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A new bed-exiting alarm system for welfare facility residents

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***Abstract*— A newly developed alarm system detects welfare facility residents leaving their beds, and does not respond to the care staff, who wear shoes or slippers. It employs a stainless steel tape electrode, several linear integrated circuits and a low-power 8-bit single chip microcomputer. The electrode, which is used as a bed-exiting detection sensor, is attached to the floor mat to record changes in the always-present AC (alternating current) voltage induced on the patient's body by electrostatic coupling from the standard 100 volt, 60 Hz AC utility power wiring in the room walls and ceiling. The resident's body movements, before trying to get out of bed and after leaving the bed, are detected by the microcomputer from changes in the induced AC voltage. The microcomputer alerts the care staff station, via a power line communication system or PHS (personal handy phone System).**

I. Introduction

In Japan, physical restraint of patients at welfare facilities and hospitals was prohibited with the enforcement of a long-term care insurance law. Therefore, 24-hour staff monitoring is required for care of the residents. Those with dementia have behavior disorders, such as wandering at any time, day or night. This is a serious problem for care staffs, as it is a major cause of death in the elderly population. However, the care staff cannot personally observe the resident's behavior constantly, so remotely detecting the resident's behavior before and upon leaving the bed is very important [1-5].

Whether the resident is in or out of bed has been detected by measuring the resident's weight in bed and also by the distribution of a magnetic wave around the bed. Weight was measured with four weight sensors attached under the four legs of the bed frame. The magnetic system, which is considered to have no biological effects, emitted a magnetic wave to the patient. The detected distribution of the magnetic field indicates the location and movement of the resident in the bed. These systems have the problem that not only the resident, but also the care staff and visitors trigger the alarm [6-17].

This newly-developed bed-exiting system detects welfare facility residents leaving their beds, and does not respond to the care staff, who wear shoes or slippers. The system detects changes in the small, harmless, but always-present, AC (alternating current) voltage on the patient's body, as induced by electrostatic coupling to the patient body from the normal AC power wiring in patient room walls, floor and ceiling. An electrode attached to the floor mat records this voltage, without patient awareness of the system's existence. The system does not use any patient-attached sensors or a magnetic field, and has nothing attached to or within the bed, which makes it inexpensive and easy to use and maintain.

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II. Method

Figure 1 shows the bed-exiting alarm system. It is well known that the field produced by 100V or 200V 60 Hz power lines surrounding resident rooms induces an AC voltage to the body by electrostatic coupling (Cab), when people are in rooms of any building that has standard AC power wiring. The field often causes interference to sensitive ECG and EEG research recordings, which may require a special shielded room. In general, the 60 Hz field is a constant problem in clinical and research settings, although the filters in modern medical instruments greatly reduce its influence.

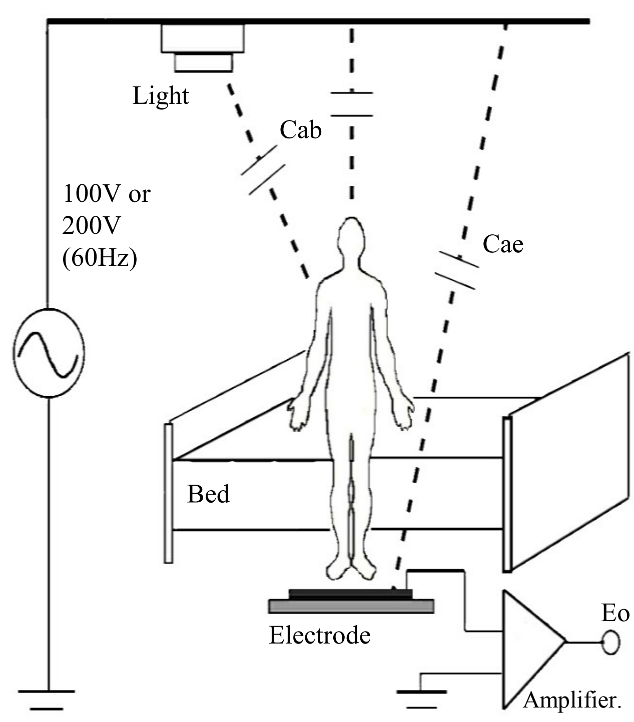

Fig.1 The overall bed-exiting alarm system.

This system usefully employs the usually-undesirable 60 Hz AC voltage induced in the resident as a signal source for detecting bed-exiting (the authors hope this delights our fellow biomedical engineers; we all constantly fight 60 Hz interference). In bed, and initially upon bed exit, the residents are always barefoot or have on thin socks, which provide a relatively low-impedance connection, as compared to shoes or slippers, to the floor mat electrode. Although socks may seem to be high-impedance, they contain, after a few minutes of wearing, a small amount of foot perspiration, which lowers their impedance. The mat is always stepped on with one or both feet when the resident starts to get out of bed, increasing the pad induced voltage from baseline. On the other hand, care staff and visitors wear high-impedance shoes or slippers, so when they step on the floor mat, the induced pad voltage increase is lower than that caused by the resident. Therefore, the system detects residents leaving their beds, and does not respond to the staff or visitors.

