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RESEARCH ON THE APPLICATION OF WEARABLE DEVICES IN THE MANAGEMENT OF SEAFARERS' FATIGUE

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Abstract. Global concerns on the issue of fatigue at sea are widely evident across the shipping industry. Fatigue-induced human errors have already been identified and widely accepted as major contributing factors in most maritime accidents. It is confirmed that sleep and rest are the most crucial elements affecting human fatigue and subsequent impaired work performance. A deep and uninterrupted sleep is important for a normal seafarer who wants to have a good performance at work. Although many studies and research projects concerning fatigue have been undertaken in recent years, there are so far no effective or sufficient measures to deal with the problem because of sophisticated challenges and lack of knowledge.
This paper attempts to explore an approach to set up a new strategy of fatigue management for seafarers based on smart phone application combined with wearable devices. Smartphone-based interactive information platform and wearable devices, such as mi band wristband which has the function of sphygmomanometer, wrist movement monitor and sleep monitor, are introduced and used to collect and record each physiological data naturally and conveniently. These data is stored in the smart phone in real time via Bluetooth and can then be uploaded and stored in the Cloud once the smart phone is connected to the internet. Moreover, the data can be analyzed by the smart phone Apps and a report implying the fatigue level can be proposed based on the analysis. Besides, with the interactive information platform, it will be easy for the manager of the shipping company to discover the fatigue risks of their seafarers and it could be convenient for them to manage fatigue.

Key words: seafarers, fatigue monitoring, wearable devices

1 INTRODUCTION

Fatigue is a common problem in the general population (Bensing, et al, 1999; David, et al, 1990). Prevalence of fatigue in the general working population has been estimated to be as high as 22% (Bültman et al., 2002). Among the general working population, fatigue has been associated with accidents and injuries (Bonnet and Arand, 1995; Hamelin, 1987). There is also a clear link between fatigue and ill health (Andrea, et al, 2003; Folkard, et al, 2005; Huibers, et al, 2004; Leone, et al, 2006), as well as impaired work performance (Charlton and Baas, 2001), sick leave and disability (Janssen, et al, 2003; van Amelsvoort, et al, 2002).

A great amount of research has shown that fatigue is still a major issue at sea. It was regarded as the first concern of seafarers in a study concerning ship manning (National Research Council, 1990). It was revealed in a US Coastguard study that 16% of critical vessel accidents and 33% of personal injury accidents were caused by fatigue directly or indirectly (McCallum, et al, 1996). It was also found in the study that fatigue's contribution to groundings and to collisions was 36% and 25% respectively (McCallum, et al, 1996). However, the values were much higher in another Japanese study: 53% for groundings and 38% for collisions (Det Norske Veritas, 1999).

Fatigue varies from one person to another due to individual attributes as well as circumstances, among which sleep is a factor that can not be ignored. It is certain that sleep and rest are the most crucial elements affecting human fatigue and subsequent impaired work performance. It has been confirmed that quality, quantity and duration of sleep are three key components for a good sleep. A deep and uninterrupted sleep is important for a normal seafarer who wants to have a good performance at work (IMO, 2001). For most people, any less than five hours sleep can lead to drowsiness the next day. According to the Research of the US Coast Guard, people need 7-8 hours of sleep per 24-hours to perform at their best.

2 FATIGUE MONITORING METHODS

Most people are aware of the dangers of driver fatigue but our ability to recognize the signs diminishes as we become more fatigued. Therefore the monitoring of fatigue becomes very important for the prevention and reduction of the effect of fatigue. The researchers all over the world have proposed many methods and means for the monitoring of fatigue. Pan Xiaodong, Li Junxian (Pan and Li, 2011)developed a method to develop the driver s' fatigue based on the eye movement of the drivers; Sun Hui (Sun, 2013) introduced a algorithm for on-time fatigue monitoring based on electroencephalogram (EEG); Xiong Yunxia (Xiong, 2014) introduced a fatigue monitoring system based on pulse signal; Mao Zhe (Mao, 2006) developed a method for the recognition of fatigue based on the analysis of the physiological feature of the driver, such as blood pressure, body temperature, breathing frequency, etc..

