Chapter 30
Sleep Monitoring System Equipped with a Flexible Non-Contact ECG, Respiration, and Body Motion Sensor

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ABSTRACT

This study focuses on non-contact ECG measurement technology and introduces a sleep monitoring system equipped with non-contact electrocardiogram (ECG) electrodes and a respiration/motion sensor. The non-contact ECG measurement can be attained using capacitively-coupled electrode technology. The ECG of a subject with nightwear, such as pajamas, can be measured using this technique because it measures the ECG through a capacitor formed between the electrode and the ECG signal source. Using this sleep monitoring system, various sleep conditions of the elderly can be monitored, and abnormalities can be identified, such as abnormal heart rate and sleep behavior, including ambulation and sleep apnea, without disrupting their sleep. In many industrialized countries, including Japan, society is rapidly aging, and there is increasing demand for a system that can monitor the sleep of the elderly in nursing homes and care facilities and those living alone at home and thus increase their quality of life. By connecting this system with the hospital information systems or electronic medical record system, medical support and care planning will be more efficient.

INTRODUCTION

Japanese society has been aging, and more than 25% of the population is now over 65 years old (Cabinet Office, Government of Japan, 2010). Care facilities are increasing as a result, and more than 840,000 elderly people are living in such facilities in 2009 (Ministry of Health, Labor and Welfare, 2009). The number of staff at nursing homes is increasing, but fewer staff work at night. Hence, an increased number of accidents after midnight remain a concern, e.g., falls when trying to get out of bed, respiratory arrest due to aspiration,

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and sauntering after midnight (e.g., Fujiwara, Kanamori, Noda, Nakano, Matsuura & Makikawa 2006, pp. 93-94). To prevent such accidents at care facilities, a sleep monitoring system has been developed here (Ishida, Shiozawa & Makikawa, 2006, pp. 85-88).

In this sleep monitoring system, electrocardiogram (ECG) and respiration are monitored. The reason to monitor the ECG is that various information on health conditions can be obtained from the electrocardiography and heart abnormal function, such as arrhythmia, (Maruyama, Shiozawa & Makikawa, 2006, pp. 177-183). The ECG is commonly used as an indicator of heart function in hospitals during surgery, for postoperative monitoring, and for monitoring heart activity in daily life. In addition, many researchers have studied the quantitative evaluation of the function of the autonomic nervous system using heart variability; studies to evaluate the comfort quantitatively (e.g., Ogata, Ishii, Mukai, Ohnishi & Yagi, 2009, pp. 1808-1814), to evaluate mental stress using heart variability (e.g., Nishikoji, Matsumura & Kurita, 2001, pp. 249-252), and to estimate sleep depth (e.g., Michimori, Fukushima & Hagiwara, 2003; Bonnet & Arand, 1997, pp. 29-33) have been conducted. Because of the increasing demand for healthcare, the arterial pulse wave detector has started to be equipped with healthcare products and health appliances, i.e., a massage chair with a plethysmograph (e.g., Inbe & Michimori, 1996, pp. 405-408) and a wristwatch-style ECG monitor.

Even though the ECG measurement skin electrode is commonly used, this skin electrode has various problems for long-term measurements, such as ECG measurements during sleep. The attachment of electrodes to the skin for lengthy times causes skin irritation or electrode deterioration. Because the electrodes are physically connected to the monitoring apparatus by signal cables, the user should re-paste the electrodes or re-connect the signal cables every time he/she moves to another room. Therefore, non-invasive, non-contact capacitively-coupled electrode technology to measure the biosignals of users with nightwear, such as pajamas, has been studied more extensively in recent years (Lim, Kim & Park, 2004; Kim, Lim & Park, 2004; Lim, Kim & Park, 2007).

Capacitively-coupled electrodes form an electrical capacitor between the biological source and the electrode with clothing as an insulator, and the biosignal can be measured through this capacitor. This capacitively-coupled electrode has been studied since 1973 (Geddes & Valentinuzzi, 1973, pp. 356-367), and in recent years, researchers have reported on non-contact ECG measurement on the surface of clothes (e.g., Ueno, Furusawa, Hoshino & Ishiyama, 2004, pp. 1664-1671). Thus, we adopted this capacitively-coupled electrode technology in our sleep monitoring system.

Figure 1 shows the outline of our sleep monitoring system. As shown in Figure 1, this system was developed for care facilities for the elderly, where nurses and certified care workers need to monitor the health condition of residents. ECG, respiration and motion signals are measured by the non-contact ECG electrode and the respiration/motion sensor on the bed, and these signals are transmitted to the monitoring server at the care station via a LAN. The on/off-bed status of each resident and their physiological signal based on ECG and respiration are monitored automatically on the server; when an abnormal physiological signal, such as apnea or an abnormal ECG, is detected, the server sends out an alarm, warning the care station and the mobile phones of the doctors through public communication lines. Doctors can see the abnormal data on the screen of their smart phones. This paper focuses on non-contact ECG measurement techniques and describes a sleep monitoring system for the elderly.

ECG MEASUREMENT USING CAPACITY-COUPLED ELECTRODE TECHNOLOGY

Figure 2 shows the principle of ECG measurement using a capacitively-coupled electrode (Maruyama, Shiozawa & Makikawa, 2006, pp.