III. System Description

The system consists of the electrode and a bed-exiting alarm circuit. The circuit can detect when the resident is trying to get out of bed, is successfully exiting the bed, or is in or out of the bed.

Figure 2 shows the configuration of the electrode attached to the 60 cm x 45 cm x 0.2 mm polypropylene sheet floor mat. The electrode is SUS 304 stainless steel tape (Nitto, PROSELF, in a comb configuration, as shown in Figure 2.

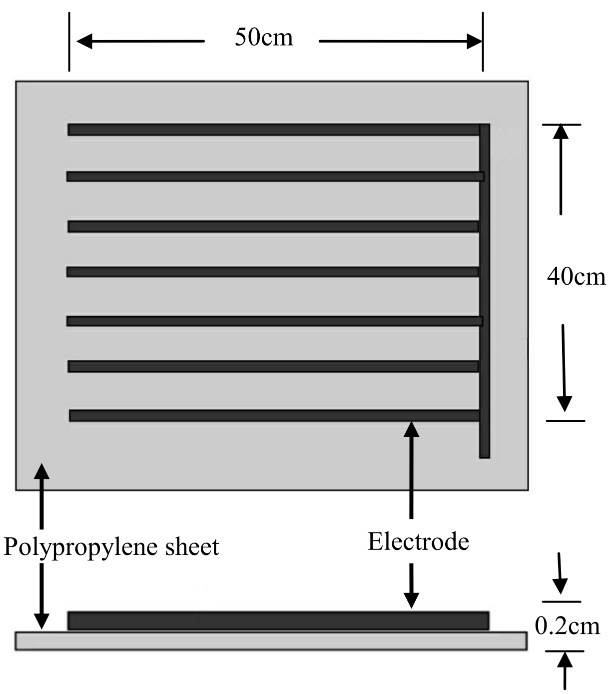

Fig. 2. Configuration of the floor mat electrode.

This electrode design reduces its area so that the AC voltage induced by electrostatic coupling (Cae) from the ever-present AC power line field around the resident's bed to the electrode is low. Therefore, the recorded voltage baseline is small, and greatly increases when the resident steps on the electrode.

Figure 3 shows the block diagram of the bed-exiting alarm circuit. The circuit consists of an impedance converter, a 60Hz band-pass filter, a digital potentiometer (DALLAS SEMICONDUCTOR, DS1803), a non inverter amplifier, RMS/DC converters (Linear Technology, LTC1966) and a low-power 8-bit single chip microcomputer (Microchip Technology, PIC16C877). The microcomputer judges if the resident is trying to leave the bed and alerts the care staff station, via a power line communication system or PHS

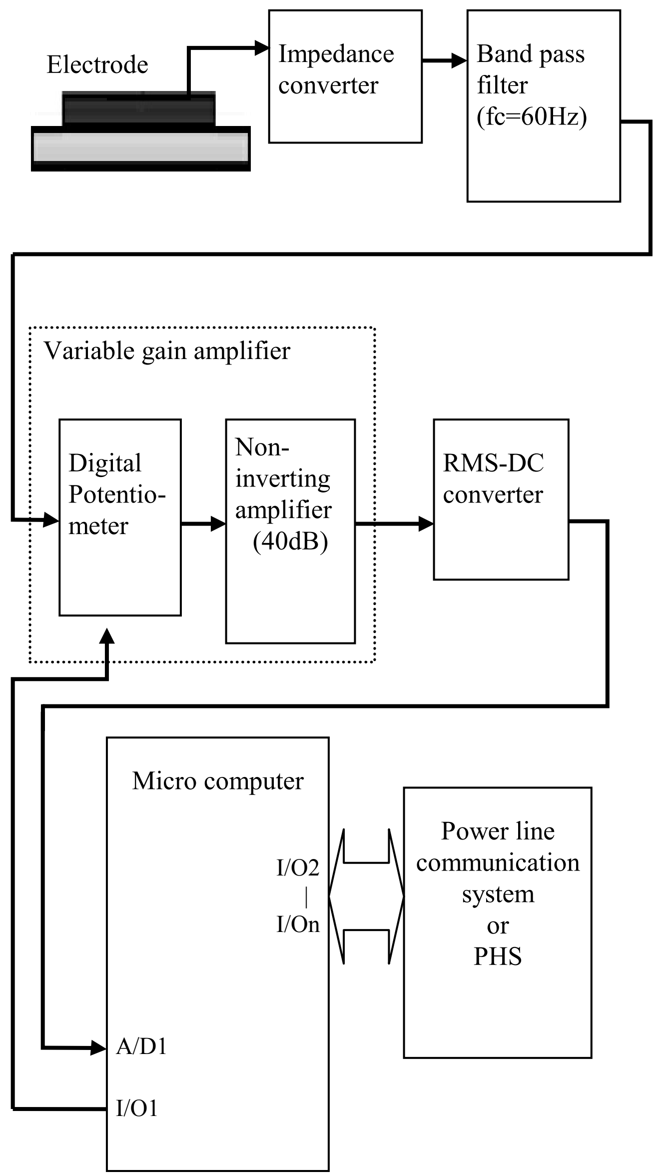

Fig.3. Block diagram of the bed-exiting alarm circuit.