As to the monitoring and assessment of seafarers' fatigue, the following methods were used: a questionnaire survey of working and rest hours, physical and mental health; Physiological assays assessing fatigue; Instrument recordings of sleep, ship motion, and noise; Self-report diaries recording sleep quality and work patterns; Objective assessments and subjective ratings of mental functioning; Pre- and post-tour assessments and Analysis of accident and injury data.

Even though many methods or techniques were developed to overcome the limitation of fatigue monitoring, there are still some disadvantages, among which inconvenience is the most serious one due to the size and procedure of the equipment used in these methods.

3 FATIGUE MONITORING BASED ON MI BAND

The miniaturization of electrical and electronic equipment is certainly not a new phenomenon, and its effects have long been evident in the healthcare sector. Wearable devices are of emerging interest due to their potential influence in certain aspects of modern healthcare practices, most notably in delivering point of care service, by providing remote monitoring, ambulatory monitoring within the healthcare environment, and support for rehabilitating patients, the chronically ill and the disabled. Among all these equipment, Smartband is the most famous one as it is very simple to operate by non medical professionals in uncontrolled environments.

3.1 Introduction of the device and the APP

In the research, Mi band is chosen as the monitoring device. Mi band is the wearable device produced by Xiaomi, a very popular Internet company in China. The band is composed of a military-grade accelerometer, a low-power Bluetooth chip, wristband and rechargeable battery. The data is stored in the band and can be synchronized if the band is connected with smart phone or tablet computer. The data can be stored in the band for 7 days if it is not synchronized to the smart phone.

The APP used in the experiment is Mi Fit which is developed by Xiaomi company. The APP is consisted of several elements, namely data collection unit, data storage unit, data analysis unit and share and feedback unit.

The users can access and read the data via the APP installed in a smart phone. The data is analyzed in the database, giving the result in the form of bar chart. The body movement is collected when the wearer is asleep and the wake-sleep situation can be indicated indirectly by measuring the motion state and amount of exercise continuously. Moreover, the data can be uploaded and stored in the Cloud if the phone is networked. As a new feature, the achievement of your exercise, as well as your sleep quantity and quality, can be shared with your friends via facebook, twitter and wechat.

4 DATA COLLECTION

The data collected by Mi Band includes sleep onset latency (SOL), wake after sleep onset (WASO), total sleep time (TST), deep sleep time (DST) and light sleep time (LST). The total sleep time, as well as percentage and distribution of deep sleep time and light sleep time, can be read directly in the APP, as shown in Figure 1. The statistic of these data can be stored and displayed for as long as 30 days, as shown in Figure 2. Moreover, deep sleep time can be demonstrated by bar chart in a

