiration rhythm, and body movement during sleep. There are two main goals to introduce this system to nursing home. The first goal is to monitor healthcare and sleep quality of nursing home residents. Through analyzing data from 5 nursing home residents, we obtained long term “in bed” and “out of bed” data, from which circadian rhythms could be confirmed as shown in Fig. 3. Furthermore, fragmented sleep and circadian rhythm variations of nursing home residents can be also easily confirmed by body movement and time in bed as shown in Fig. 4, 5, 8 and 9. The frequency of body movement and circadian rhythm variation may provide evidence for sleep disturbances and low sleep quality of nursing home residents with chronic diseases [4][5].

As for the other goal, it is to lessen the labour burden of nursing home staff. At first, this system is convenient and does not require the nursing home staff’s maintenance. All data are transmitted to servers via Internet for further processing. Furthermore, data obtained by this system are supplementary to nursing home staff’s records. The data obtained by this system have a higher temporal resolution (1 min) compared with nursing home staff’s records, which are usually written in an interval about 30 min. Some detailed information, such as body movement and time in bed can be easily obtained by our system. Our system is more sensitive to find body movement in bed, which was overlooked by nursing home staff. By using our system, it may help nursing home staff to timely obtain the detailed health status of nursing home residents and provide necessary care if necessary. And it is also possible to help realize personal specific healthcare service by employing the information obtained by this system.

On the other hand, Ben-dov et al. have proved that cardiovascular subjects with no reduced heart rate during night’s sleep may have a higher mortality [20]. Song also confirmed that demented subjects may show sleep disturbances such as sleep fragmentation and sleep latency [4]. Therefore, long term heart rate and sleep quality information estimated by our system are also useful for the diagnosis of chronic cardiovascular and sleep diseases in nursing home residents. The estimation of heart rate and respiration rhythm during sleep is hampered mainly due to body movement. Weak signals caused by low contact pressure are rare as shown in Fig. 8 and 9. This proved the reliability of our system in detecting heart rate and respiration rhythm during sleep.

5. Conclusion

In this research, we employed an automatic sleep monitoring system to estimate time in bed and physiological indexes during sleep in nursing home residents. Through analyzing 231 whole days’ data from 5 subjects, our system can provide reliable and accurate information about time in bed and physiological indexes for further analysis of circadian rhythm and circadian rhythm variations, and sleep quality. Our system may serve as a tool to estimate health status and sleep quality of nursing home residents, and ease the labour burden of nursing home staff through providing high temporal resolution information of nursing home residents.

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References