The alternating voltage induced to the human body, as measured by the electrode, is inputted to an impedance converter, which is designed with a CMOS operational amplifier (Burr Brown, OPA4336), having 10^{13} ohm input impedance. This voltage can be recorded precisely due to the device's ultra-high input impedance.

The impedance converter output is fed into a 60 Hz band pass filter; therefore only the 60 Hz AC voltage induced to the resident's body is detected. The variable gain amplifier consists of a non-inverting amplifier and a digital potentiometer. The variable gain amplifier automatically adjusts its output to compensate for variations in electrode area, location, 60 Hz field intensity, and bed type. The adjusted voltage is converted by a RMS-DC converter into effective non-contact baseline voltage of approximately one volt. This system output is digitized at a rate of 20 Hz by the microcomputer's 10-bit A/D converter.

The microcomputer detects when resident steps on the electrode, with either one or two feet, and if so, it alerts the care staff station that he/she is attempting to get out of bed (one foot on pad), or is indeed out bed (two feet on pad). The electrode voltage increase is approximately the same, with either one or two feet on the pad.

IV. SYSTEM TRIAL

Measurements were performed on five normal male subjects, age 22-61 years, in a third floor room, with 100 and 200 volt AC power lines in the ceiling and under the floor. Three fluorescent lights were attached to the ceiling 2 meters above the bed.

The effective voltages were measured for various electrode surface areas, ranging from 185 cm^2 to 395 cm^2. The electrode tape width was 1 cm, and the surface areas were changed by varying the electrode length. A non-contact voltage was measured and then the subjects stood on the electrode in the states of bare feet, socks, slippers and shoes. The effective voltage for bare feet was adjusted to 3V at 200 cm^2 electrode surface area.

V. RESULTS AND DISCUSSION

Figure 4 shows a typical experiment result. The effective voltages increased with the electrode surface area. Bare feet and socks produced almost the same effective voltage on various electrode surface areas and much higher voltages than slippers and shoes, which yielded almost-identical low effective voltages for various electrode surface areas. Their effective voltage was only 0.15 V higher than with no person on the pad. The effective voltage difference between socks and slippers is significant, averaging 1.2 V over the tested pad area range.

Therefore, these results indicate that the 185 cm^2 electrode surface area is suitable for detection of when the resident steps on the floor mat.

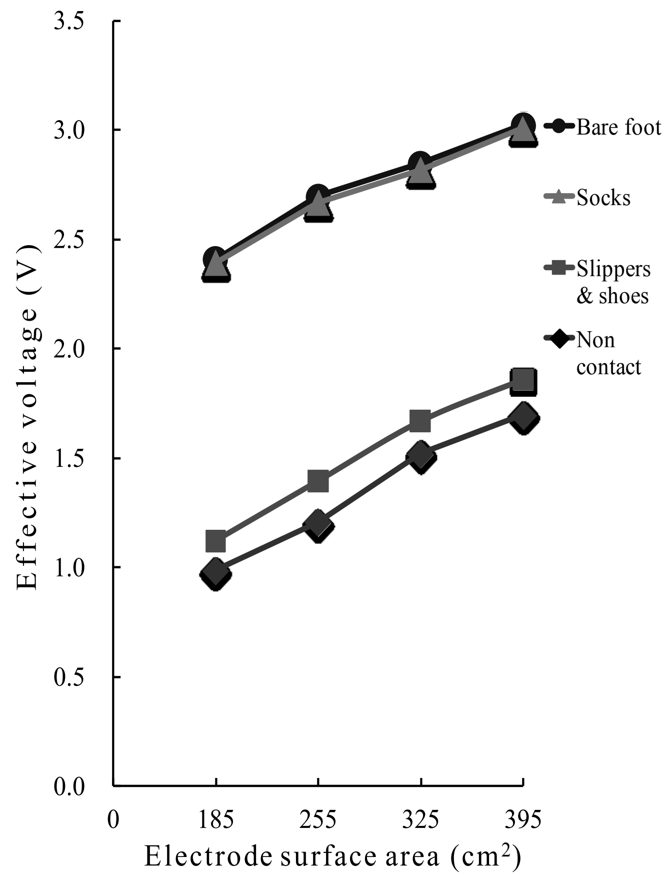

Fig.4 The effective voltage for various electrode surface areas

VI. CONCLUSION

This paper presents a new bed-exiting alarm system for residents in elderly care facilities. The system employs stainless steel tape installed directly on the floor mat. This tape is used as an electrode, which detects the 60 Hz voltage induced on the resident by electrostatic coupling to the room's AC power wiring. This induced voltage is measured, to indicate if and when the resident exits the bed, or attempts to exit, which requires placing one or both feet on the electrode. The developed system does not require any special electrical or magnetic fields or body-mounted sensors and offers a very effective method for protecting residents from accidental injury.

The developed system is not only applicable to welfare facility residents, but could also be useful for at-home elderly people and hospital patients.

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