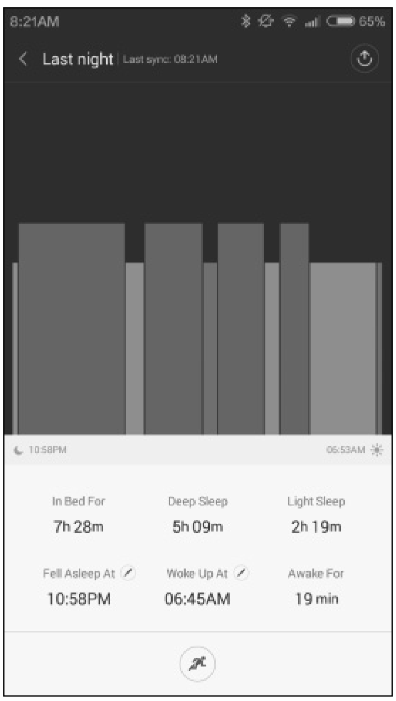

Figure 1
Total sleep time

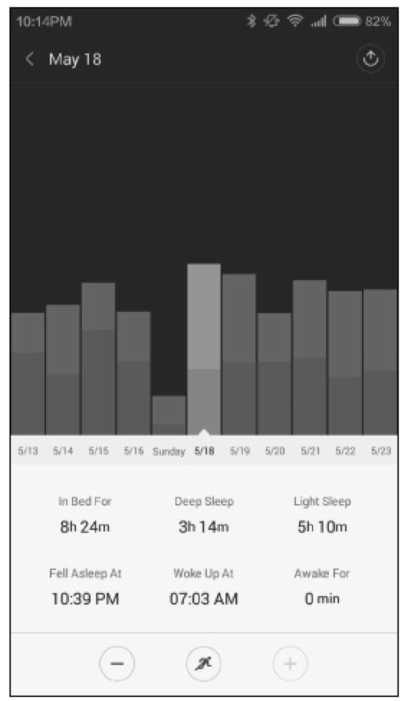

Figure 2
Record of sleep time for 11 days

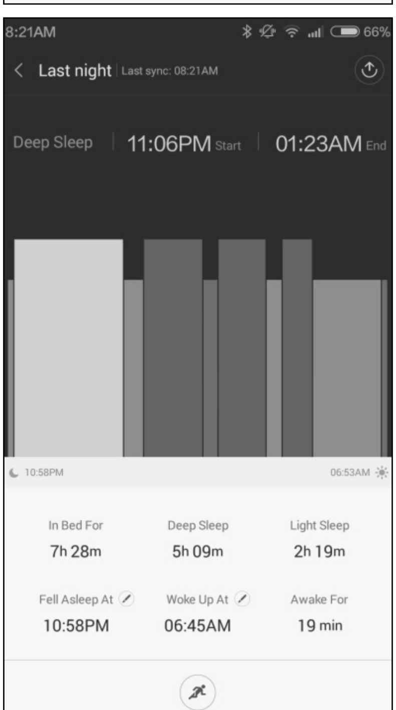

Figure 3
Distribution of deep sleep time

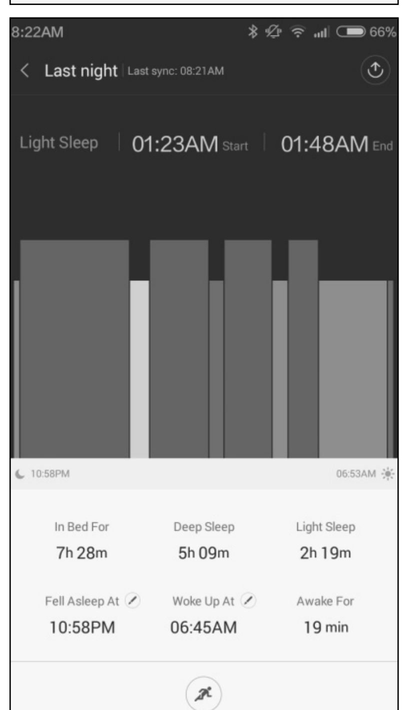

Figure 4
Distribution of light sleep time

daily basis, shown as Figure 3. Similarly, each light sleep time can be displayed by bar chart like Figure 4.

5 EXPERIMENT ON THE MONITORING OF SLEEP

5.1 Experiment setup

In the experiment, 2 vessels were selected and 12 ratings joined the experiment as volunteers, among whom 6 from deck department and 6 from engine department. During the experiment, each person should wear the Mi band the whole day for one week, even when taking a shower.

As a comparison, the volunteers were also asked to record and grade their sleep quality (SQ) in a daily basis. The value for each grade is within the interval of [0,100]. The grades for the sleep quality were divided into five levels v_1, v_2, v_3, v_4, v_5, namely very bad, bad, medium, good and very good, as shown in table 1. So the appraisal set is obtained as follows:

$$V= \{v_1, v_2, v_3, v_4, v_5\} =$$
{ very bad, bad, medium, good and very good }

Table 1 levels of sleep quality

Level	V_1	V_2	V_3	V_4	V_5
Score	<60	60~70	70~80	80~90	90~100

5.2 Selection of indexes

According to Pittsburgh sleep quality index (PSQI), 7 important indexes were selected as the features for classification and prediction, which include sleep onset latency (SOL), wake after sleep onset (WASO), total sleep time (TST), sleep efficiency (SE, TST/(WASO+SOL+TST)), awake sleep ratio (ASR, WASO/TST), deep sleep time ratio (DSTR, DST/TST) and light sleep time ratio (LSTR, LST/TST).

5.3 Result and analysis

The result of sleep quality of each person can be demonstrated by a line chart, as shown in Figure 5. And the sleep quality of these 12 volunteers was classified, as shown in Figure 6. From the result, it is clear that the sleep quality of half of the volunteers were moderate.

As a comparison, some statistical analysis was done on the grades given by these volunteers. The analysis indicated that almost half of the volunteers thought their sleep quality were moderate, which is consistent with the data obtained by the Mi band. Therefore, it can be speculated that the Mi band can be used for the monitoring of seafarers' sleep and further for the evaluation of their fatigue degree.

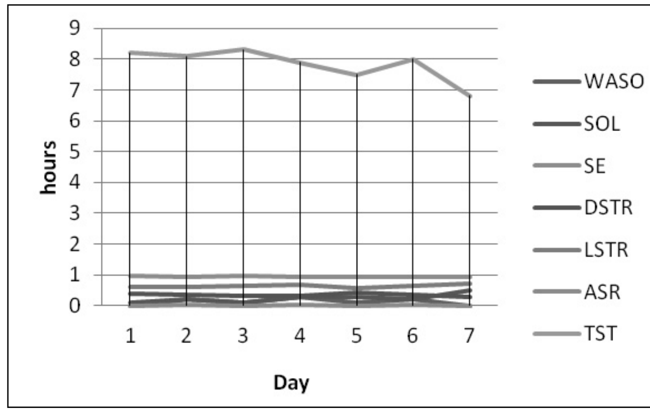

Figure 5 Result of the indexes

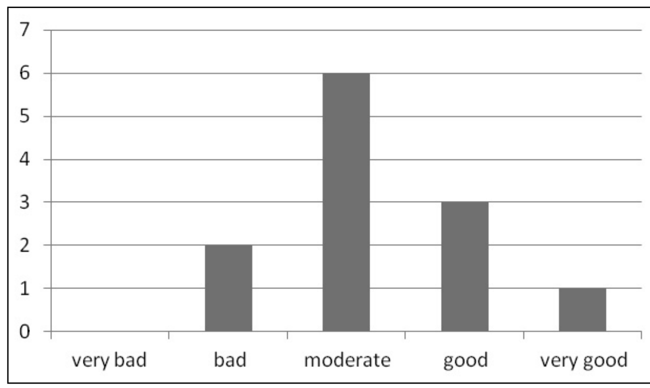

Figure 6 Distribution of each level of sleep quality of volunteers

6 CONCLUSION

The paper tried to demonstrate that the Mi ban, a wearable device, can be used in the monitoring of seafarers' sleep and for the evaluation of their fatigue degree. By contrasting the data obtained by Mi band with the appraisal grade given by the volunteers in the experiment, it proved that the data obtained by the band has high accuracy.

However, there are still some problems as to the design of the experiment. Firstly, the number of volunteers is not large enough, which has weak persuasiveness on the result of the experiment. Secondly, the experiment time is not long enough. The experiment will be carried out for 30 days in the future research. Last but not least, more work still need to do on the principle for each level of sleep quality.

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